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UNIT-I

TRANSFORMER

Introduction - Ideal and Practical Transformer – Phasor diagram-– Per Unit System – Equivalent circuit- Testing- Efficiency and Voltage Regulation– Three Phase Transformers –Applications- Auto Transformers, Advantages- Harmonics.

INTRODUCTION

- The transformer is a ***static device*** which transforms electrical power from one alternating current circuit to another with desired change in voltage and current, without any change in frequency.
- Thus the transformer is used to increase (step up) or decrease (step down) the voltage as per the requirement.

Induced e.m.f:

Induced e.m.f. can be either

(i) Dynamically induced

(ii) Statically induced

Dynamically induced e.m.f:

In the first case, usually the field is stationary and conductors cut across it.

e.g. D.C. generators.

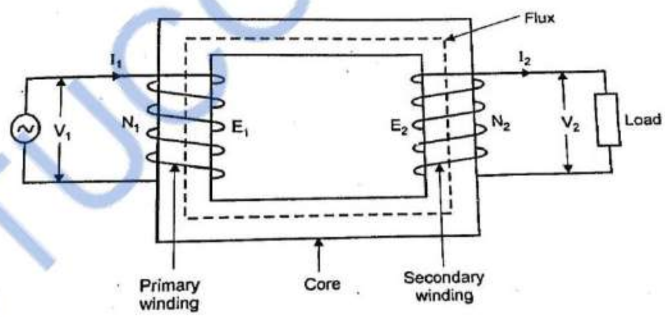
Statically induced e.m.f:

The conductors or the coil remains stationary and flux linked with it is changed by simply increasing or decreasing the current producing this flux.

e.g. transformers.

This e.m.f can be further sub divided into

1. Mutually induced e.m.f
2. Self induced e.m.f



CONSTRUCTIONAL DETAILS OF A TRANSFORMER

1. Give the classification of transformer based on primary-secondary arrangement, Rating and application.

Transformers are classified on the basis of:

Duty they perform:

- Power transformer - for transmission and distribution purposes
- Current transformer - instrument transformers.
- Potential transformer - instrument transformers.

Construction:

- Core type transformer.
- Shell type transformer.
- Berry type transformer.

Voltage output:

- **Step-up transformer:** The number of turns in the secondary winding is higher than the primary winding.
- **Step-down transformer:** The number of turns in the secondary winding is less than the primary winding.

Application:

- Welding transformer.
- Furnace transformer.

Cooling:

- Duct type transformer
- Oil immersed.
  - → Self-cooled.
  - → Forced air cooled.
  - → Water cooled.
  - → Forced oil cooled.

Input supply.

- Single phase transformer.
- Three phase transformer.
  - → Star-star.
  - → Star-delta.
  - → Delta-delta.
  - → Delta-star.
  - → Open-delta.
  - → Scott connection.

2. Discuss in detail about the constructional details of a transformer.(May/June 2011, 12, 13)

- Transformer works on the principle of electromagnetic induction. A transformer is a static device which changes the alternating voltage from one level to another at same frequency.
- It consists of two windings insulated from each other and wound on a common core made up of magnetic material.
- The main components of a transformer are
  1. The magnetic core.
  2. Primary and secondary windings.
  3. Insulation of windings.
  4. Conservator.

5. Lead and tapping's for coils with the supports, terminals and terminal insulators. Tank, Oil, Cooling arrangement, temperature gauge, oil gauge.
6. Buchholz relay.
7. Silica gel breather.

The magnetic core:

- Magnetic circuit consists of an iron core.
- The transformer core is generally laminated and is made out of a good magnetic material like silicon steel.
- The laminations are insulated from each other by coating them with a thin coat of varnish.

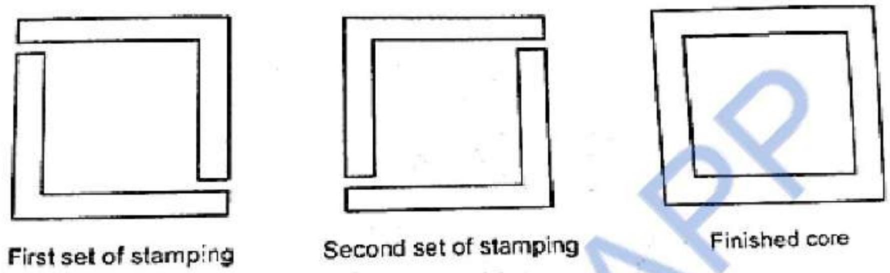


Fig 2.1: various types of stampings and laminations

- The joints are staggered to avoid continuous gap causing increase in magnetising current. The two types of transformers are:
  1. Core type.
  2. Shell type.

Core type transformer:

- The windings surround a considerable part of core and have only one magnetic path. It has two limbs for the two windings and is made up of two L-type stampings.

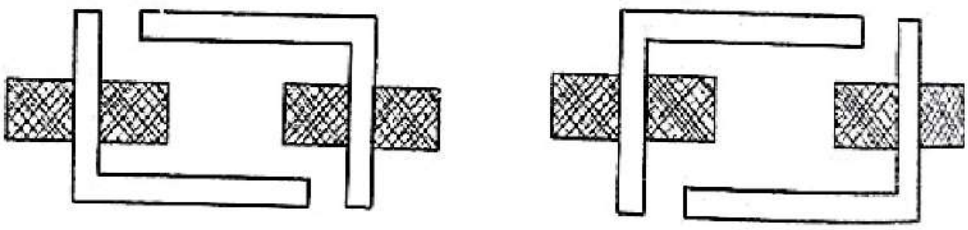
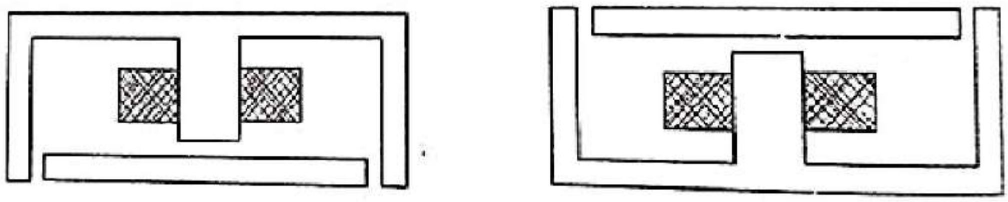


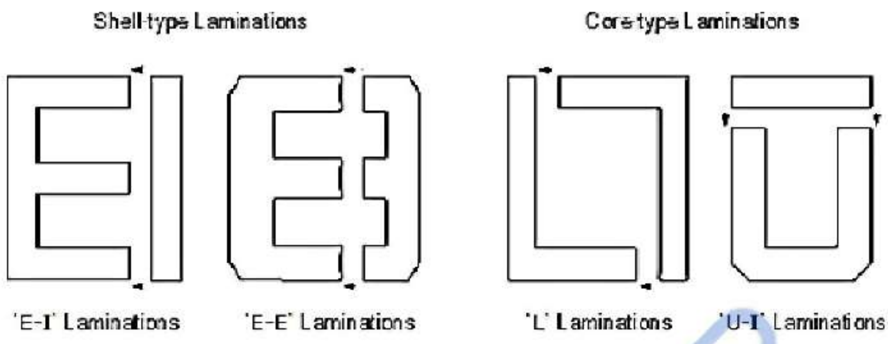
Fig 2.2: L- type stampings

- The coils used usually are of cylindrical type and usually wound. For transformer of higher rating, stepped core with circular cylindrical coils are used.
- For transformer of smaller rating, rectangular coils with core of square are used. Insulating cylinders are used to separate windings from the core and from each other.

Shell type transformer:



(b)



2.3: Shell type transformer

- The core surrounds a considerable part of windings. The two windings are carried by central limb.
- The core made up of E and I stampings and has three limbs. It has two parallel paths for magnetic flux.
- The coils used are of multilayer disc type and are former wound in the form of pan- cakes. Each layer is insulated from each other by paper.

Windings:

- There are two windings in a transformer. They are called primary and secondary windings. Generally the windings are made up of copper.

Insulating oil:

- The oil used in transformer protects the paper from dust and moisture and removes the heats produced in the core and coils. It also acts as insulating medium. The oil must possess the following properties.
- High dielectric strength.
- Free from inorganic acid, alkali and corrosive sulphur to prevent injury to the conductor.
- Low viscosity to provide good heat transfer.
- Good resistance to emulsion so that the oil may throw down any moisture entering the tank instead of holding it in suspense.

Conservator:

- The main tank of the transformer is connected by a pipe to a small auxiliary tank mounted above the main tank.

- The oil level of a transformer changes with change in temperature of oil which in turn depends upon the load on the transformer.
- The oil expands with the increase in load and contracts when the load decreases.
- The function of the expansion tank is to keep the main tank of the transformer completely filled with the changes in temperature.

Buchholz relay:

- The first warning that a fault is present may be given by the presence of bubbles in the oil.
- If the transformer is fitted with a conservator and there are no pockets in which gas can collect, the gas bubbles will rise up the pipe joining the conservator to the tank.
- It is used to give alarm in case of minor fault and to disconnect the transformer from supply main in case of severe internal faults.

Breather:

- In between the main and conservator tanks, some chemical compound in a pot is fitted externally. This is called as silica gel.
- If any moisture tries to enter from atmospheric air existing over the conservator oil level into transformer tank through oil, then immediately the silica gel absorbs the moisture.

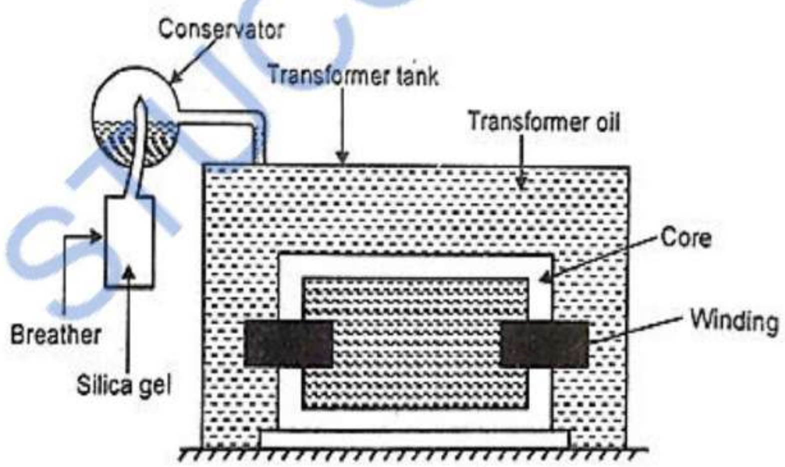


Fig 2.4: Transformer construction

Cooling arrangement in transformers:

- Oil immersed natural cooled transformers.
- Oil immersed forced air cooled transformers.
- Oil immersed water cooled transformers.
- Oil immersed forced oil cooled transformers
- Air blast transformers.

PRINCIPLE OF OPERATION OF TRANSFORMER

3. Explain the principle of operation of transformer. (May/June 2011, 12, 13)

INTRODUCTION:

- Transformer works on the principle of electromagnetic induction.
- A transformer is a static device which changes the alternating voltage from one level to another at same frequency.
- It consists of two windings insulated from each other and wound on a common core made up of magnetic material.
- Alternating voltage is connected across one of the windings called the primary windings.
- In both the windings e.m.f is induced by electromagnetic induction. The second winding is called the secondary winding.

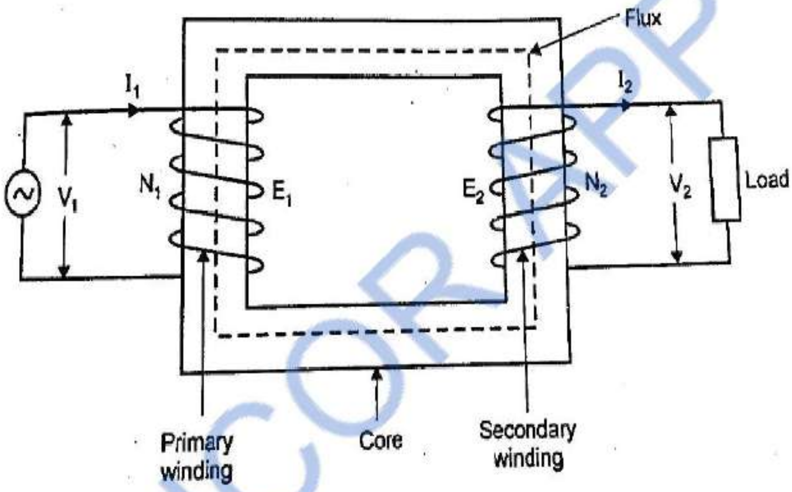


Fig 2.5: Transformer

Working principle of a transformer:

- When primary winding is connected to an ac source an exciting current flow through the winding.
- As the current is alternating, it will produce an alternating flux in the core which will be linked by both the primary and secondary windings.
- The induced e.m.f in the primary winding (E_1) is almost equal to the applied voltage V_1 and will oppose the applied voltage.
- The e.m.f induced in the secondary winding (E_2) can be utilized to deliver power to any load connected across the secondary.
- Thus power is transferred from the primary to the secondary circuit by electromagnetic induction.
- The flux in the core will alternate at the same frequency as the frequency of the supply voltage.
- The frequency of induced e.m.f in the secondary is the same as that of the supply voltage.

- The magnitude of the e.m.f induced in the secondary winding will depends upon its number of turns.
- If the number of turns in the secondary winding is higher than the primary winding, it is called as step-up transformer.
- If the number of turns in the secondary winding is less than the primary winding, it is called as step-down transformer.

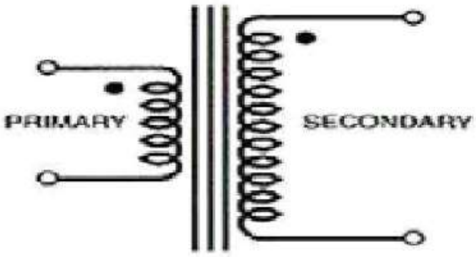


Fig 2.6(a): step up transformer

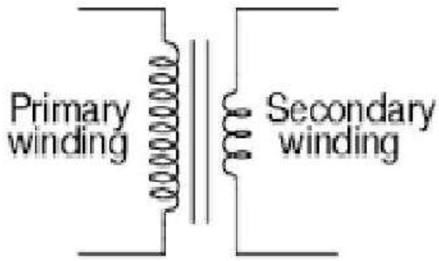


Fig 2.6(b): step down transformer

Applications of Transformer:

Transformers are used in:

- Electrical power engineering for transmission and distribution.
- As an instrument transformer for measuring current (CT) and measuring voltage (PT).
- As a step down transformer and step up transformer to get reduced or increased output voltage.
- Radio and TV circuits, telephone circuits, control and instrumentation.
- Furnaces and welding transformer.

4. Derive the E.M.F equation of Transformer. [Dec 10 ,11]

Consider a transformer as shown in figure.

N_1- Number of primary turns.

N_2- Number of secondary turns.

Φ_m- Maximum value of flux in the core in wb.

B_m- Maximum value of flux density in the core in wb/m^2.

A-Area of the core in m^2.

f- Frequency of the AC supply in Hertz.

V_1- Supply voltage across primary in volts

V_2 - Supply voltage across primary in volts.

I_1 - Full load primary current in amperes.

I_2 - Full load secondary in amperes.

E_1- E.m.f induced in the primary in volts.

E_2- E.m.f induced in the secondary in volts.

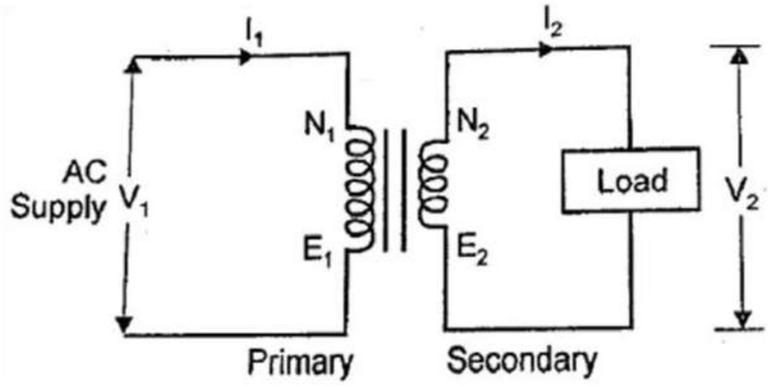


Fig 2.7 simple transformer circuit

- Since applied voltage is alternating in nature, the flux established is also an alternating one.
- From the figure it is clear that the flux is attaining its maximum value in one quarter of the cycle i.e., T/4 sec where 'T' is the time period in second

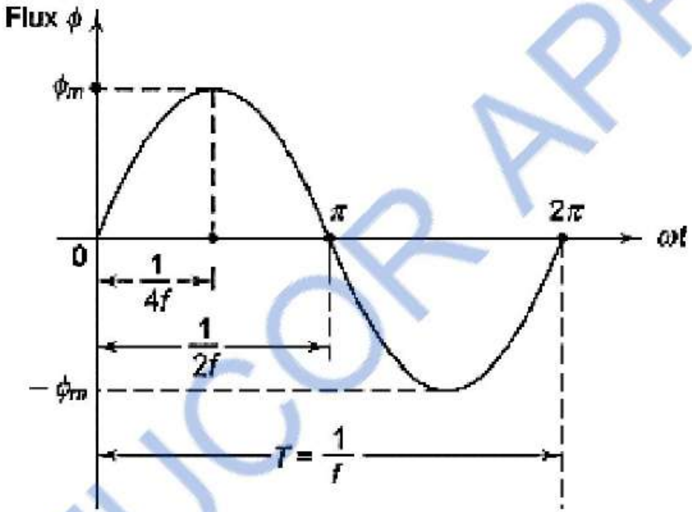


Fig 2.8: output waveform

Φ_m = maximum flux in the core in Webbers.

$$= B_m \text{ x A}$$

Average rate of change of flux = $\frac{\Phi_m}{\frac{1}{4f}}$

$$= 4f\ \Phi_m \text{ wb/sec}$$

If we assume single turn coil, the according to faraday's law of electromagnetic induction,

Average value of e.m.f induced/turn = 4 f Φ_m volt

For sinusoidal wave form

Form factor = $\frac{R.M.S\ value}{Average\ value}$ =1.11

R.M.S value of e.m.f induced/turn =1.11 x 4f Φ_m=4.44 x f Φ_m volt

Now R.M.S value of e.m.f induced in primary winding

$$E_1 = 4.44f\ N_1\ \Phi_m \quad \textbf{volt}$$

$$E_1 = 4.44f\, N_1 B_m\, A \quad \text{volt} \text{ --------- } (1)$$

Similarly, R.M.S value of e.m.f induced in secondary winding.

$$E_2 = 4.44f\, N_2\, \phi_m \quad \text{volt}$$

$$E_2 = 4.44f\, N_2 B_m\, A \quad \text{volt} \text{ --------- } (2)$$

Voltage Transformation Ratio:

- The transformation ratio is defined as of the ratio of the secondary voltage to primary voltage. It is denoted by K. From the equations of induced e.m.f E_1 and E_2 we get

$$V_1 = E_1 \,;\; V_2 = E_2$$

$$V_1 I_1 = V_2 I_2$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} \,;\, \frac{E_2}{E_1} = \frac{I_1}{I_2} \text{ --------- } (3)$$

From equations 2 and 1,

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \text{ --------- } (4)$$

From equations 3 and 4,

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = \mathbf{K} \text{ --------- } (5)$$

- This constant K is known as voltage transformation ratio.
- If $N_2 > N_1$ i.e. K>1, then transformer is called step up transformer.
- If $N_2 < N_1$ i.e. K<1, then transformer is called step down transformer.
- Again for an Ideal Transformer

$$\text{Voltage ratio} = \frac{E_2}{E_1} = K$$

$$\text{Current ratio} = \frac{I_1}{I_2} = K$$

IDEAL TRANSFORMER

5. What are the characteristics of an ideal transformer? (May 13)

The ideal transformer has the following properties.

1. No winding resistance. i.e. purely inductive.
2. No magnetic leakage flux.
3. No I^2R loss i.e., no copper loss.
4. No core loss (hysteresis and eddy current losses).

- From the below diagram the secondary is open. The AC supply is connected to the primary winding. A current flows through the winding.
- This current is called magnetizing current. It is denoted as I_μ.

- This current is mainly used to magnetize the core. The value of magnetizing current is small. It is lagging V_1 by 90°.The current I_μ produces an alternating flux Φ.

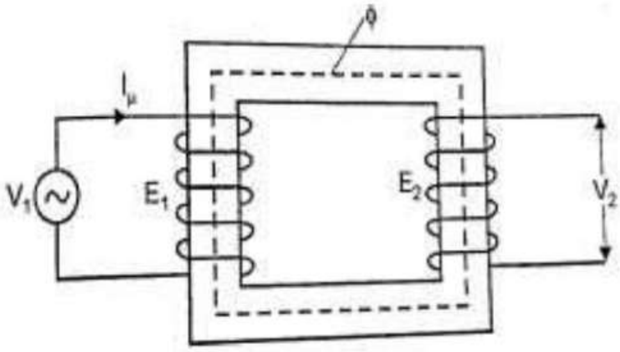


Fig 2.9: Ideal transformer

- I_μ and Φ are in phase. This changing flux is linking with primary and secondary windings.
- Due to the alternating flux, a self-induced e.m.f is produced in the primary winding.
- It is denoted as E_1 and equal to and in opposition to V_1. It is known as counter e.m.f or back e.m.f of the primary winding.
- Similarly an induced e.m.f E_2 is produced in the secondary winding because the alternating flux is linking with secondary winding. This e.m.f is known as mutually induced e.m.f.
- This e.m.f E_2 is in opposition to V_1 and its magnitude is proportional to the rate of change of flux and number of secondary turns.
- Figure shows input voltage V_1, induced e.m.f (E_1, E_2), flux Φ and magnetizing current I_μ waveforms.

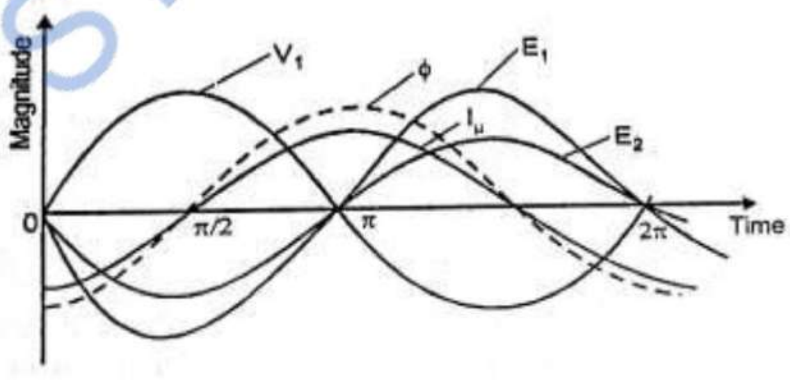


Fig 2.10: Output waveform

<u>**Vector diagram on no-load:**</u>

Step 1: First draw the input voltage line V_1 (OA).

Step 2: Draw the flux line Φ (OB). The angle between V_1 and Φ is 90°.

Step 3: Draw the magnetizing current I_μ (OC). It is in phase with flux.

Step 4: Draw the induced e.m.fs E_1, *and* E_2. The angle between E_1 *and* V_1 is 180° i.e., E_1 *and* $V1$ are in opposite directions (OD and OA).

Step 5: Then draw E_2 line. It is in phase with E_1 (OE).

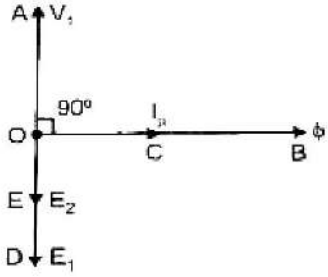


Fig 2.11: No-load vector diagram

6. Explain the operation of practical Transformer on no – load with vector diagrams.(nov/dec 2011,2012)

- If the primary winding is connected to alternating voltage and secondary winding is left open, then the transformer is said to be on no-load.

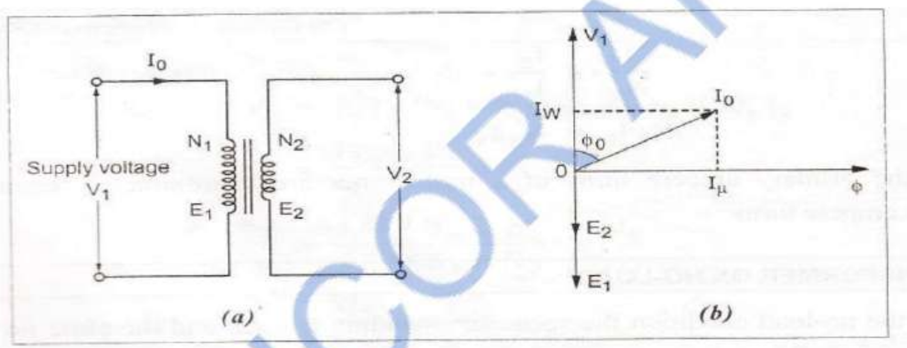


Fig 2.12: Practical transformer on no- load

- Let the supply alternating voltage V_1 volts. This causes an alternating current to flow through the primary.
- Since secondary winding is open, this current is called no-load primary current I_0.
- This I_0 establishes a flux 'ϕ' in the core.
- Thus I_0 is not as behind V_1, but lags it by an angle $\phi_0 < 90°$. No load input power $P_0 = V_1 I_0 \cos\phi_0$.
- I_0 has two components. Active or Working or Iron Loss or wattful Component I_W.
- I_W is in phase with V_1 and supplies the iron loss and negligible amount of primary copper loss.

$$I_W = I_0 \cos \Phi_0$$

Where, $\cos \Phi_0 = No - load\ powerfactor$

- Reactive (or) Magnetizing (or) wattless Component (I_μ).
- I_μ is in quadrature with V_1 and it sustains the flux in the core.

$$I_\mu = I_0 \sin \Phi_0$$

- From the above equations, $I_0 = \sqrt{I_W^2 + I_\mu^2}$

From the above discussion,

→ The no-load primary current (I_o) is very small as compared to the full primary current.

→ As I_0 is very small, no-load primary copper loss is negligibly small which means that no load primary input is practically equal to the iron – loss in a transformer.

→ Core loss is responsible for shift in the current vector.

7. Explain the operation of practical Transformer on ON load with vector diagrams.(nov/dec 2009, 2011, 2012, Apr/May 2011)(Accounting for finite permeability and core loss)

- When the secondary is loaded, the secondary current I_2 is set-up. The magnitude and phase of I_2 with respect to V_2 is determined by the load characteristics.
- For non-inductive load, current I_2 is in phase with V_2. If the load is inductive, I_2 lags V_2 and load is Capacitive I_2 leads V_2.

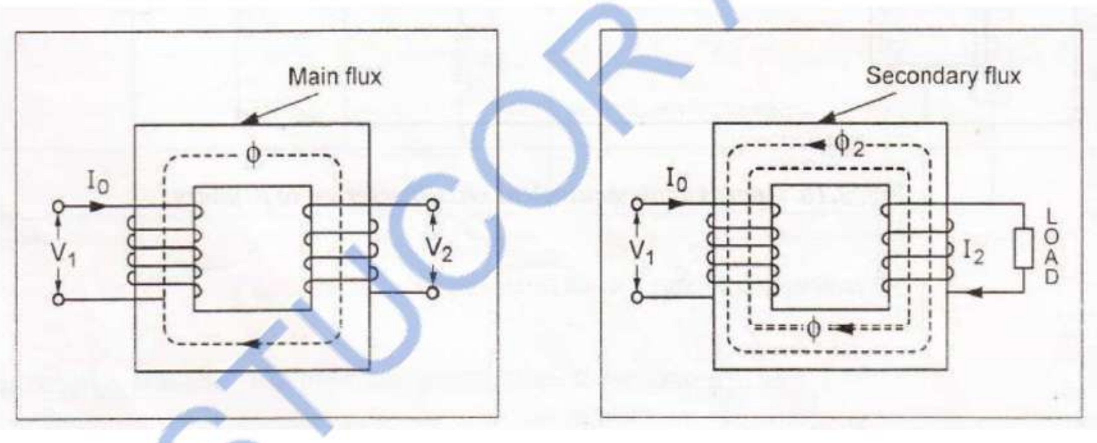
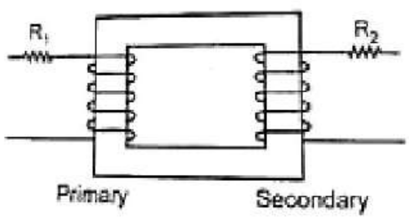


Fig 2.13: transformer under no-load and loaded condition

Transformer winding resistance:

- In the practical transformer, the windings have some resistances. The primary winding has primary resistance. It is denoted as R_1. Similarly secondary winding has secondary resistance. It is denoted as R_2.



Transformer winding leakage reactance:

- In practice, all the flux generated by the primary winding does not link the secondary winding. Some part of the flux passes through air rather than around the core. This flux is called the primary leakage flux. It is denoted as ΦL_1.

- This flux does not link with secondary winding. This flux induces an e.m.f eL_1 in primary winding.
- The flux ΦL_1 is in phase with I_1. Similarly a leakage flux is set up in the secondary winding. This flux is known as secondary leakage flux. It is denoted as ΦL_2.
- This flux induces an e.m.f eL_2 in secondary winding. The flux ΦL_2 does not link with primary. It is in phase with I_2.

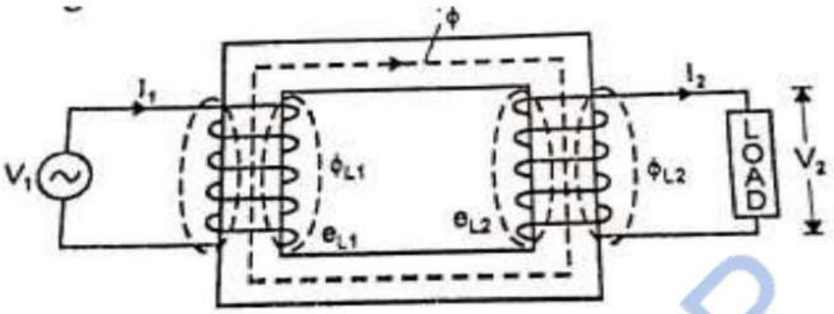
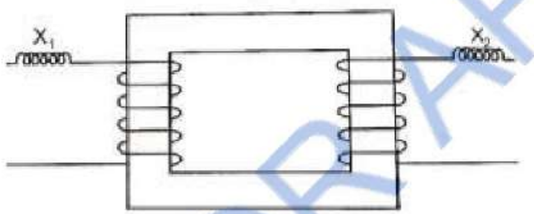


Fig 2.14: primary and secondary flux



- The primary leakage reactance X_1 and secondary leakage reactance X_2 are indicated in fig below.

Vector diagram of transformer on load:

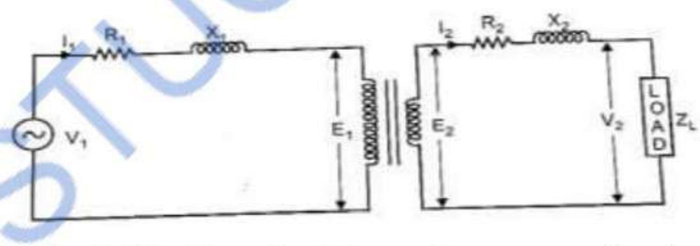


Fig 2.15: Practical transformer on load

Case (i) No winding resistances and leakage reactance's (R_1, R_2, X_1, X_2 neglected):

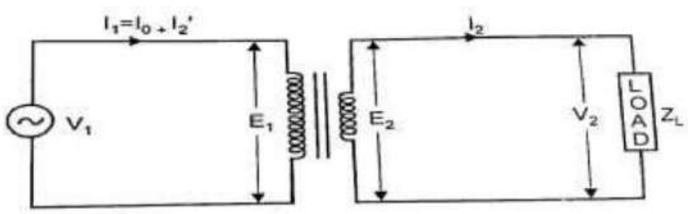


Fig 2.16: Practical transformer with assumptions that winding resistances and leakage reactance are neglected

Vector diagram of transformer on load:

The following steps are followed to draw the vector diagram.

Step 1: Draw the flux line Φ. It is the reference vector.

Step 2: Draw the V_1 vector. The angle between the V_1 and Φ is 90°

Step 3: Draw the induced e.m.f E_1 and E_2 vector. They opposes V_1 i.e., 180° out of phase.

Step 4: Draw the no-load primary current Io. The current Io is lagging with respect to V_1 by an angle Φ_o.

Step 5: Draw the secondary current I2.

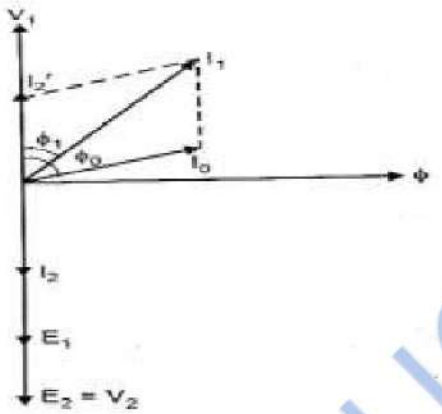
Unity power factor : V_2 and I_2 are in phase.

Lagging power factor : Secondary current is lagging with respect to V_2 by an angle Φ_2.

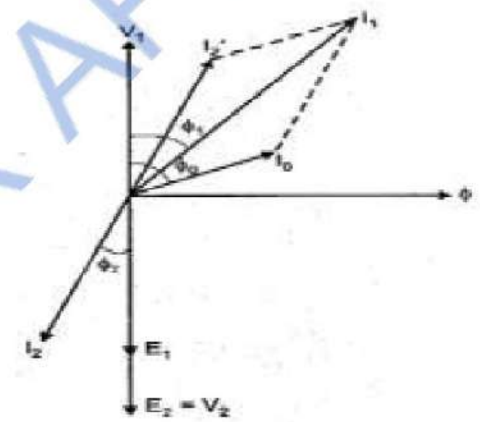
Leading power factor : Secondary current I_2 is leading with respect to V_2 by an angle Φ_2.

Step 6: Draw the load component of primary current I'_2. It is opposite and equal in magnitude to I_2.

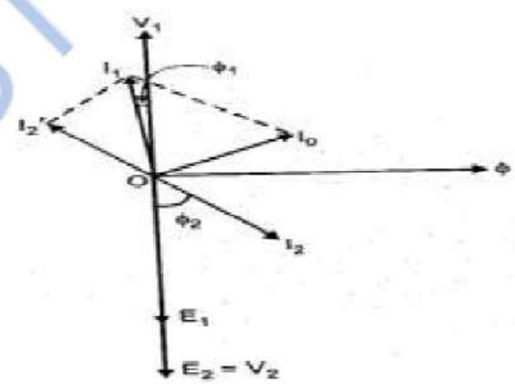
Step 7: Draw the primary current I_1. This current is lagging with respect to V_1 by an angle of Φ_1. I_1 is the vector sum of I'_2 and I_o.



(a) Unity power factor



(b) Lagging power factor



(c)Leading Power factor

Fig 2.17: vector diagrams

Case (ii) Transformer with resistances and leakage reactance:

- Consider R_1, R_2, X_1, X_2. Input voltage is applied to the primary winding. Current I1 is flowing through the primary winding.
- There is a voltage drop in R_1 and X_1, so that the primary induced e.m.f is less than the input voltage V_1. The load is connected in the secondary side.

- Current I_2 is flowing through the load. There are voltage drops in R_2 and X_2.so that secondary terminal voltage V_2 is less than the secondary induced e.m.f.

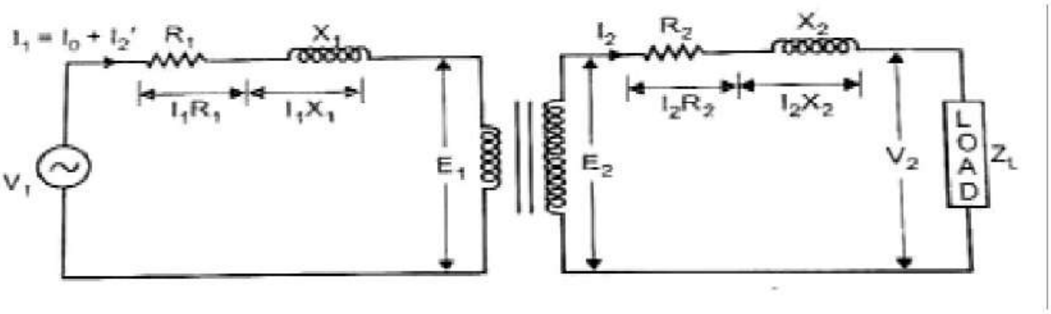


Fig 2.18: Transformer with resistances and leakage reactance

- In the secondary side, the load is inductive and so the secondary current I_2 is lagging V_2 by an angle Φ_2.
- If the load is resistive, then I_2 and V_2 are in phase.

Problem 1:

A 200- KVA, 3300/240 volts, 50Hz single phase transformer has 80 turns on the secondary winding. Assuming an ideal transformer, calculate (i) primary and secondary currents on full load (ii) the maximum value of flux (iii) the number of primary turns. (AMIE Summer 1990) (Anna Univ May – 18, Marks 8)

Solution:

V_1 = 3300 volts, V_2 = 240 volts, f = 50 Hz, N_2 = 80

(i) $\frac{V_2}{V_1} = \frac{N_2}{N_1}$ = K, K = 240/3300 = 12/165

$\frac{240}{3300} = \frac{80}{N_1}$, N_1 = 1100

(ii) for an Ideal Transformer

Input (VA) = output (VA) $\therefore V_1 I_1 = V_2 I_2$

$200 \times 10^3 = 240 \times I_2$

I_2 = 200000 / 240

I_2 = 833.33 A

K = I_1 / I_2

I_1 = K I_2

= (12 / 165) x 833.33

= 60.6 A

(iii) $E_1 = 4.44 f N_1 \Phi_m$

$3300 = 4.44 \times 50 \times 1100 \times \Phi_m$

Φ_m = (3300 / 4.44 x 50 x 1100)

= 0.01351 Wb Φ_m = 13.5 m Wb

Problem 2:

A 25 KVA transformer has 500 turns on the primary and 50 turns on the secondary winding. The primary is connected to 3000 V, 50 Hz supply. Find the full load primary and secondary currents, the secondary e.m.f. and the maximum flux in the core neglect leakage drops and no- load primary currents.

Solution:

N_1 = 500, N_2 = 50, E_1 = 3000 volt, f = 50Hz. I_1 = ?, I_2 = ?, E_2 = ?, ϕ_m = ?

$$E_1 = 4.44 f N_1 \phi_m$$

$$\phi_m = (3000 / 4.44 \times 50 \times 500)$$

$$= 0.0270 \text{ Wb}$$

(i) $\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$,

$\frac{E_2}{3000} = \frac{50}{500}$ E_2 = (50 x3000) / 500 = 300 volts

(ii) for an Ideal Transformer

Input (VA) = output (VA)

$\therefore$ $V_1 I_1 = V_2 I_2$

$25 \times 10^3 = 300 \times I_2$

$I_2 = (25000 / 300)$

= 83.33 A

$I_1 = K I_2$

= (300 / 3000) x 83.33

I_1 = 8.33 A

Exercise:

1. A single phase 2200 /250V, 50 Hz transformer has a net core area of 36 cm^2 and maximum flux density of 0.6 Wb/m^2 .Calculate the number of primary and secondary turns.

2. For a single phase transformer having primary and secondary turns of 440 and 880 respectively, determine the transformer KVA rating if half load secondary current is 7.5A and maximum value of core flux is 2.25mWb. Assume frequency of 50 Hz.

CIRCUIT MODEL OF TRANSFORMER (Equivalent Circuit of Transformer)

8. Explain the circuit model of a transformer. (or) Draw the equivalent circuit diagram of transformer with respect to primary side. (May 18)

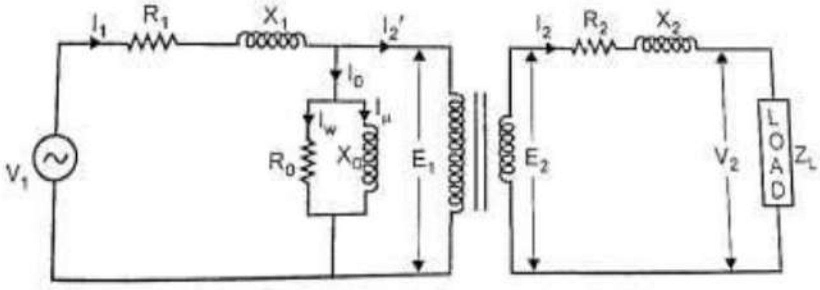


Fig 2.19: Transformer circuit

- Under no-load condition, the primary of a transformer draws no-load current I_o.
- It is mainly used to supply the iron-loss and to produce the flux in the core.
- The effect of iron loss is represented by a non-inductive resistance R_o and the magnetizing current is represented by X_o.
- Both of them are connected in parallel with primary winding.
- This circuit is known as exciting branch or no-load branch.

Where,

R_1, X_1- Primary winding resistance and reactance in Ω.

R_o- No-load resistance in Ω.

X_o -No-load reactance in Ω.

I_1- Full load primary current in A.

I_o- No-load primary current in A.

I'_2- Load component of primary current in A.

I_w- Working component.

I_μ- Magnetising component.

E_1- Induced e.m.f in primary winding in V.

E_2 - Induced e.m.f in secondary winding in V.

R_2, X_2 - Primary winding resistance and reactance in Ω.

Z_L - load impedance in Ω.

I_2 - Full load secondary current in A.

K - Transformation ratio.

Equivalent circuit of a transformer referred to primary:

- If all the secondary parameters are transferred to the primary side, we get the equivalent circuit of a transformer referred to primary.
- When secondary parameters are referred to primary, resistances and reactances are divided by K^2,
- Voltages are divided by K and currents are multiplied by K.

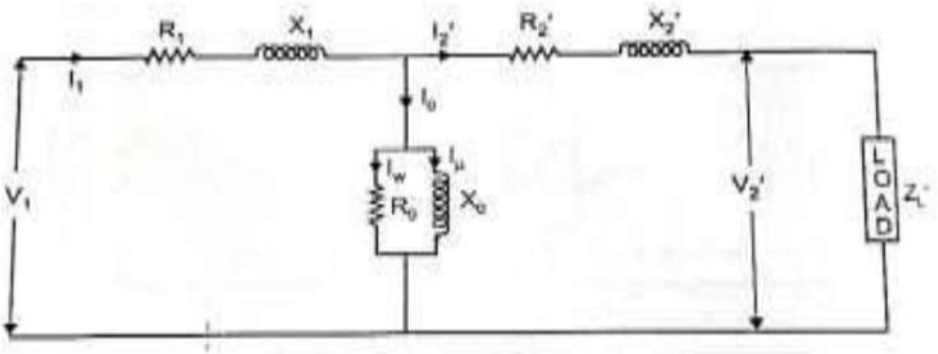


Fig 2.20: Equivalent circuit of a transformer referred to primary

$$R_2' = \frac{R_2}{K^2}$$

$$X_2' = \frac{X_2}{K^2}$$

$$V_2' = \frac{V_2}{K}$$

$$E_2' = \frac{E_2}{K} ;$$

$$N_2' = \frac{N_2}{K}$$

$$I_2' = \text{K } I_2$$

$$Z_L' = \frac{Z_L}{K^2}$$

Approximate equivalent circuit:

- The no-load current Io is only 1-3 % of rated primary current. I'_2 is practically equal to I_1.
- Due to this, the equivalent circuit can be simplified by transferring the exciting branch (Ro and Xo) to the left position of the circuit.

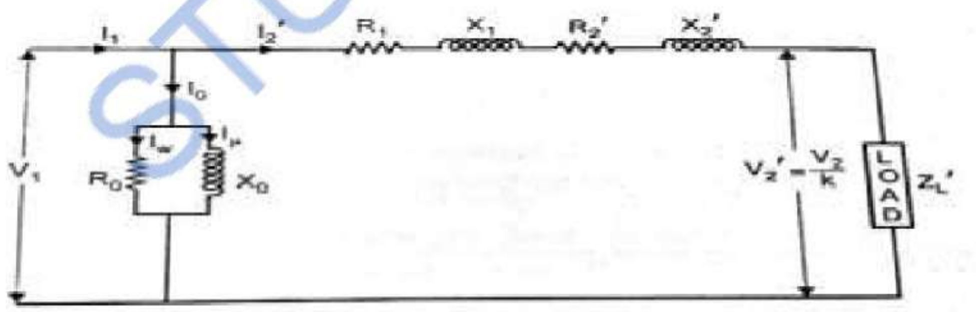
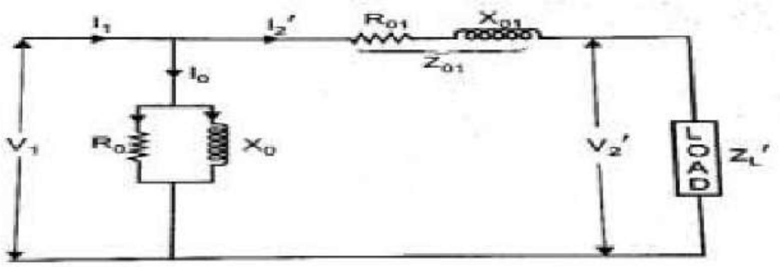


Figure shows combined R_1 and R'_2 and X_1 and X'_2

i.e $R_{01} = (R_1 + R'_2)$ and $X_{01} = (X_1 + X'_2)$; $Z_{01} = \sqrt{(R_{01}^2 + X_{01}^2)}$



2.21: Equivalent circuit of transformer referred to Secondary

$R_1' = K^2 R_1$; $X_1' = K^2 X_1$; $V_1' = K V_1$; $E_1' = K E_1$; $N_1' = K N_1$; $I_1' = \frac{I_2}{K}$

$R_{02} = (R'_1 + R_2) = R_1 K^2 + R_2$

$X_{02} = (X'_1 + X_2) = X_1 K^2 + X_2$

$Z_{01} = \sqrt{(R_{02}^2 + X_{02}^2)}$

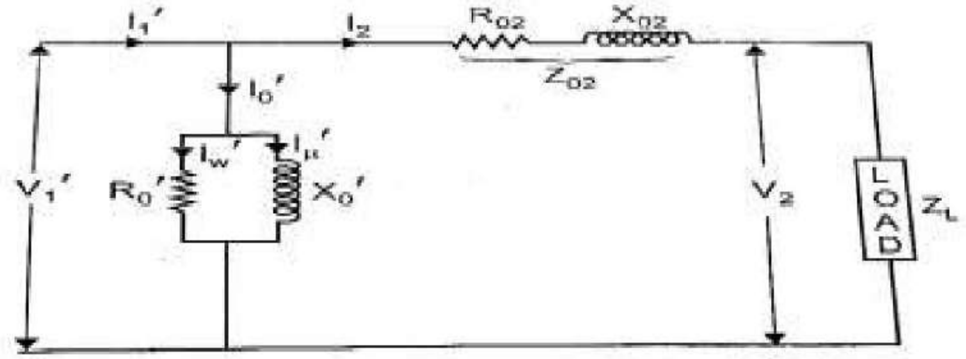


Fig 2.22: Approximate equivalent circuit

PER UNIT SYSTEM

9. Per unit system of a transformer.

- It is usual to express voltage, current, VA and impedance in per unit of the base or reference values of these quantities.
- The per unit (pu) value of any quantity is defined as the ratio of actual value to base value.

$$\textbf{Per unit value} = \frac{\text{actual value}}{\text{base value}}$$

- The rated value of the device is chosen as the base value.
- The per unit value is same on either side of the transformer.
- For a single phase system, the base volt ampere is

$$(VA)_{base} = V_{base} I_{base} \;\ldots\ldots\ldots\ldots (1)$$

$$Z_{base} = \frac{V_{base}}{I_{base}} \;\ldots\ldots\ldots\ldots (2)$$

$$Y_{base} = \frac{I_{base}}{V_{base}} \;\ldots\ldots\ldots\ldots (3)$$

$$Z_{base} = \left[\frac{V_{base}}{I_{base}}\right]\left[\frac{V_{base}}{V_{base}}\right] = \frac{V^2{}_{base}}{VA_{base}}$$

- Always, (VA)base and Vbase are first selected and their choice automatically fixes the other base values as per Equations (1)-(3).
- It immediately follows from these equations that

$$Z_B = \frac{V_B^2}{(VA)_B}$$

$$Z(pu) = \frac{Z(\Omega) \times (VA)_B}{V_B^2} \ldots\ldots\ldots\ldots(4)$$

- The large devices and systems it is more practical to express the bases in kVA/MVA and kV. Then equation (4) is written as

$$Z(pu) = \frac{Z(\Omega) \times (kVA)_B}{1000 \times (kV)_B^2} \ldots\ldots\ldots\ldots(5)$$

$$Z(pu) = \frac{Z(\Omega) \times (MVA)_B}{(kV)_B^2} \ldots\ldots\ldots\ldots(6)$$

- When $(MVA)_B$ and $(kV)_B$ are modified, the new pu impedance is given by

$$Z(pu)_{new} = Z(pu)_{old} \times \left(\frac{(MVA)_{B,new}}{(MVA)_{B,old}}\right) \times \left(\frac{(kV)_{B,old}}{(kV)_{B,new}}\right)^2 \ldots\ldots\ldots\ldots(7)$$

- In the 3-phase system, the bases are chosen as

$(MVA)_B$ = 3-Phase MVA

$(kV)_B$ = Line-to-line kV

- Assuming star connection (equivalent star can always be found),

$$Z_B = \frac{\left((kV)_B/\sqrt{3}\right)^2}{\frac{1}{3}(MVA)_B} = \frac{(kV)_B^2}{(MVA)_B}$$

$$Z(pu) = \frac{Z(\Omega) \times (MVA)_B}{(kV)_B^2} \ldots\ldots\ldots\ldots(8)$$

- Assuming delta connection,

$$Z_B(\Delta) = \frac{((kV)_B)^2}{\frac{1}{3}(MVA)_B} = \frac{3(kV)_B^2}{(MVA)_B}$$

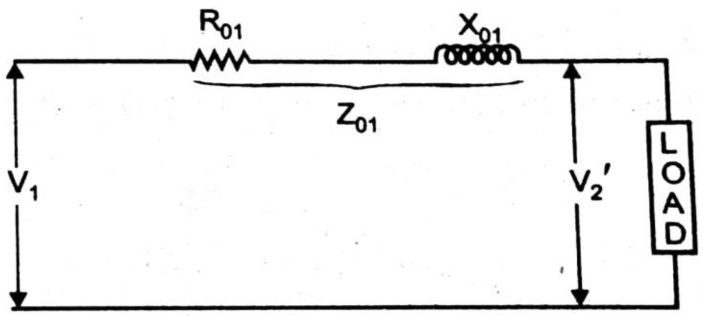
$$Z(pu) = \frac{(Z/3) \times (MVA)_B}{(kV)_B^2}$$

VOLTAGE REGULATION

10. Explain the voltage regulation of a transformer and state its significance.

- The regulation of the transformer is defined as the reduction in magnitude of the terminal voltage due to load, with respect to the no-load terminal voltage.

$$\% \text{ Regulation} = \frac{V_2 \text{ on no load} - V_2 \text{ when loaded}}{V_2 \text{ on no load}} \times 100$$

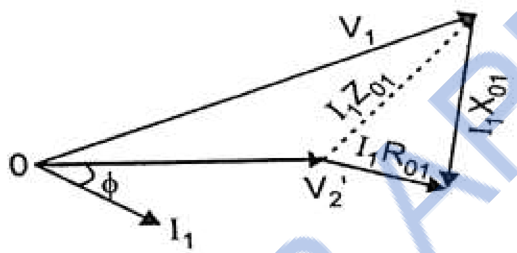


- For an ideal transformer, regulation is 0% since voltage drops, due to R_1, X_1, R_2, X_2 are negligible.

Lagging power factor:

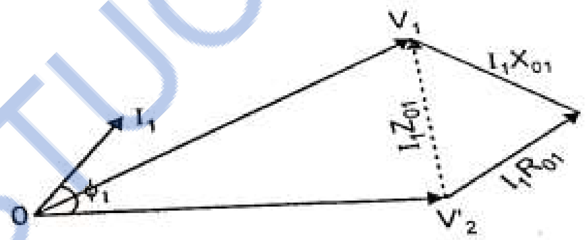
V'_2= secondary terminal voltage referred to primary.

I_1 = primary current.



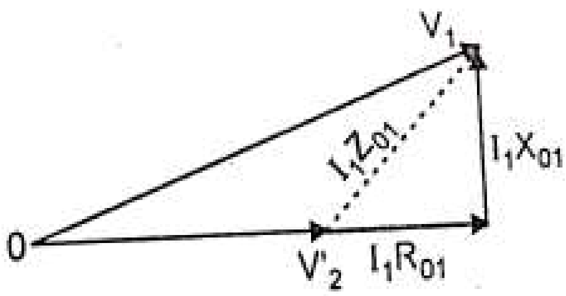
$$\% \textbf{ Regulation} = \frac{I_1 R_{01} \cos\phi + I_1 X_{01} \sin\phi}{V_1} \times 100$$

Leading power factor:



$$\% \textbf{ Regulation} = \frac{I_1 R_{01} \cos\phi - I_1 X_{01} \sin\phi}{V_1} \times 100$$

Unity power factor:



$$\% \textbf{ Regulation} = \frac{I_1 R_{01}}{V_1} \times 100$$

11. Enumerate the various losses in the transformer.

- In a transformer, there are no moving or rotating parts. Hence there is no friction and windage loss. The losses occur in transformer are
  1. Core (or) Iron loss
     - Hysteresis loss
     - Eddy current loss
  2. Copper loss

1. Core loss (or) Iron losses:

- Iron loss is caused by the alternating flux in the core and consists of hysteresis loss and eddy current loss.
- The core flux in a transformer remains practically constant for all loads, and so the core loss is practically the same at all loads.

$$\textbf{Hysteresis loss } P_h = K_h B^{1.6}_{max} f$$

$$\textbf{Eddy current loss } P_e = K_e B^{2}_{max} f^2$$

Where,

K_h = proportionality constant which depends upon the volume and quality of the core material.

K_e = proportionality constant whose value depends upon the volume and resistivity of the core material, thickness of laminations.

B_m = Maximum flux density in the core.

f = Frequency of the alternating flux.

- Hysteresis loss can be minimized by using steel of high silicon content for the core loss and eddy current loss can be minimized by using very thin laminations of transformer core.

2. Copper Loss

- This loss is due to the ohmic resistance of the transformer windings.
- Total copper Loss = $I_1^2 R_1 + I_2^2 R_2$

Where,

- I_1 and I_2 are primary and secondary currents R_1 and R_2 are primary and secondary winding resistance.

EFFICIENCY

12. Derive efficiency of a Transformer.(nov/dec 2015)

- The efficiency of a transformer at a particular load and power factor is defined as the output power divided by the input power.

Transformer efficiency η = output power / Input power

= output power / (output power + Losses)

= output power/ (output power + Cu loss + Iron Loss)

$$\eta = (\text{Input power} - \text{Losses}) / \text{Input power}$$

$$\text{Efficiency} = 1 - (\text{Losses} / \text{Input power})$$

$$\eta = \frac{\text{Output}}{\text{Output} + \text{Losses}} = 1 - \frac{\text{Losses}}{\text{Output} + \text{Losses}}$$

$$\text{Transformer efficiency} = \frac{n\, V_2 I_2 \cos\phi}{(n\, V_2 I_2 \cos\phi + P_i + n^2 P_{cu})} \times 100$$

Where,

V_2 - secondary terminal voltage at load

I_2 - secondary current at load.

Cos ϕ - Power factor of the load.

Iron loss, $P_i = W_o$, determined from OC test.

Copper loss $P_{cu} = W_s$, determined from SC test at full load.

At full load n =1

At half load n = 1/2

Copper loss at a load n times the full load = $n^2 P_{cu}$.

Condition for maximum efficiency :

$$\text{Output power} = V_2\, I_2\, COS\phi_2$$

- If R_{02} is the total resistance of the transformer referred to secondary, then

$$\textbf{Total copper loss } P_{cu} = I_2^2 R_{02}$$

$$\textbf{Total losses} = (P_i + P_{cu})$$

$$\eta = \frac{V_2 I_2 \cos\phi}{(V_2 I_2 \cos\phi + P_i + I_2^2 R_{02})}$$

- Dividing both numerator and denominator by I_2,

$$\eta = \frac{V_2 \cos\phi}{\left(V_2 \cos\phi + \frac{P_i}{I_2} + I_2 R_{02}\right)}$$

- For maximum value of efficiency for given $\cos\Phi_2$, the denominator must have the least value.
- The condition for maximum efficiency is obtained by differentiating the denominator and equating it to zero.

$$\frac{d}{dI_2}(\text{denominator}) = 0$$

$$\frac{d}{dI_2}\left(V_2 \cos\phi + \frac{P_i}{I_2} + I_2 R_{02}\right) = 0$$

$$\left(-\frac{P_i}{I_2^2} + R_{02}\right) = 0$$

$$R_{02} = \frac{P_i}{I_2^2}$$

$$I_2^2 R_{02} = P_i$$

$$P_i = P_{cu}$$

Iron loss = Copper loss = Variable loss.

Hence efficiency of a transformer will be maximum when copper losses are equal to iron losses.

13. Write short notes on All Day Efficiency:

- The all-day efficiency of a transformer is the ratio of the total energy output (kWh) in a 24-h day to the total energy input in the same time.

$$\text{All day efficiency } \eta = \frac{\text{The total energy Output(kWh)in a 24 hours}}{\text{Total energy input in the same time}}$$

- Since the core losses are constant independent of the load, the all-day efficiency of a transformer is dependent upon the load cycle; but no prediction can be made on the basis of the load factor (average load/peak load).
- It is an important figure of merit for distribution transformers which feed daily load cycle varying over a wide load range.
- Higher energy efficiencies are achieved by designing distribution transformers to yield maximum (power) efficiency at less than full load (usually about 70% of the full load).
- This is achieved by restricting the core flux density to lower values by using a relatively larger core cross-section. (It means a larger iron/copper weight ratio.)

DETERMINATION OF PARAMETERS OF CIRCUIT MODEL OF TRANSFORMER

14. Explain OC and SC test of single phase transformers. (or) write short note on open circuit test on transformer.

1. Open circuit test
2. Short circuit test

(i) Open circuit test:

Open circuit test is useful to determine:

1. Core loss.
2. No-load current.
3. R_0 and X_0.

- One winding of the transformer usually high voltage winding is left open and the other winding is connected to the supply of normal voltage and frequency.
- The applied voltage V_1 is measured by a voltmeter, the no-load current I_0 by an ammeter and no load input power W_0 by a wattmeter.
- As the normal rated voltage is applied to the primary, normal iron loss will occur in the transformer core.

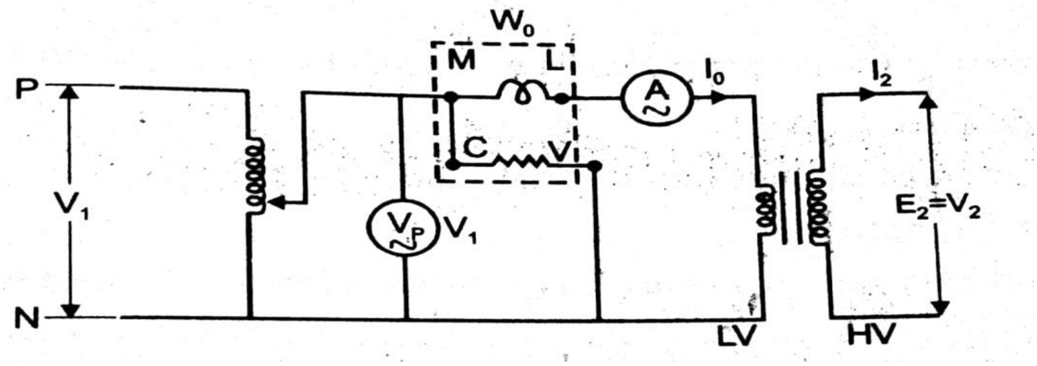


Fig 2.23: Open Circuit test

- Hence wattmeter will read the iron losses and small copper loss in the primary.
- As the no-load current I_o is small, copper losses negligible in primary and nil in secondary winding.
- Hence, wattmeter reading gives the iron losses in the transformer and it is same at all loads.

Iron loss Pi = Wattmeter reading $=W_0$

No-load current = Ammeter reading $=I_0$.

Applied voltage = Voltmeter reading $=V_1$

Input power

$$W_0 = V_1 I_0 \cos\phi_0$$

No-load power factor

$$\cos\phi_0 = \frac{W_0}{V_1 I_0}$$

$$\phi_0 = \cos^{-1}\left(\frac{W_0}{V_1 I_0}\right)$$

No-load wattful component

$$I_w = I_0 \cos\phi_0 = \frac{W_0}{V_1}$$

No-load magnetising component

$$I_\mu = I_0 \sin\phi_0 = \sqrt{(I_0^2 - I_W^2)}$$

No-load resistance

$$R_0 = \frac{V_1}{I_w} = \frac{V_1^2}{W_0}$$

No-load reactance

$$X_0 = \frac{V_1}{I_\mu} = \frac{V_1}{\sqrt{(I_0^2 - I_W^2)}}$$

Thus open circuit gives no load loss P_i, I_w, I_μ, R_0, X_0.

(ii) Short circuit test:

The short circuit test is useful to find:

1. Full-load copper loss.
2. Equivalent resistance and reactance referred to any side.

- In this test, the secondary winding (usually low voltage winding) is short circuited by a thick conductor and variable low voltage is applied to the primary winding.
- The input voltage is gradually raised with the help of a variac till I_{sc} full load current flows in the primary winding.
- There is no output from the transformer under short circuit conditions. Since applied voltage is very low, flux linking with the core is very small and therefore iron losses are so small that these can be neglected and so the reading of the wattmeter gives total copper loss at full load.

Full load copper loss P_{cu}= Wattmeter reading =W_S

Applied voltage = voltmeter reading =V_{SC}

Full-load primary current = Ammeter reading = I_1.

$$P_{cu} = (I_1^2 R_1 + I_1^2 R_2') = (I_1^2 R_{01})$$

$$R_{01} = \frac{P_{Cu}}{I_1^2}$$

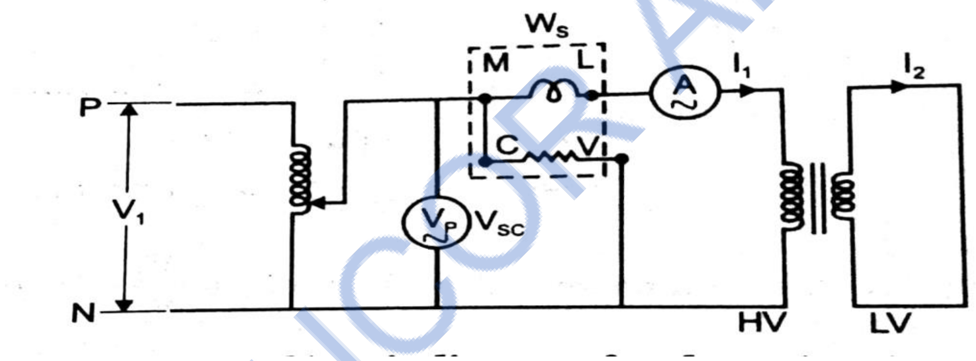


Fig 2.24: Short Circuit test

Where R_{01} is the total resistance of transformer referred to primary.

Total impedance referred to primary

$$Z_{01} = \frac{V_{SC}}{I_1}$$

Total leakage reactance referred to primary

$$X_{01} = \sqrt{(R_{01}^2 - X_{01}^2)}$$

Short circuit power factor

$$\cos\Phi_s = \frac{P_{cu}}{V_{sc} I_1}$$

Thus short circuit test gives full load cu loss, X_{01}, R_{01} and $\cos\Phi_s$.

NAME PLATE RATING

15. Explain the name plate ratings of transformer

The minimum data, rating and information which is generally shown on the name plate of a transformer includes

1. Name of the manufacturer
2. Serial number of transformer
3. Tear of manufacturer
4. Rating in KVA or MVA
5. Number of phases
6. Frequency
7. Voltage ratings
8. Connection diagram ‘
9. Cooling class
10. Rated temperature in C
11. Polarity for single phase transformer
12. % impedance
13. Phasor diagram
14. Approximate weight of transformer
15. Type of insulating liquid
16. Conductor material for winding.

THREE PHASE TRANSFORMER

16. Write short notes on three phase transformer.

- Large scale generation of electric power is usually 3- phase at generated voltages of 132 – kV or somewhat higher.
- Transmission is generally done at higher voltages of 66 kV, 110 kV, 132 kV, 220 kV, and 275 kV for which purpose 3-phase transformers are necessary to step up the generated voltage to that of transmission line.
- At the consumer end, the distribution voltages are reduced to utilization voltages of 440V, 220V, or 110V.
- Like a single phase transformers, the three phase transformers are also of the core type or shell type.
- Depending on the requirement the primary and secondary winding connected either star or delta connection. The three cores are 120° apart.
- Central leg of the three phase winding carries the flux produced by the three phase currents I_R, I_Y and I_B at any instant $I_R + I_Y + I_B = 0$, hence the sum of three fluxes is also zero.

- Any two legs of the three phase winding will act as the return for the third just as in a 3 phase system any two conductors act as the return for the current in the third conductor.
- Main drawback in a 3 phase transformer is that if any one phase becomes disabled, then the whole transformer has to be ordinarily removed from service for repairs.

Advantages of three phase transformer

- As compared to a bank of 3 – single phase transformers, the main advantages of a single 3 phase transformer are that it occupies less floor space for equal rating, weighs less, costs about 15 % less.
- Saving in iron can be achieved in constructing a single 3 phase transformer. Saving in iron is due to the joint use of the magnetic paths between the coils.
- The overall bus bar structure, switchgear and installation of single phase three phase unit is simpler.
- It can be transported easily.
- In case of three single phase units, six terminals are required to be brought while in case of single three phase unit, only three terminals are required to be brought out.

Three phase transformer connections

- Star - star connection
- Delta – Delta connection
- Star – Delta connection
- Delta – Star connection

AUTO TRANSFORMER

17. What is meant by auto transformer? Explain the principle of operation of an auto transformer with neat sketch.(May 18)

- An Auto transformer is a transformer with only one winding wound on a laminated core.
- An auto transformer is similar to a two winding transformer but differ in the way the primary and secondary winding are interrelated.
- A part of the winding is common to both primary and secondary sides.
- On load condition, a part of the load current is obtained directly from the supply and the remaining part is obtained by transformer action.
- An Auto transformer works as a **voltage regulator.**

Principle of Operation

- In auto transformer the primary and the secondary windings are connected magnetically as well as electrically.
- In fact, a part of the single continuous winding is common to both primary and secondary.
- There are two types of auto transformer based on the construction.
- In one type of transformer, there is continuous winding with the taps brought out at convenient points determined by desired secondary voltage and in another type of auto transformer, there are two or more distinct coils which are electrically connected to form a continuous winding.
- The construction of Auto transformer is shown in the figure below.

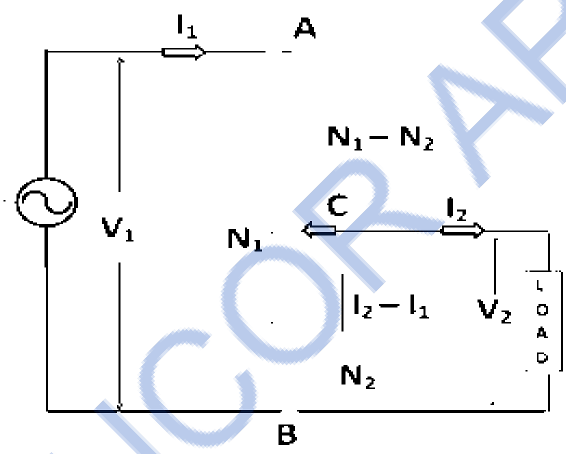


Fig 2.25 Auto transformer design

- The primary winding AB from which a tapping at C is taken, such that CB acts as a secondary winding.
- The supply voltage is applied across AB, and the load is connected across CB. The tapping may be fixed or variable.
- When an AC voltage V_1 is applied across AB, an alternating flux is set up in the core, as a result, an e.m.f E_1 is induced in the winding AB. A part of this induced e.m.f is taken in the secondary circuit.

Let,

V_1 – primary applied voltage

V_2 – secondary voltage across the load

I_1 – primary current

I_2 – load current

N_1 – number of turns between A and B

N_2 – number of turns between C and B

Neglecting no load current, leakage reactance and losses,

$$V_1 = E_1 \quad \text{and} \quad V_2 = E_2$$

Therefore the transformation ratio

$$K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

- As the secondary ampere-turns are opposite to primary ampere turns, so the current I_2 is in phase opposition to I_1.
- The secondary voltage is less than the primary. Therefore current I_2 is more than the current I_1.
- Therefore, the resulting current flowing through section BC is $(I_2 - I_1)$.
- The ampere-turns due to section BC = current x turns

$$\text{Ampere turns due to section BC} = (I_2 - I_1)N_2 = \left(\frac{I_1}{K} - I_1\right) x\, N_1 K = I_1 N_1 (1 - K) \ldots\ldots (1)$$

$$\text{Ampere turns due to section AC} = I_1(N_1 - N_2) = I_1 N_1\left(1 - \frac{N_2}{N_1}\right) = I_1 N_1 (1 - K) \ldots\ldots (2)$$

- Equation (1) and (2) shows that the ampere turns due to section BC and AC balance each other which is characteristic of the transformer action.

18. Derive an expression for saving of copper when an auto transformer is used.

- The weight of the copper is proportional to the length and area of a cross section of the conductor.
- The length of the conductor is proportional to the number of turns, and the cross section is proportional to the product of current and number of turns.
- Now, from the above figure (B) shown of the auto transformer, the weight of copper required in an auto transformer is

  W_a = weight of copper in section AC + weight of copper in section CB. Therefore,

$$W_a \propto I_1 (N_1 - N_2) + (I_2 - I_1)N_2$$

$$W_a \propto I_1 N_1 + I_2 N_2 - 2 I_1 N_2$$

- If the same duty is performed with an ordinary two winding transformer shown above in the figure (A).
- The total weight of the copper required in the ordinary transformer
- W_0 = weight of copper on its primary winding + weight of copper on its secondary winding.

$$W_o \propto I_1 N_1 + I_2 N_2$$

Therefore,

Now, the ratio of the weight of the copper in an auto transformer to the weight of copper in an ordinary transformer is given as

$$\frac{W_a}{W_o} = \frac{I_1N_1 + I_2N_2 - 2I_1N_2}{I_1N_1 + I_2N_2}$$

OR

$$\frac{W_a}{W_o} = \frac{I_1N_1 + I_2N_2}{I_1N_1 + I_2N_2} - \frac{2I_1N_2}{I_1N_1 + I_2N_2}$$

$$\frac{W_a}{W_o} = 1 - \frac{2\,I_1N_2/I_1N_1}{I_1N_1/I_1N_1 + I_2N_2/I_1N_1} = 1 - K$$

OR

$$W_a = (1 - K)W_o$$

- Saving of copper affected by using an auto transformer = weight of copper required in an ordinary transformer – weight of copper required in an auto transformer.

$$\text{Saving of copper} = W_0 - W_a = W_o - (1 - K)W_0 = KW_0$$

Therefore,

- Saving of copper = K x weight of copper required for two windings of the transformer
- Hence, saving in copper increases as the transformation ratio approaches to unity. Hence the auto transformer is used when the value of K is nearly equal to unity.

Advantages of Auto transformer

- Higher efficiency
- Small size
- Smaller exciting current
- Lower cost
- Better voltage regulation
- Continuously varying voltage can be obtained
- Required less copper.

Disadvantages of Auto transformer

- The secondary winding is not insulated from the primary winding.
- If an auto transformer is used to supply low voltage from a high voltage and there is a break in the secondary winding, the full primary voltage comes across the

secondary terminal which is dangerous to the operator and the equipment. So the auto transformer should not be used to for interconnecting high voltage and low voltage system.

- Used only in the limited places where a slight variation of the output voltage from input voltage is required.

Applications of Auto transformer

- It is used as a starter to give up to 50 to 60% of full voltage to the stator of a squirrel cage induction motor during starting.
- It is used to give a small boost to a distribution cable, to correct the voltage drop.
- It is also used as a voltage regulator
- Used in power transmission and distribution system and also in the audio system and railways.

HARMONICS ON TRANSFORMERS

- The transformer does not generate harmonics.
- The transformer has primary and secondary winding which are inductive in nature.
- The inductive load draws current linearly with the applied voltage.
- However, the transformer generates harmonics in two conditions.

Condition: 1

- When transformer is energized the magnetizing current drawn by it is non linear and it generates harmonics.
- This is because, when transformer is energized the back emf is zero and transformer draws huge magnetizing current which is not sinusoidal.
- The magnetizing current is rich in the 2nd order harmonic current.

Condition: 2

- The over excitation of the transformer. The over excitation means the transformer is operated at increased flux density than its rated flux density.
- Under over excitation of transformer the 5th order harmonic current is produced.
- The above two conditions happen for a short period of time and thus the 2nd and 5th order harmonics is not a serious problem.

- The transformer primary function is to feed power to the load. The nature of load decides whether the load current waveform has harmonics or not.
- If the load is linear, no harmonics is produced and if the load is non linear the harmonics are produced in the electrical network.

- The transformer is supposed to feed the sinusoidal current at its rated kVA.
- However, if the current flowing through the transformer winding it adversely affects the transformer performance.
- If the magnitude of the harmonic current is more, it also distorts the input voltage of the transformer. The harmonics cause following adverse effects on the transformer performance.

Effect of Harmonics on Iron Loss

- The core or iron loss of the transformer is the loss occurs due to eddy current loss and hysteresis loss.
- The hysteresis loss is directly proportional to the frequency and, eddy current loss is directly proportional to the square of the frequency.
- Thus, it is clear that the iron loss gets increased with increase in frequency.
- The harmonic current is the integral multiples of the fundamental frequency and harmonic current may have frequency of 100 Hz, 150Hz, 200Hz, 250 Hz and so on.
- Thus the iron loss of the transformer gets increased if harmonic rich current flow through the transformer.

Effect of Harmonics on Copper Loss

- The tendency of flowing of current at the outer surface of the conductor is known as skin effect.
- The higher frequency current tends to flow at the outer surface of the conductor. When the current flows at the outer surface of the conductor, the effective cross section area of the conductor gets reduced.
- The reduction in effective cross section area leads to increase in the conductor resistance. The higher resistance of the conductor cause the more copper loss(I^2R) in the transformer.
- Thus, the copper loss of the transformer gets increased with increase in the harmonic current.

Effect of Harmonics on Efficiency of Transformer

- The efficiency of the transformer is defined as the ratio of output power to input power.
- Efficiency = Output Power/ Input Power

  = Input power- Losses/ Input Power

  = 1 – Losses/Input Power
- With increase of losses in the transformer due to harmonics, the efficiency of the transformer gets decreased.

Harmonics Cause De-rating of Transformer

- If the transformer is operated at X kVA when harmonic current is absent needs to be operated at lower kVA if transformer is operated with harmonic current to control the temperature rise of the transformer.
- In a nutshell, we can say that the transformer needs to be de-rated if the transformer is to be operated in harmonic rich current.

****

TWO MARKS

1. Define transformer.[DEC 2006]

A transformer is a static device which changes the alternating voltage from one level to another without change in frequency.

2. What is the turns ratio and transformer ratio of transformer? (Or) Define voltage transformation ratio of transformer.

Turns ratio = $\frac{N_2}{N_1}$ Transformer = $\frac{E_2}{E_1} = \frac{I_1}{I_2}$ = K.

3. Mention the difference between core and shell type transformers? [Nov/Dec 2008][May/June 2014]

In core type, the windings surround the core considerably and in shell type the core surrounds the windings i.e winding is placed inside the core.

4. Give the principle of transformer. [May/June 2010]

The principle of mutual induction states that when two coils are inductively coupled and it current in one coil is changed uniformly then an e.m.f induced in the other coil. This e.m.f can derive a current, when a closed path is provided to it. The transformer works on the same principle.

5. What is staggering in the construction of transformers?[Nov/Dec2005]

In transformer, the joints in the alternate layers are staggered in order to avoid the presence of narrow gaps right through the cross-section of the core.

6. What determines the thickness of the lamination or stampings?

- Frequency.
- Iron loss.

7. Classify the transformer according to the construction.

- Core type transformer.
- Shell type transformer.
- Berry type transformer.

8. What is the purpose of laminating the core in a transformer?(Or) Why is the core of transformer laminated?

The purpose of laminating the core in a transformer is to minimize eddy current loss.

9. Write down the e.m.f equations of a single phase transformer.

Emf induced in the primary coil $E_1 = 4.44f\Phi_m N_1$.

Emf induced in the secondary Coil $E_2 = 4.44f\Phi_m N_2$.

f = Frequency of AC supply in HZ.

Φ_m = Maximum value of flux in the core in wb.

N_1, N_2 = Number of primary & secondary turns.

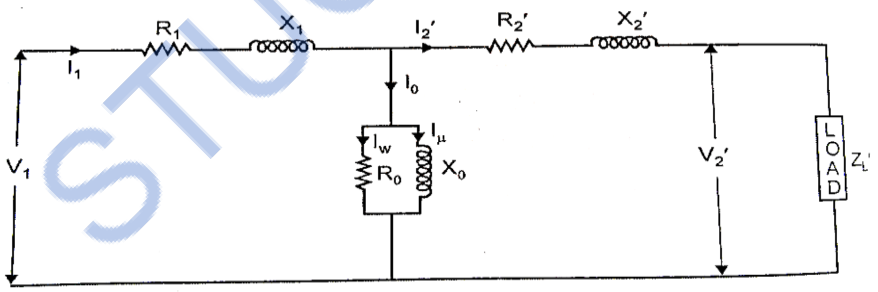
10. Does transformer draw any current when secondary is open? Why?

Yes, it (primary) will draw the current from the main supply in order to magnetize the core and to supply for iron and copper losses on no load. There will not be any current in the secondary since secondary is open.

11. Define step up and step down transformer.(Or) What do you meant by step down transformer?

- If the number of turns in the secondary winding is higher than the primary winding, it is called as **step-up transformer**.
- If the number of turns in the secondary winding is less than the primary winding, it is called as **step-down transformer.**

12. Draw the exact equivalent circuit of a transformer.



13. Why transformer rating is expressed in terms of kVA?[Dec2006,May/June 2003, 08,09, Nov/Dec2006,11].

- Copper loss of a transformer depends on current & iron loss on voltage.
- Hence total losses depend on Volt-Ampere and not on PF. That is why the rating of transformers is in kVA and not in kW.

14. What are the properties of an ideal transformer?

- No winding resistance i.e., purely inductive.
- No magnetic flux.
- No I^2R loss i.e., no copper loss.
- No core loss.

15. What is the application of equivalent circuit of a single phase transformer? [Nov/Dec 2001,05].

- To determine circuit parameters.
- To predetermine efficiency and voltage regulation.

16. Explain why in a real transformer $V_1:V_2 \neq N_1:N_2$, where V_1 and V_2 are terminal voltages.

For ideal transformer

$V_1:V_2 = N_1:N_2$ i.e., $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

But in case of real transformer, $\frac{N_2}{N_1}$ ratio is fixed but voltage ratio $\frac{V_2}{V_1}$ is varied because of voltage drop due to resistance and leakage reactance. That is why, the real transformer $\mathbf{V_1:V_2 \neq N_1:N_2}$

17. Explain on the material used for core construction.

- The core is constructed by sheet steel laminations assembled to provide a continuous magnetic path with minimum of air gap included.
- The steel used is of high silicon content sometimes heat treated to produce a high permeability and a low hysteresis loss at the usual operating flux densities.
- The eddy current loss is minimized by laminating the core, the laminations being used from each other by light coat of core-plate vanish or by oxide layer on the surface. The thickness of lamination varies from 0.35mm for a frequency of 50 Hz and 0.5mm for a frequency of 25 Hz.

18. How does change in frequency affect the operation of a given transformer?

With a change in frequency, iron and copper loss, regulation, efficiency & heating varies so the operation of transformer is highly affected.

19. List the arrangement of stepped core arrangement in a transformer?

- To reduce the space effectively.
- To obtain reduce length of mean turn of the winding.
- To reduce I^2R loss.

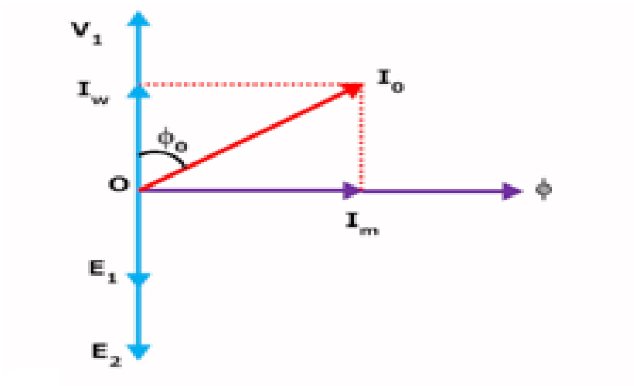
20. Why are breathers used in transformers?

- Breathers are used to entrap the atmospheric moisture and thereby not allowing it to pass on to the transformer oil.
- It permits the oil inside the tank to expand and contract as its temperature increases and decreases.

21. What is the function of transformer oil in a transformer?

- It provides good insulation
- Cooling.

22. Draw the no-load vector diagram of a transformer.



Phasor diagram of practical transformer on no load

23. Explain the term percentage impedances applicable to transformer.

Percentage impedance at full load % Z = $\frac{I_1 Z_{01}}{V_1}$ *100 = $\frac{I_2 Z_{02}}{V_2}$

% Z = $\sqrt{(\%R^2 + \%X^2)}$

24. Mention the properties of oil used in transformers.

- High dielectric strength.
- Free from inorganic acid, alkali and corrosive sulphur to prevent injury to the conductor.
- Low viscosity to provide good heat transfer.
- Good resistance to emulsion so that the oil may throw down any moisture entering the tank instead of holding it in suspense.

25. Define regulation up and regulation down for a transformer.[Nov/Dec 2005].

The change in secondary terminal voltage from no-load to full load is V_{2NL}-V_2. This change is divided by V_{2NL} is known as regulation down. If this change is divided by V_2, then it is called as regulation up.

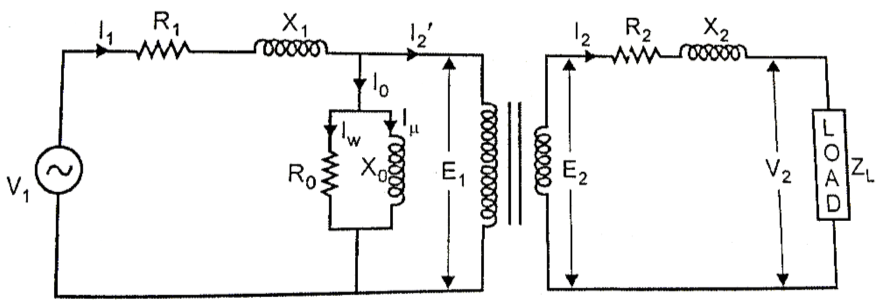
% Regulation down = $\frac{V_{2NL}-V_2}{V_{2NL}}$ *100

% Regulation up = $\frac{V_{2NL}-V_2}{V_2}$ *100

26. What is an ideal transformer? [May/June 2004, Nov/Dec 2004].

100% efficiency of the transformer is called ideal transformer.

27. Draw the typical equivalent circuit of a single phase transformer.[Nov/Dec 2003].



28. State the condition for maximum efficiency of a transformer. Then what is the corresponding output current?

Iron loss= copper loss (or) constant loss = Variable loss.

Hence efficiency of a transformer will be maximum when copper losses are equal to iron loss. The load current corresponding to maximum efficiency is given by $I_2 = \sqrt{\left(\frac{P_i}{R_{02}}\right)}$

29. What happens if DC supply is applied to the transformer?[May/June 2012].

If DC supply is given, the current will not change due to constant supply hence mutual induction is not possible and transformer will not work. The resistance of primary winding is very small and inductive reactance is zero for DC. Hence primary will draw very high current for DC supply which may cause damage to the transformer due to extra heat generated. This may cause saturation of the core. Hence DC supply is not applied to the transformers.

30. Define "all day efficiency" of a transformer.

It is computed on the basis of energy consumed during a certain period, usually a day of 24 hrs.

$$\text{All day efficiency} = \frac{\text{Energy Output in kWh for 24 hrs}}{\text{Energy Input in kWh for 24 hrs}}$$

31. Define regulation and efficiency of the transformer.(Or) Give the expression for percentage voltage regulation of a single phase transformer.[Nov/Dec 2003,13] (Or) Define voltage regulation of a transformer.[May 18]

The regulation of the transformer is defined as the reduction in magnitude of the terminal voltage due to load, with respect to the no-load terminal voltage.

$$\%\ \text{Regulation} = \frac{|V_2 \text{ on no-load}| - |V_2 \text{ when loaded}|}{|V_2 \text{ on no-load}|} * 100$$

$$\text{Transformer Efficiency } \eta = \frac{\text{Output power}}{\text{Input power}} * 100$$

32. List out the various applications of an autotransformer.[May/June 2005, 06, 09, Nov/Dec20013]

The major applications are induction motor starters, interconnection of HV systems at voltage levels with ratio less than 2, and in obtaining variable voltage power supplies (low voltage and current levels).

33. Name the factors on which hysteresis loss depends?

- Frequency
- Volume of the core
- Maximum flux density

34. Why the open circuit test on a transformer is conducted at rated voltage?

The open circuit on a transformer is conducted at a rated voltage because core loss depends upon the voltage. This open circuit test gives only core loss or iron loss of the transformer.

35. What are the necessary tests to determine the equivalent circuit of the transformer?

- Open circuit test
- Short circuit test

36. Why is the range of efficiency in transformer higher than those of other electrical machines?

The range of efficiency in transformer is higher than those of other electrical machine because there are no rotating parts in the transformer. i.e., rotational loss is zero.

37. Mention the two different components of core loss in a transformer.

- Hysteresis loss
- Eddy current loss

38. Give the expression for the load current when the transformer operates at its maximum efficiency. Nov/Dec 2006.

$$I_2=\sqrt{\left(\frac{P_i}{R_{02}}\right)}$$

Where,

I_2=load current,

P_i=Iron loss,

R_{02}=Equivalent resistance to secondary.

39. Explain why the wattmeter in OC test on transformers reads core loss and that in SC test reads copper loss at full load.

- In OC test, the transformer secondary is open. The transformer is operated at rated voltage. Here only iron loss occurs in transformer core.
- In SC test, the transformer secondary winding is short circuited. The transformer is operated at rated current. Here the input voltage is low. The full load current depends upon the copper loss.

40. Why is the short circuit test on a transformer performed on HV side?

The short circuit test is normally conducted on transformer HV side and LV side is short circuited, because on the high voltage side, the current rating is low. So we have to use normally available meter range.

41. Under what type of power factor a transformer gives zero voltage regulation?

Under leading power factor a transformer gives zero voltage regulation.

42. What are the various losses in a transformer? (May 18)

- Core loss (or) Iron losses.
- Hysteresis loss.
- Eddy current loss.
- Copper losses.

43. Why polarity test has to be done in a transformer?

A polarity is carried out to find out the terminal having the same instantaneous polarity assuming that the terminals are not marked.

44. What are the different types of testing of transformer?

- Polarity test.
- Load test.
- Open circuit and short circuit test.
- Sumpner's test.
- Ratio test.

45. What is the use of load test of a transformer?

Load test is helpful to determine the efficiency and regulation of the transformer.

46. What is the purpose of open circuit test and short circuit tests in a transformer?

The open circuit test is useful to find:

i. Core loss.
ii. No-load current.
iii. R_0 and X_0.

The short circuit test is useful to find:

- Full-load copper loss.
- Equivalent resistance and reactance referred to any side.

By using two tests we can determine the efficiency and regulation of the transformer.

47. How can the iron loss be minimized in a transformer?

- The iron loss be minimized in a transformer is made up of Hysteresis loss and Eddy current loss.
- Hysteresis loss can be minimized by using high silicon content for the transformers core.
- Eddy current loss can be minimized by using very thin lamination of transformers core.

48. What are the advantages of OC and SC tests on the transformer?

- Power required to carry out SC tests is very small as compared to the full load output of the transformer.

- These tests enable us to determine the efficiency of the transformer accurately at any load and power factor without actually loading the transformer.
- The short circuit test is used to determine R_{01} and X_{01} (or) $R_{02}$and X_{02}. By using this data we can find out voltage drop and voltage regulation of the transformer.

49. Compare two winding transformer and autotransformer.[Nov/Dec 2011].

S.No	Two winding transformer	autotransformer
1.	Copper required is more.	Copper required is less.
2.	Size and cost is more.	Size and cost is less.
3.	The efficiency is less due to high. values of resistances and leakage reactances.	The efficiency is more due to less. values of resistances and leakage reactances.
4.	Smooth and continuous variation of voltage is not possible.	Smooth and continuous variation of voltage is possible.
5.	The primary and secondary are electrically isolated.	There is no electrical isolation between primary and secondary.

50. What is the purpose of providing Taps in transformer and where these are provided?

In order to attain the required voltage, taps are provided, normally at high voltages side (low current).

51. What material is used in the transformer core? [Nov/Dec 2002]

High grade silicon steel laminations are used for the construction of the core.

52. Distinguish power transformers & distribution transformers?

POWER TRANSFORMERS	DISTRIBUTION TRANSFORMERS
They have very high rating in the order of MVA	Power ranging will be small in order of kVA.
They are used in generating and receiving stations	They are used in receiving side.
Sophisticated controls are required.	Complicated controls are not needed.
Voltage ranges will be very high	Voltage levels will be medium

53. What is the angle by which no-load current will lag the ideal applied voltage?

- In an ideal transformer, there are no copper & core loss i.e. loss free core.
- The no load current is only magnetizing current therefore the no load current lags behind by angle 900.
- However the winding possess resistance and leakage reactance and therefore the no load current lags the applied voltage slightly less than 900.

54. What are the applications of step-up & step-down transformer?

Step-up transformers are used in generating stations. Normally the generated voltage will be either 11kV. This voltage (11kV) is stepped up to 110kV or 220kV or 400kV and transmitted through transmission lines (simply called as sending end voltage).

Step-down transformers are used in receiving stations. The voltage are stepped down to 11kV or 22kV are stepped down to 3phase 400V by means of a distribution transformer and made available at consumer premises. The transformers used at generating stations are called power transformers.

55. List out any four general application of Transformers.

Transformers are used in:

- Electrical power engineering for transmission and distribution.
- As an instrument transformer for measuring current (CT) and measuring voltage (PT).
- As a step down transformer and step up transformer to get reduced or increased output voltage.
- Radio and TV circuits, telephone circuits, control and instrumentation.
- Furnaces and welding transformer.

56. Define leakage inductance.[Nov/Dec 2002]

Inductance offered by the winding due to the leakage flux associated with it is called leakage inductance. It is the ratio of leakage flux linkages with the winding to the current passing through the winding.

57. Why is the efficiency of transformers more than that of other rotating machines? [May/June 2003]

There are no moving parts in transformer hence the friction and mechanical losses are absent in transformer. Hence efficiency of the transformer is more than of other rotating machines.

58. What are the advantages of autotransformer over two winding transformer? [May/June 2008, Nov/Dec 2008,12,13]

The auto transformer has lower reactance, lower losses, smaller exciting current and better voltage regulation compared to its two-winding.

59. What are the conditions of parallel operation of transformers?[May/June 2010, Nov/Dec2010]

- The transformers must have the same voltage-ratio to avoid no-load circulating current when transformers are in parallel on both primary and secondary sides.

- The transformers must be connected properly as far as their polarities are concerned so that the net voltage around the local loop is zero. A wrong polarity connection results in a dead short circuit.
- The ratio of equivalent leakage reactance to equivalent resistance should be the same for all the transformers.

60. What are no load losses in a two winding transformer and state the reasons for such losses.[Nov/Dec 2010]

The primary current in the transformer under no load condition has to supply iron losses which includes hysteresis and eddy current losses and small primary copper losses due to the primary winding resistance. The hysteresis losses are due to the cyclic magnetization of the core due to alternating current through it while the eddy current loses are due to induced e.m.f in the core material.

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UNIT-II

DC MACHINES

Introduction – Constructional Features– Motor and Generator mode - EMF and Torque equation – Circuit Model – Methods of Excitation- Characteristics – Starting and Speed Control – Universal Motor- Stepper Motors – Brushless DC Motors- Applications.

INTRODUCTION:

DC Machines can be used as a generator or as a motor. Hence DC Machines are classified in to:

i) DC Generator
ii) ii) DC Motor

1. Describe the construction of DC Machine with neat sketch?[MAY 2018](OR) Explain the construction and working of the dc generator? (OR) Explain in detail about the construction and working of dc motor?

A dc generator is a machine that converts mechanical energy into electrical energy (dc voltage and current) by using the principle of magnetic induction.

Construction:

The construction of DC generator and DC motor are the same. Any DC generator can be run as a DC Motor and vice-versa. All DC machines have a stator and Rotor.

The stator consist of

- Yoke or Magnetic frame.
- Field system poles - Field winding, Inter-poles.

The Rotor has the following parts

- Armature-Armature core, Armature winding.
- Commutator.
- Brushes, Bearing.

Yoke:

- It acts as a protecting cover for DC machine.
- It provides mechanical support for the poles.
- It carries the magnetic flux produced by the poles.
- Material used:

  Small machine: cast iron

  Large machine: cast steel

Pole core, pole shoes:

- Pole core carries field winding which is necessary to produce the flux.
- Pole shoes spread out the flux in the air gap and also to reduce the reluctance.
- They support the exciting coils.

Material used:

Small machine: cast iron

Large machine: cast steel

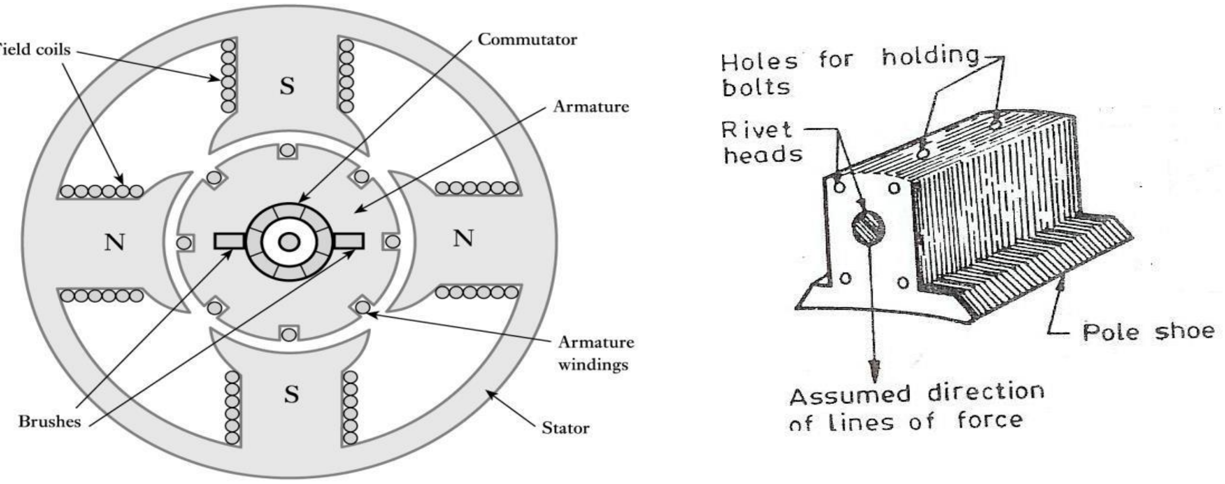


Fig 3.1: General arrangement of dc machines

Inter poles:

- Inter poles or the commutating poles are fixed to the frame in between main poles.
- They are used for improve commutation.

Field winding:

- The field winding is placed on the pole core.
- To carry the current and to produce the magnetic flux. Material used: It is made up of aluminium or copper.

Armature:

- It is further divided into two parts namely:
- Armature core
- Armature winding

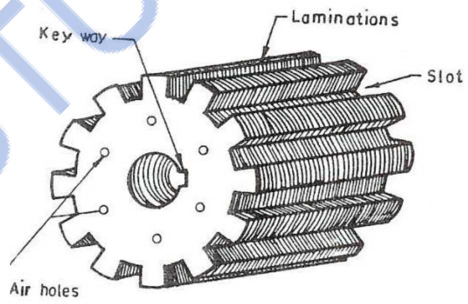


Fig 3.2: Isometric view of armature

Armature core:

- It is cylindrical in shape with slots on its outer periphery.
- It is mounted on the shaft.
- It provides the house for armature conductors.

Material used:

Small machine: cast iron

Large machine: cast steel

Armature winding:

- The armature windings are placed into the slots on the armature surface.
- The ends of the coils are soldered with commutator segments.

Functions: When the armature rotates an emf is induced in the armature conductors in case of generators.

Material used: Copper.

Commutator:

- The basic nature of emf induced in the armature conductor is alternating.
- This needs rectification in case of DC generator, which is made possible by a device called commutator.

Material used: Copper.

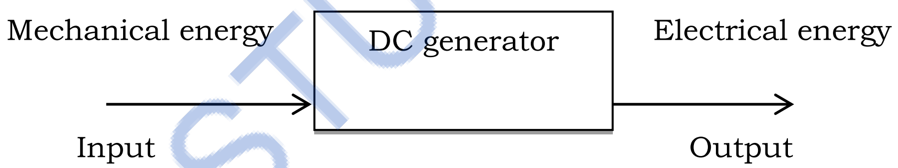
Brushes & Bearings:

- The function of brushes is to collect current from commutator.

DC GENERATOR:

INTRODUCTION:

- An electrical generator is a device that converts mechanical energy to electrical energy, generally using the principle of electromagnetic induction.
- According to Faraday's Laws of Electro-Magnetic Induction, when a conductor or a coil is rotated in a magnetic field in such a way, to cut the magnetic lines of flux, an e.m.f is induced in a conductor or in the coil.



2. Explain the principle of operation of the DC generator.

PRINCIPLE OF OPERATION:

- When a conductor move in a magnetic field in such a way conductors cuts across a magnetic flux of lines and so the emf produces in a generator.
- It is defined by faradays law of electromagnetic induction emf causes current to flow if the conductor circuit is closed.
- Let us consider a single turn coil ABCD rotated on a shaft within a uniform magnetic field of flux density. It is rotated in an anticlockwise direction.
- Let 'l' be the length and 'b' be the breadth of the coil in meters.
- When the coil sides AB and CD are moving parallel to the magnetic field, the flux lines are not being cut and no emf is induced in the coil.

- At this position we assume the angle of rotation 'θ' as zero.
- This vertical position of the coil is the starting position. According to Faraday's law II, the emf induced is propositional to the rate of change of flux linkages.

$$e = -N\frac{d\varphi}{dt}$$

Where 'N' is the number of turns, 'φ' is the flux and 't' is the time

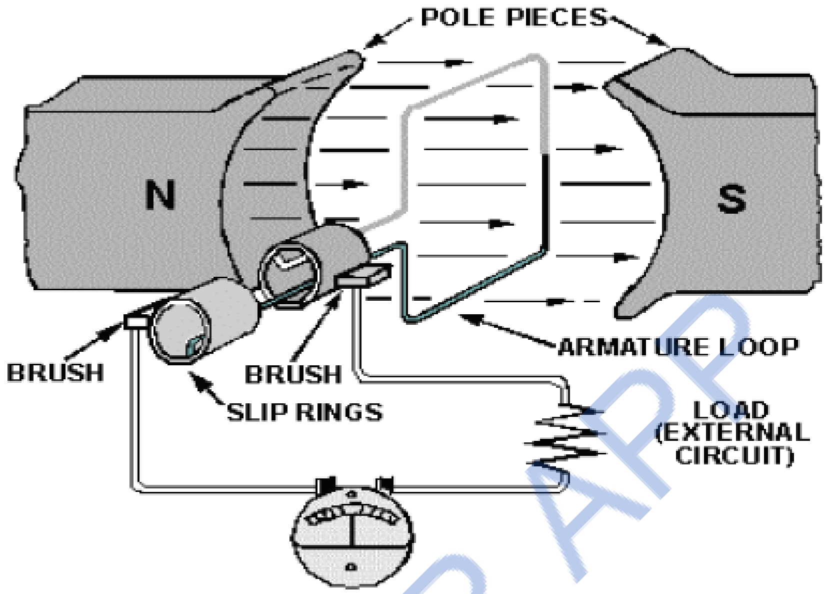


Fig 3.3: Schematic diagram of simple DC generator

- When 'θ' = 90°, the coil sides are moving at the right angles to the flux lines. The flux lines are cut at maximum rate and the emf induced is maximum.
- When 'θ' = 180°, the coil sides are again moving parallel and the emf induced is zero.
- When 'θ' = 270°, the coil sides are again move at right angle to the flux but with their position reversed. Hence induced emf is maximum in opposite direction.
- When 'θ' = 360°, the coil sides are once again move parallel to the magnetic field making induce emf equal to zero.
- The coil has now come back to the starting point.

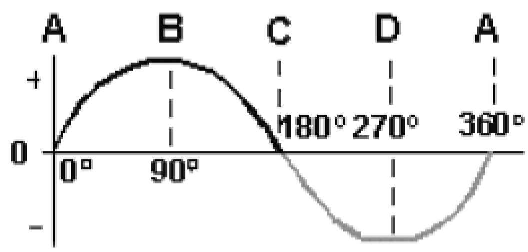


Fig 3.4: Generator terminal voltage

- The emf changes from instant to instant and becomes alternatively positive and negative. Such an emf is called alternating emf.

- The induced emf in the coil can be increased by

(i) increasing the flux density(B) and

(ii) by increasing the angular velocity (ω).

- The current flowing in the external resistance to a D.C generator is made unidirectional by connecting the coil side to a slip ring.
- The slip ring is split into two segments a and b and the segments are insulated from each other and from shaft.
- The coil sides AB is always attached to the segment a and likewise CD to b.
- The brushes B_1 and B_2 touch these segments and are meant to collect the current.

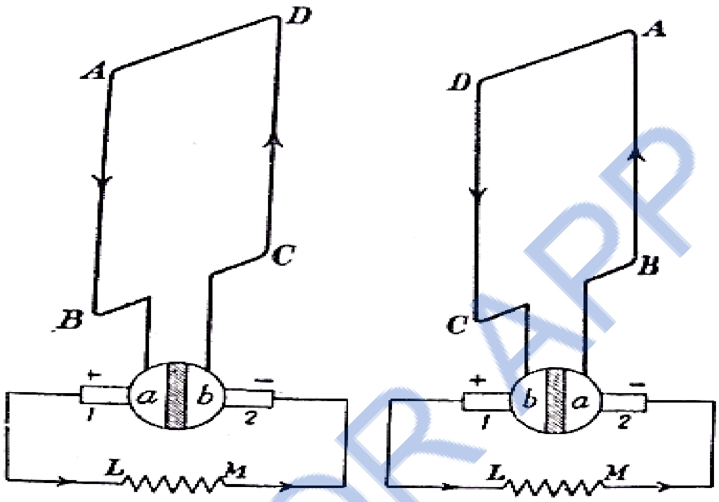


Fig 3.5: coil ABCD connected to the slip ring

- During the first half revolution, current flows along ABLMCD through brush B1 which is positive and into B2(negative brush)
- After half a cycle AB and CD have exchanged positions along with the segments a and b and current now flows, through DCLMBA. B1 is now in contact with b.
- For each half revolution, the positions of segments a and b also reverse. Hence the current in the load is always unidirectional.
- The changeover of segments a and b takes place when flux linkage or induced emf is minimum. In a generator, the split-rings are called commutator.

3. Derive the EMF equation of the DC generator.[NOV/DEC-2015]

Let,

φ= flux per poles in weber

N= speed of armature in RPM

P= Number of poles

$\frac{N}{60}$= Speed of armature in RPS

Z = Total number of armature conductors.

E = EMF induced in any parallel path in the armature in volts

A = Number of parallel paths.

According to Faraday's law, the induced emf is proportional to the rate of change of the magnetic flux.

$$\text{i.e.,}\ e = -\frac{d\varphi}{dt}$$

Let us consider a single conductor moving during one revolution. The flux produced by it is given by,

$d\varphi = \varphi P$weber

Number ofrevolutions per second $= \frac{N}{60}$ seconds

Time taken to complete one revolution,$dt = \frac{60}{N}$seconds.

According to Faraday's laws of electromagnetic induction.

EMF generated / conductor $= \frac{d\varphi}{dt}$ ………………(1)

Substituting,$d\varphi = \varphi p$ and $dt = \frac{60}{N}$ in equation (1) gives

$$\frac{d\varphi}{dt} = \frac{\varphi P}{\left(\frac{60}{N}\right)}$$

EMF generated/conductor,

$$\frac{d\varphi}{dt} = \frac{\varphi PN}{60}$$

Number of conductors in one path of armature $= \frac{Z}{A}$

EMF generated / path$= \frac{\varphi NP}{60}\left(\frac{Z}{A}\right)$ **Volts**

For wave winding, A= 2

EMF generated/path$= \frac{\varphi NP}{60}\left(\frac{Z}{2}\right)$ Volts

$$= \frac{\varphi NPZ}{120}\text{Volts}$$

For lap winding, A=P

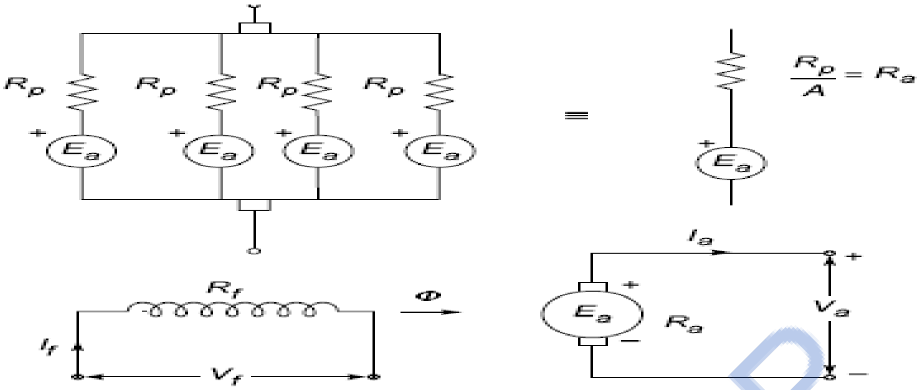
EMF generated/path$= \frac{\varphi NP}{60}\left(\frac{Z}{P}\right)$ Volts

$$= \frac{\varphi NZ}{60}\text{Volts}$$

4. Explain the Circuit Model of a dc machine.

- The parallel paths of dc machine armature are symmetrical and each has an induced emfEa and a resistance Rp. as shown in Fig below for A = 4.
- Its Thevenin equivalent is drawn by the side in which

$V_{OC} = E_a, R_{TH} = \frac{R_p}{A} = R_a$



- The armature can be represented by the symbol as shown in Fig with Ea within circle and the series resistance Ra written by its side.
- The armature resistance is quite small so as to limit the copper- loss to an acceptable value. Figure 7.16 also shows the field circuit of the machine and the field coil axis is placed at 90° to the brush axis.
- Since most of the time steady-state dc behaviour of the machine will be considered.

The armature induced emf $E_a = K_a \Phi \omega_m$

Machine torque $T = K_a \Phi I_a$

- The voltage drop at brush-commutator contact is fixed (1–2 V), independent of armature current as the conduction process is mainly through numerous short arcs.
- This voltage being small is modelled as linear resistance and lumped with Ra.

Generating Mode

- The machine operates in generating mode (puts out electrical power) when Ia is in the direction of induced emfEa as in Fig. (a). For the armature circuit

$V_t(\text{Armatureterminalvoltage}) = E_a - I_a R_a$

$V_t < E_a$

- Thus a dc machine is generating if its armature induced emf (Ea) is more than its terminal voltage (Vt).
- The electromagnetic power converted from mechanical to electrical from is

$E_a I_a = P_{Mech}(in)|_{net} = P_{elec}(out)|_{gross}$

The net electrical power output is

$P_0 = V_t I_a$

$E_a I_a - V_t I_a = I_a^2 R_a = \text{armaturecopper} - \text{loss(inclusiveofbrushloss)}$

$P_{Mech}(in)|_{gross} = \text{shaftpower} = P_{Mech}(in)|_{net} + \text{rotationalloss}$

- In this mode torque (T) of electromagnetic origin is opposite to the direction of rotation of armature, i.e., mechanical power is absorbed and a prime-mover is needed to run the machine.
- The conductor emf and current are also in the same direction for generating mode as shown in the cross sectional view of Fig.

Motoring Mode

- In this mode, Ia flows in opposition to induced emfEa as in Fig(b). Ea is now known as the back emf to stress the fact that it opposes the armature emf. For the armature circuit

$V_t(\text{Armatureterminalvoltage}) = E_a + I_a R_a$

- Thus a DC machine is motoring if armature terminal voltage (Va) is more than its induced emf (Ea).
- The electromagnetic power converted from mechanical to electrical from is

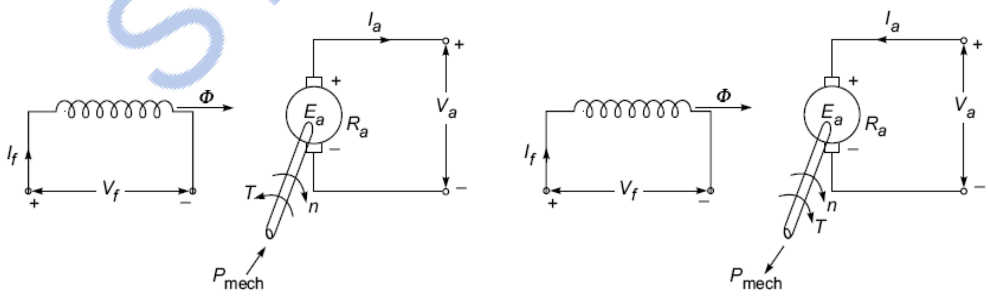
$E_a I_a = P_{elec}(in)|_{net} = P_{mech}(out)|_{gross}$

The electrical power input is $P_i = V_t I_a$

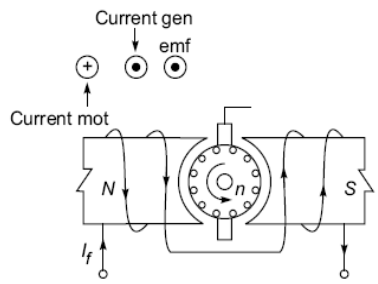
$V_t I_a - E_a I_a = I_a^2 R_a = \text{armaturecopper} - \text{loss(inclusiveofbrushloss)}$

$P_{Mech}(out)|_{net} = \text{shaftpower} = P_{Mech}(out)|_{gross} - \text{rotationalloss}$

- In this mode torque (T) of electromagnetic origin is in the direction of armature rotation, i.e., mechanical power is put out and is and absorbed by load (mechanical).
- Conductor emf and current are also in opposite directions for motoring mode as shown in Fig (c).



(a) Generating mode (b) Motoring mode



(c) Generating/motoring modes

Lap Versus Wave Winding

- Consider a P pole machine having flux/pole Φ and rotating at ω_m rad/s. It has a total of Z conductors and maximum permissible conductor current is Ic.
- Let us derive the expression for power converted and torque developed.

$$E_a = \left(\frac{ZP}{2\pi A}\right)\Phi\omega_m$$

$$I_a(\text{Permitted}) = AI_c$$

$$\text{Powerconverted} = E_a I_a = \left(\frac{ZP}{2\pi}\right)\Phi\omega_m I_c$$

Torque developed

$$T = \left(\frac{ZP}{2\pi A}\right)\Phi I_a$$

Or

$$T = \left(\frac{ZP}{2\pi}\right)\Phi I_c$$

- Find that the power converted and torque developed are independent if the number of parallel paths.
- It means that these values are that same whether the conductors are lap connected or wave. These in fact depend on number of conductors and permissible conductor current.

5. explain the different types of D.C Generators in detail (OR)Explain various excitation methods of D.C Generator.[May/June -2013]

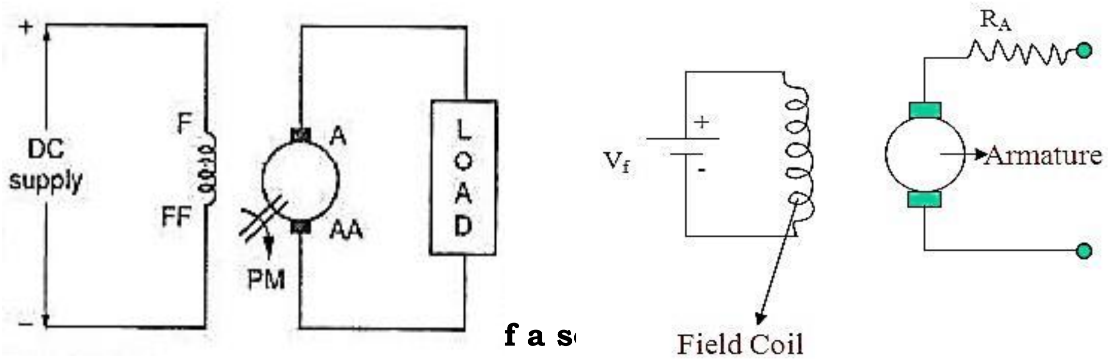
Generators are generally classified according to their methods of field excitation. On this basis, d.c. generators are divided into the following two types:

(i) Separately excited d.c. generators

(ii) Self-excited d.c. generators

(i) Separately Excited DC Generator:

A d.c. generator whose field magnet winding is supplied from an independent external d.c. source (e.g., a battery etc.) is called a separately excited generator.



- Armature current I_a= load current I_L

- R_a= Resistance of the armature winding.
- **Terminal voltage $V = E_g - I_a R_a - V_{brush}$**
- V_{brush} = Voltage drop at contacts of the brush
- **Generated emf $E_g = V + I_a R_a + V_{brush}$**
- Power developed in the armature, $P_a = E_g I_a$
- Power delivered to load = $V I_a$

(ii) Self-Excited D.C. Generators:

A d.c. generator whose field magnet winding is supplied current from the output of the generator itself is called a self-excited generator.

There are three types of self-excited generators depending upon the manner in which the field winding isconnected to the armature, namely;

(a) Series generator;

(b) Shunt generator;

(c) Compound generator

Series Generator:

In a series generator, the field winding is connected in series with armature winding. So that whole armature current flows through the field winding as well as the load.

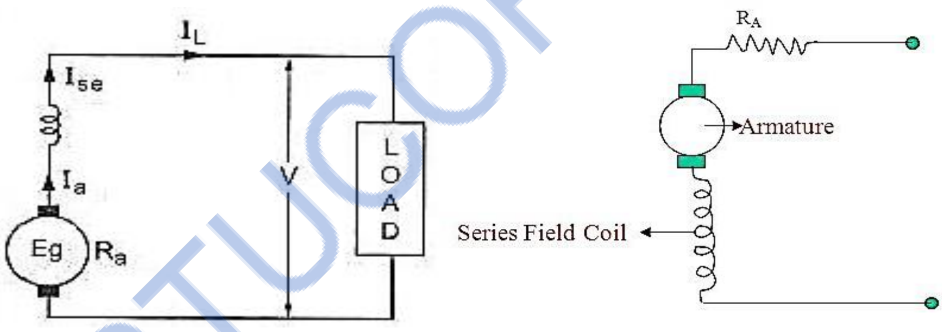


Fig 3.7: Connections of a seriesgenerator

- $\therefore I_a = I_L = I_{se}$
- **Terminal voltage $V = E_g - I_a R_a - I_a R_{se} - V_{brush}$**
- **Generated emf,** $E_g = V + I_a R_a + I_a R_{se} + V_{brush}$
- V= terminal voltage in volts.
- $I_a R_a$= Voltage drop in the armature resistance
- $I_a R_{se}$= Voltage drop in the series field winding resistance
- V_{brush} = Voltage drop at contacts of the brush
- Power developed in the armature, $P_a = E_g I_a$
- Power delivered to load, = $V I_a$(or) $V I_L$

Shunt Generator:

In a shunt generator, the field winding is connected in parallel with the armature winding.

Only a part of armature current flowsthrough shunt field winding and the rest flows through the load.It is a "constant speed" machine.

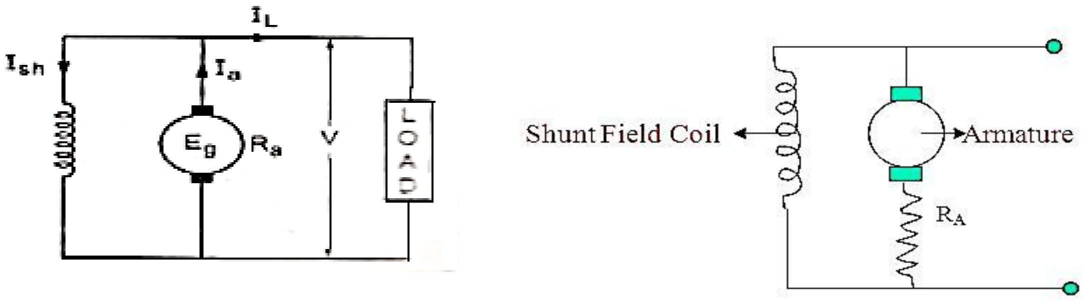


Fig 3.8: Connections of a shunt generator

- **Terminal Voltage $V = E_g - I_a R_a$**
- Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$
- Armature current, $I_a = I_L + I_{sh}$
- Power developed in the armature, $P_a = E_g I_a$
- Power delivered to load, $= V I_L$

Compound Generator:

In a compound-wound generator, there are two sets of field windings on each pole,one is in series and the other in parallel with the armature.

Depending upon these two winding connections, it is further classified into two types

- Long shunt compound generator
- Short shunt compound generator

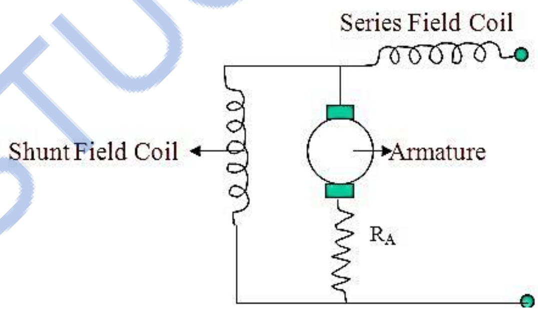


Fig 3.9: Connections of a compound generator

Long shunt compound generator:

Shunt field winding is connected between both series and armature winding.

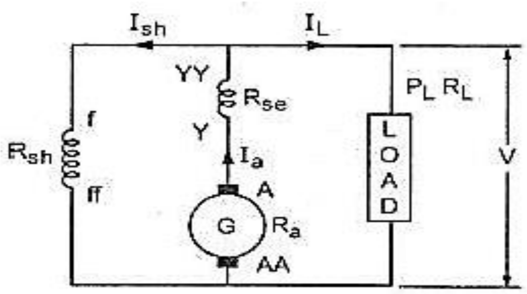


Fig 3.10: Connections of a long shunt compound generator

- Series field current, $I_{se} = I_a = I_L + I_{sh}$
- Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$
- **Generated emf,** $E_g = V + I_a(R_a + R_{se}) + V_{brush}$
- **Terminal voltage** $V = E_g - I_a(R_a + R_{se}) - V_{brush}$
- Power developed in the armature, $P_a = E_g I_a$
- Power delivered to load, $= V I_L$

Short shunt compound generator:

Shunt field winding is connected in parallel with the armature and this combination is connected in series with series field winding.

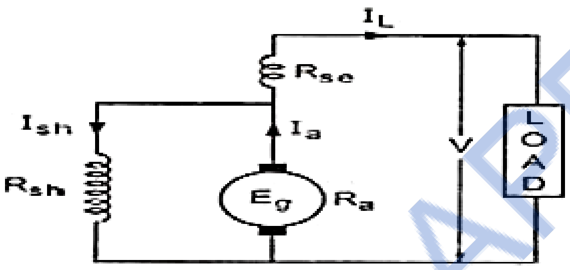


Fig 3.11: Connections of a short shunt compound generator

- Load current, $I_L = I_{se}$(series field current)
- Armature current, $I_a = I_{sh} + I_{se}$
- Shunt field current, $I_{sh} = \frac{(V + I_{se}R_{se})}{R_{sh}}$
- **Generated emf,** $E_g = V + I_aR_a + I_{se}R_{se} + V_{brush}$
- **Terminal Voltage** $V = E_g - I_aR_a - I_{se}R_{se} - V_{brush}$
- Power developed in the armature, $P_a = E_g I_a$
- Power delivered to load, $= V I_L$

6. **What are the applications of DC generator?**

APPLICATIONS OF DC GENERATOR:

DC Separately Exited Generator:

As a supply source to DC Motors, whose speed is to be controlled for certain applications. Where a wide range of voltage is required for the testing purposes.

DC Shunt Generator:

The terminal voltage of DC shunt generator is more or less constant from no load to full load .Therefore it is used where constant voltage is required.

- For electro plating
- Battery charging
- For excitation of Alternators.

DC Series Generator:

The terminal voltage of series generator increases with load current from no load to full load .Therefore these generators are,

- Used as Boosters
- Used for supply to arc Lamps

DC Compound Generator:

- Differential Compound generators are used to supply dc welding machines.
- Level compound generators are used to supply power for offices, hostels and Lodges etc.
- Over compound generators are used to compensate the voltage drop in Feeders.

7. Explain the open circuit and load circuit characteristics of separately excited DC generator (OR) performance characteristics[NOV/DEC 2009](OR) Explain the internal and external characteristics of DC generators.[APR/MAY 2015]

There are three types of characteristics in DC generator.

- Open circuit characteristics (OCC) (or) Magnetization characteristics [E_gVs I_f]
- Internal characteristics (or) Total characteristics [E VsI_a)
- External characteristics (or) Voltage regulated characteristics [V Vs I_L]

These three characteristics are applicable for both self-excited and separately excited DC generator.

SEPARATELY EXCITED DC GENERATOR:

From generator emf equation,

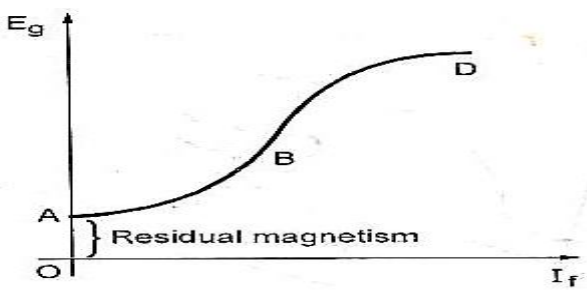
$$E_g = \frac{\varphi ZN}{60}\left(\frac{P}{A}\right)$$

- It is clear that the induced emf is proportional to the flux. If the speed is kept constant, and the flux is varied, then the induced emf also varies.

$$Eg \propto \varphi N$$

Open circuit characteristics:

- If N is constant, Φ increases E_g increases Fig. shows the separately excited circuit diagram for OCC.
- The variation of flux with the induced emf is called the no-load magnetization curve (or) saturation curve of the generator. Measurement of flux is difficult, instead the curve is plotted between field current (If) and induced emf (E_g).

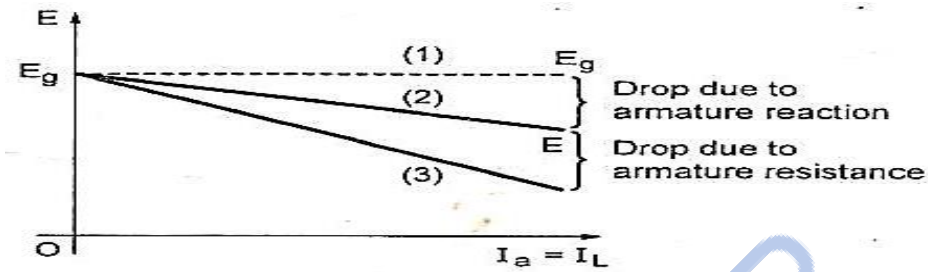


Internal and External Characteristics:

- The internal and external characteristics are obtained due to armature reaction drop and armature resistance drop.

Internal Characteristics

- This curve is drawn between the emf (E) and armature current (I_a). By increasing the I_a induced emf, E will decrease due to armature reaction is shown in Fig. This is represented as curve (2).



External Characteristics

- This curve is drawn between the terminal voltage (V) and armature current (I_a).By increasing I_a, the induced emf again decreases due to armature resistance. This is represented as curve (3).

(i)DC Shunt Generator Characteristics:

- This is one type of self-excited DC generator. If the armature and field winding are connected in parallel it is called shunt excitation.

a) Open Circuit Characteristics (OCC):

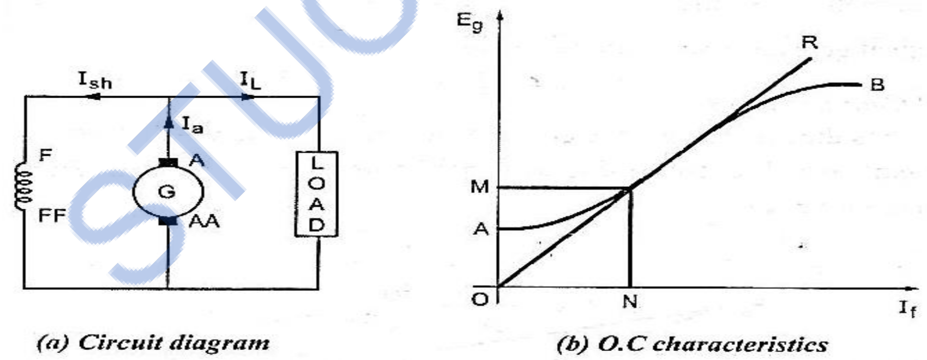


Fig 3.12: Open circuit characteristics of a DC shunt generator.

- Initially the field current is zero, but emf OA is induced in the generator due to residual magnetism. Due to this voltage, field current increases and emf also increases. The emf and field current increase till it reaches point B.
- At this point, the field current is just sufficient to produce the voltage till B. There is no further increase in field current (or) induced emf. This curve is drawn between field current and induced emf. It is called as open circuit characteristics.

Internal and External Characteristics:

- There are several reasons that cause reduction of terminal voltage.

- I_a increases causing a drop of voltage in the armature resistance Ra, Drop in the brush contact resistance and Drop due to armature reaction.

The above three factors cause a decrease in the induced emf. It is expressed by the following equation.

$$V = E_g = \left[\begin{Bmatrix}\text{Drop in} \\ \text{armature resistance}\end{Bmatrix} + \text{Brush Drop} + \begin{Bmatrix}\text{Drop in} \\ \text{armature reaction}\end{Bmatrix}\right]$$

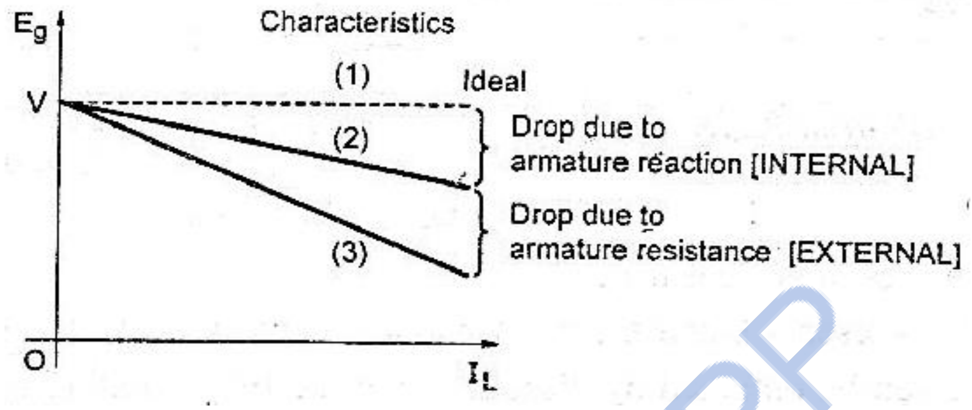


Fig 3.13: shows the characteristics of DC shunt generator

From the characteristics curve,

- The curve (1) represents Ideal DC generator (i.e.,) by increasing load current the terminal voltage should be constant. There is no armature drop.
- The curve (2) shows internal characteristics, here the drop is due to the armature reaction.
- The Curve (3) shows external characteristics, here the drop is due to the armature resistance. By increasing the load current the terminal voltage increases.

DC Series Generator Characteristics:

- Curve (l) represents Open Circuit Characteristics (OCC) of a series generator. This curve can be obtained by disconnecting the field winding from the machine and excited by separate d.c source.
- The curve (2) represents the internal characteristics (i.e.,) E_g/Ia. Here, the drop is due to armature reaction. By increasing the load current, the induced emf E decreases,

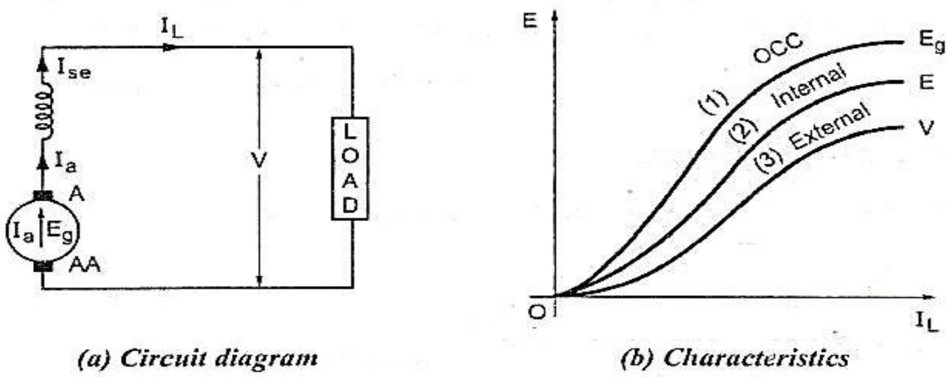


Fig 3.14: Circuit diagram and characteristics curve of DC series generator

- The curve (3) represents the external characteristics. Here, the drop is due to armature resistance and series field resistance. By increasing the load current, the terminal voltage decreases.
- It is seen from characteristics shown in Fig. that the series generator has a rising characteristic (i.e.,) voltage increases with increase in load.

Compound Generator:

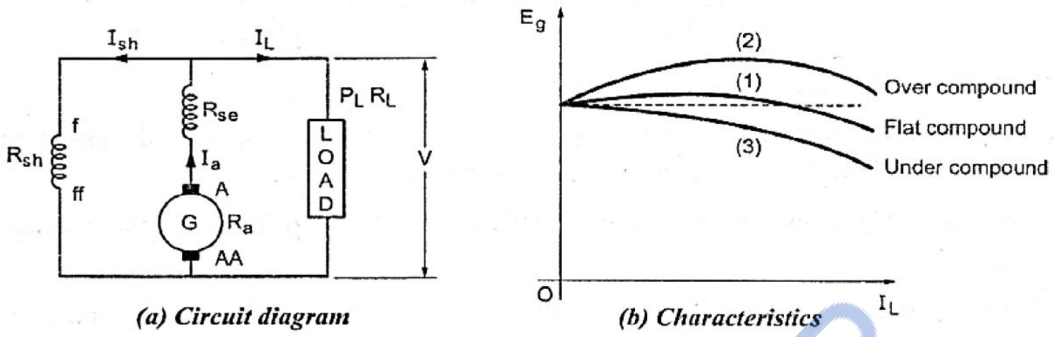


Fig 3.15: circuit diagram and characteristics curve of compound generator

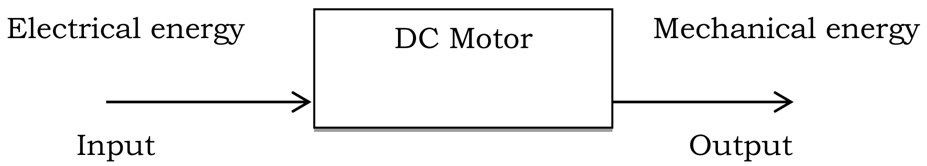
There are three curves presented in the characteristics of DC compound generator. They are,

- The curve (1) represents curve of flat compound generator.
- Curve (2) represents the characteristics of over compound generator.
- The curve (3) represents the characteristics of under compound generator.

D.C MOTOR

INTRODUCTION

- A machine that converts electrical energy into mechanical energy is known as dc motor.
- Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.
- The fundamental principles and construction of the DC motors are identical with the DC generators.
- A DC machine that runs as a motor will also operate as a generator.



8. Explain the principle of operation of DC Motor.[NOV/DEC 2015]

The basic principle of operation of DC motor is a "Whenever current carrying conductor is placed in magnetic field, the conductor experiences a force tending to move it".

The force whose direction is given by Fleming's Left-Hand Rule and whose magnitude is given by

F=BILNewtons

B=Magnetic field intensity in wb/m2

I=Current in Amperes

L=Length of the conductor in meter.

OPERATION:

- When voltage is applied to the loop of wire a current flows, and a magnetic field is created that will interact with the field of the magnet.
- Repulsion and attraction of the fields will cause the loop to turn.
- The loop moves away from the strong field toward the weak field.
- The direction of the rotation can be determined by "the right-hand rule".

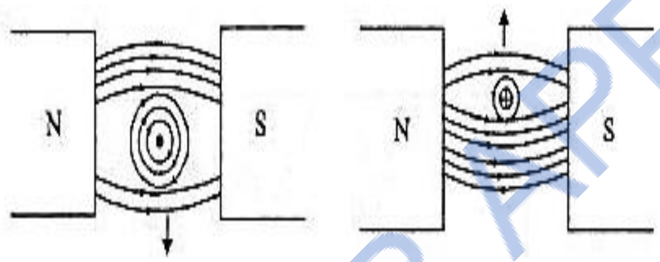


Fig 3.16: Interaction of two fluxes and forces experienced by the conductor

- In a dc motor, the stator poles are supplied by dc excitation current, which produces a dc magnetic field.
- The rotor is supplied by dc current through the brushes, commutator and coils.
- The interaction of the magnetic field and rotor current generates a force that drives the motor.
- A current is supplied to the coil by a battery and the torque acting on the current-carrying coil causes it to rotate.

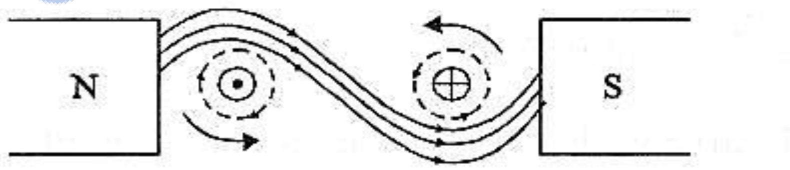


Fig 3.17: Direction of rotation of conductor

Back emf of a Motor:

- As the coil rotates in a magnetic field, an emf is induced in the coil. This induced emf always acts to reduce the current in the coil and is called back emf.
- The back emf increases in magnitude as the rotational speed of the coil increases.

$$E_b = \frac{\varphi ZN}{(60)}\left(\frac{P}{A}\right)$$

9. Derive the Torque and Speed Equations of the DC Motor.

- Torque is turning or twisting moment of a force about an axis. It is measured by the product of the force and the radius at which this force acts.
- Consider a pulley of radius 'r' meter acted upon by a circumferential force of 'F' newton which causes it to rotate at speed N rpm.

Torque, T = F × r (Nm)

Work done by this force in one revolution = Force x distance

= F x 2πr joules.

And P = Power developed = Work done/time

$$= \frac{Fx2\pi r}{\text{time for one revolution}}$$

$$= \frac{Fx2\pi r}{(60/N)} = (F\,x\,r)\,x\left(\frac{2\pi N}{60}\right)$$

P = T x ω watts

Where

T = Torque in Nm

ω = Angular speed in rad/sec = 2πN/60

$$P = \frac{2\pi NT}{60} \text{ watts}$$

Armature Torque of a motor:

- Let 'T_a' be the gross torque developed by the armature of motor running at ***N*** rpm. It is also called armature torque.

- Power developed in armature$= \frac{T_a(2\pi N)}{60}$ .... (i)

We also know that

Electrical power converted into mechanical power in the Armature = $E_b I_a$........... (ii)

Equating (i) and (ii) we get,

$$\frac{T_a(2\pi N)}{60} = E_b I_a$$

But '*Eb*' in a motor is given by

$$E_b = \frac{\varphi ZN}{60}\left(\frac{P}{A}\right)$$

$$\frac{T_a(2\pi N)}{60} = \frac{\varphi ZN}{60}\left(\frac{P}{A}\right) I_a$$

$$T_a = \left(\frac{1}{2\pi}\right) Z\varphi I_a \left(\frac{P}{A}\right) \text{Nm}$$

$$T_a = 0.159\varphi Z I_a \left(\frac{P}{A}\right) \text{Nm}$$

Speed and Torque Equation:

For a DC motor, the speed equation is obtained as follows:

We know

$$E_b = V - I_a R_a = \frac{\varphi Z N}{60}\left(\frac{P}{A}\right)$$

(Or)

$$V - I_a R_a = \frac{\varphi Z N}{60}\left(\frac{P}{A}\right)$$

$$N = \frac{(v - I_a R_a)}{Z} x \left(\frac{60A}{P}\right)$$

Since for a given machine, $Z, AandPareconstants$.

$$\therefore N = K\frac{(V - I_a R_a)}{\varphi}$$

Where 'K' is constant.

Speed equation becomes

$$\therefore N\ \alpha\ \frac{(V - I_a R_a)}{\varphi}$$

10. Explain in detail the various types of dc motor with suitable diagram.

DC MOTOR TYPES

The types of DC motors are

1. DC Series motor
2. DC Shunt motor
3. DC Compound motor

DC series motor:

In DC series motor means the field winding is connected in series with armature.

Same current flows through field as armature.

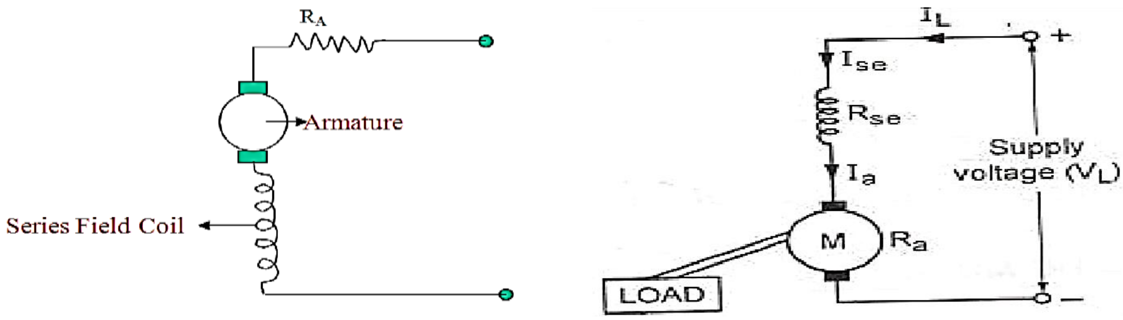


Fig 3.18: Connection of series motor

- $V = Eg - (IaRa + IseRse + Vbrush)$
- $I_a = I_L = I_{se}$
- Hence $V = Eg - Ia(Ra + Rse) + Vbrush$
- I_aR_a= Voltage drop in the armature resistance
- I_aR_{se}= Voltage drop in the series field winding resistance
- V_{brush}= Voltage drop at connects of the brush

Normally V_{brush} is neglected and hence $V = Eg - (Ra + Rse)$

DC Shunt motor:

In DC shunt motor, the field winding is connected across the armature.

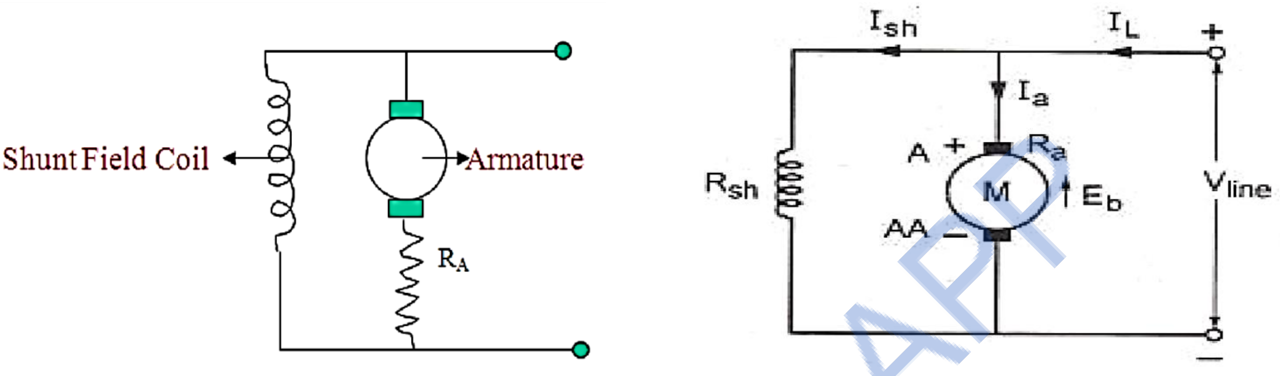


Fig 3.19: Connection of a shunt motor

- A "constant speed" machine.
- Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$
- Armature current, $I_a = I_L - I_{sh}$
- $\therefore I_L = I_a + I_{sh}$
- Back emf, $E_b = V_L - I_aR_a - V_{brush}$
- $V = Eg - Ia\ (Ra + Rse) + Vbrush$

Compound DC motor:

The DC compound motor consists of both series and shunt field windings.

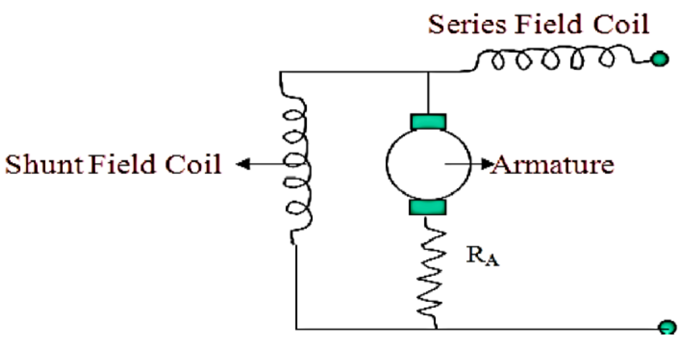


Fig 3.20: Connection of compound motor

Depending upon these two winding connections, it is further classified into two types

- Long shunt compound Motor
- Short shunt compound Motor

LONG SHUNT COMPOUND MOTOR:

- Shunt field winding is connected between both series and armature winding.

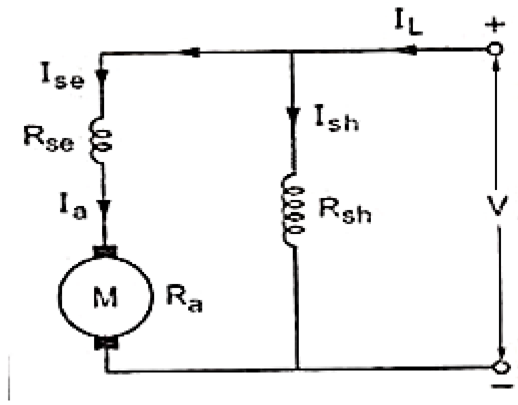


Fig 3.21: Connection of a long shunt compound motor

- Series field current, $I_{se} = I_a = I_L - I_{sh}$ (or) $I_L = I_a + I_{sh}$
- Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$
- Back emf, $E_b = V - I_a(R_a + R_{ae}) - V_{brush}$
- $V = Eg - Ia\ (Ra + Rse) + Vbrush$

SHORT SHUNT COMPOUND MOTOR:

- Shunt field winding is connected in parallel with the armature and this combination is connected in series with series field winding.

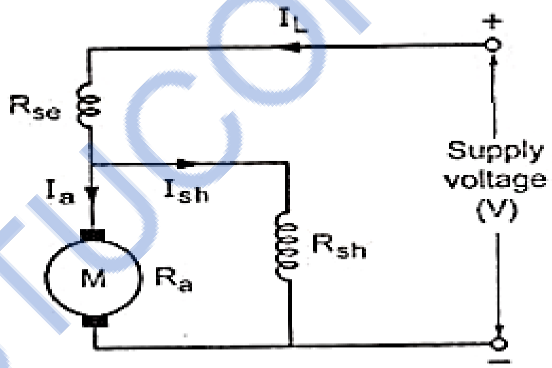


Fig 3.22: Connection of a short shunt compound motor

- Load current, $I_L = I_{se}$
- $I_L = I_a + I_{sh}$
- Shunt field current, $I_{sh} = \frac{(V - I_{se}R_{se})}{R_{sh}}$
- Generated emf, $E_b = V - I_aR_a - I_{se}R_{se} - V_{se}$

11. What are the applications of DC motors?

APPLICATIONS OF DC MOTORS:

D.C Shunt Motors:

It is a constant speed motor.Where the speed is required to remain almost constant from noload to full load.Where the load has to be driven at a number of speeds and any one of which is nearly constant.

Industrial use:

- Lathes
- Drills
- Boring mills
- Shapers
- Spinning and Weaving machines.

D.C Series motor:

It is a variable speed motor.The speed is low at high torque. At light or no load the motor speed attains dangerously high speed.The motor has a high starting torque.(elevators,electric traction)

Industrial Uses:

- Electric traction
- Cranes
- Elevators
- Air compressor

D.C Compound motor:

Differential compound motors are rarely used because of its poor torque characteristics.

Industrial uses:

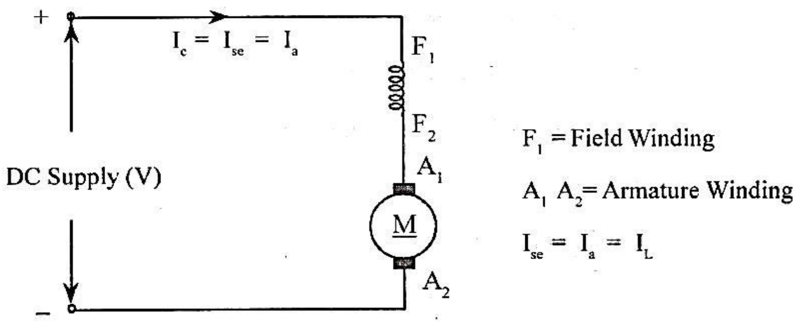
- PressesShears
- Reciprocating machine.

12. Explain the characteristics of dc shunt dc series motor[APR/MAY -2015](OR) Explain the performance characteristics of any one type of dc motor.[NOV/DEC 2015]

DC motors are shunt, series or compound motors. We are generally interested in the following three characteristics.

- Speed - armature current characteristics
- Torque - armature current characteristics
- Speed - torque characteristics

DC SERIES MOTOR

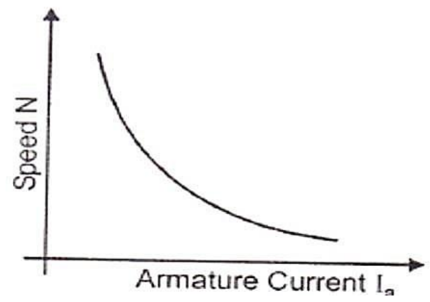


- The motor in which the field winding is connected in series with the armature is called series motor.

i) Speed-armature current characteristics

- As the flux depends on the field current I_{se} which is same as the line current, the flux is not constant with loads. The speed equation

$$N = K\frac{(V - I_a R_a)}{\varphi}$$



$$N = K\frac{(V - I_a R_a)}{I_a} \because \varphi \propto I_a$$

$$\boldsymbol{N \propto \frac{E_b}{I_a}}$$

- From the above equation it is clear that by, increasing the armature current, speed will decrease. It is shown in figure.

- DC Series motor should never be started without some load. Otherwise the motor speed will rise to a dangerous value and get damaged.

ii) Torque – armature current characteristics

- We know that, $T \propto \varphi I_a$.
- In DC series motor, flux is directly proportional to armature current,

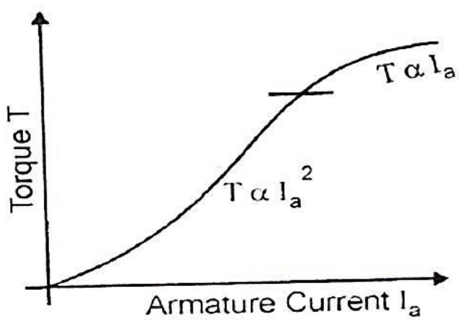
$\varphi \propto I_a$

$T \propto I_a^2$ $(Beforesaturation)$

$T \propto I_a$ $(Aftersaturation)$

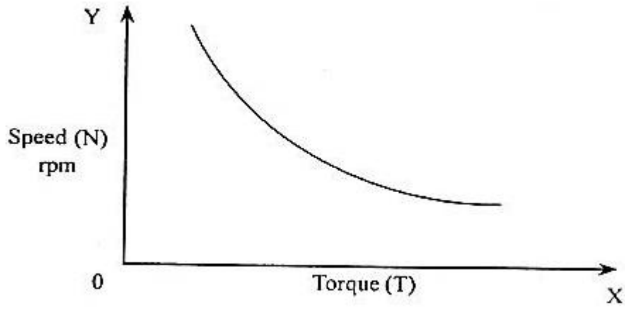
- At light load, armature current, I_a and hence flux φ is small. But as I_a increases, torque increases as the square of the current. Hence this characteristic is a parabola. It is shown in the figure.

- After saturation, the flux is constant. i.e. φ is independent of I_a, hence torque is directly proportional to armature current. So the curve becomes a straight line



iii) Speed-torque characteristics

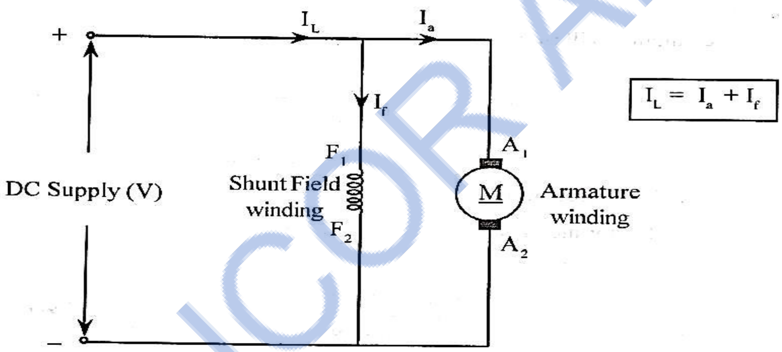
- This characteristics can be got from the above two characteristics. Here the DC series motor speed is high, the torque is low and vice- versa. It is shown in figure.



DC SHUNT MOTOR

- The shunt motor field winding is connected in parallel to the armature winding.
- Shunt motor normally called as constant speed motor. In DC shunt motor

$I_L = I_a + I_f$



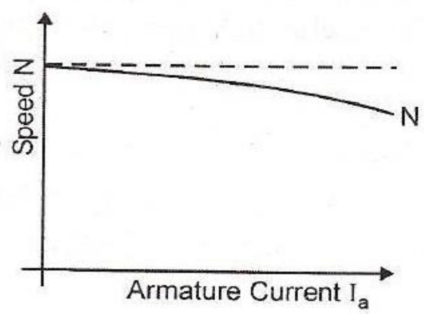
- Since, the field winding is directly connected to supply voltage 'v' which is also constant, the field current If is also constant.

i) Speed - armature current characteristics:

- The speed equation of the DC motor is

$$N = K\left(\frac{V - I_a R_a}{\varphi}\right)$$

- Since I_{sh} and φ are nearly constant, N = K (V - $I_a R_a$)
- Where K is a constant. This implies that speed is nearly constant except for a small drop. This is shown in fig.



ii) Torque – armature characteristics:

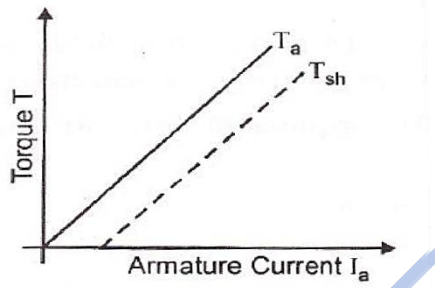
- It is also called electrical characteristics. The DC shunt motor torque is directly proportional to flux and armature current.

$$T \,\alpha\, \varphi I_a$$

Here, φ is constant

$$\therefore \; T \,\alpha\, I_a$$

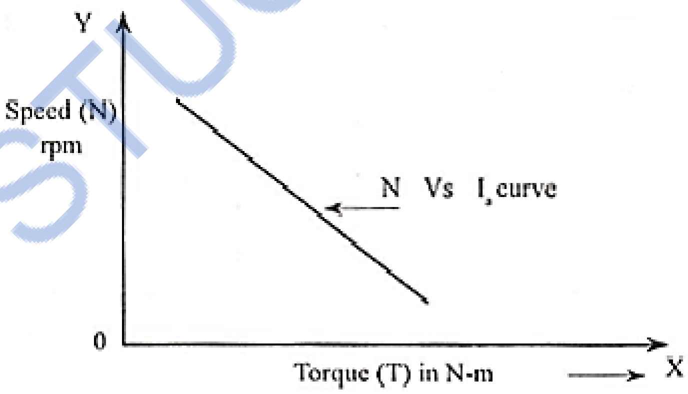
- So when the armature current increases, the torque also increases. It is shown in the figure.



iii) Speed – Torque characteristics:

- It is also called mechanical characteristics. This characteristic can be got from the above two characteristics. It is shown in figure.

- Here, when the load torque increases, the speed slightly decreases.



Speed - Torque Characteristics of DC Shunt Motor

<u>Necessity of D.C. Motor Starter</u>

- At starting, when the motor is stationary, there is no back e.m.f. in the armature.
- Consequently, if the motor is directly switched on to the mains, the armature will draw a heavy current (Ia = V/Ra) because of small armature resistance.
- As an example, 5 H.P., 220 V shunt motor has a full-load current of 20 A and an armature resistance of about 0.5Ω. If this motor is directly switched on to supply, it

would take an armature current of 220/0.5 = 440 A which is 22 times the full-load current.

- This high starting current may result in:

(i) Burning of armature due to excessive heating effect,

(ii) Damaging the commutator and brushes due to heavy sparking,

(iii) Excessive voltage drop in the line to which the motor is connected. The result is that the operation of other appliances connected to the line may be impaired and in particular cases, they may refuse to work.

- In order to avoid excessive current at starting, a variable resistance (known as starting resistance) is inserted in series with the armature circuit. This resistance is gradually reduced as the motor gains speed (and hence E_b increases) and eventually it is cut out completely when the motor has attained full speed.
- Starting current is limited to 1.25 to 2 times the full-load current.

Types of D.C. Motor Starters

13. Explain the types of D.C. Motor Starters.

- The stalling operation of a d.c. motor consists in the insertion of external resistance into the armature circuit to limit the starting current taken by the motor and the removal of this resistance in steps as the motor accelerates.
- When the motor attains the normal speed, this resistance is totally cut out of the armature circuit.
- It is very important and desirable to provide the starter with protective devices to enable the starter arm to return to OFF position

(i) When the supply fails, thus preventing the armature being directly across the mains when this voltage is restored. For this purpose, we use no-volt release coil.

(ii) When the motor becomes overloaded or develops a fault causing the motor to take an excessive current. For this purpose, we use overload release coil.

- There are three types of d.c. motor starters, they are two-point starter, three-point starter and four-point starter.

Two-Point Starter:

- A two-point starter is used for starting dc motor which has the problem of over-speeding due to loss of load from its shaft. Such a starter is shown in fig(3.23).
- DC motor starting, two and three point starter. Here for starting the motor,the control arm is moved clockwise from its OFF position to the ON position against the spring tension.

- The control arm is held in the ON position by an electromagnet. The hold-on electromagnet is connected in series with the armature circuit.
- If the motor losses its load,current decreases and hence the strength of the electromagnet also decreases.The control arm returns to the OFF position due to spring tension,this preventing the motor from overspeeding.

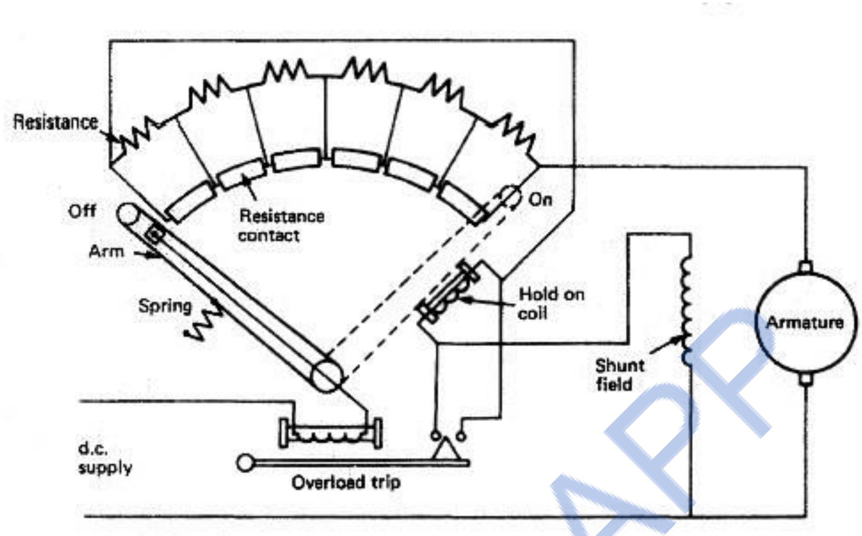


Fig 3.23Two point starter

- ThestarterarmalsoreturnstotheOFF-positionwhenthesupplyvoltagedecreasesappreciably.LandFare two pointsofthestarterwhichareconnectedwiththesupplyandmotorterminals.

Three-Point Starter:

- This type of starter is widely used for starting shunt and compound motors.
- Fig. (3.24) shows the schematic diagram of a three-point starter for a shunt motor with protective devices.

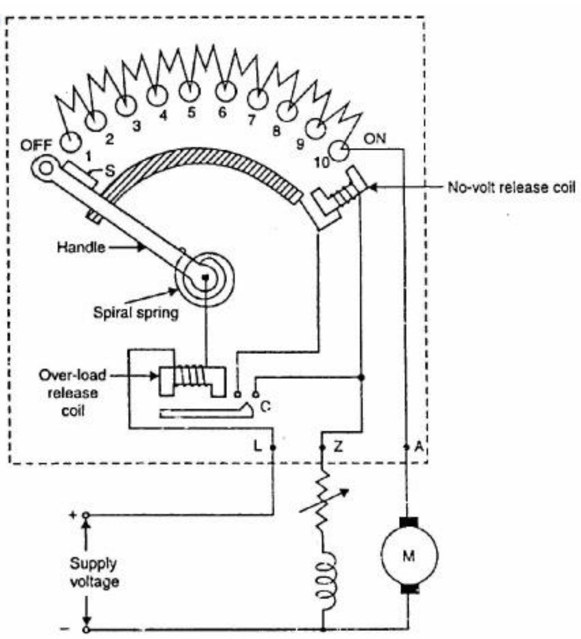


Fig 3.24 Three point starter

- It is so called because it has three terminals L, Z and A. The starter consists of starting resistance divided into several sections and connected in series with the armature.
- The tapping points of the starting resistance are brought out to a number of studs.
- The three terminals L, Z and A of the starter are connected respectively to the positive line terminal, shunt field terminal and armature terminal.
- The other terminals of the armature and shunt field windings are connected to the negative terminal of the supply.
- The no-volt release coil is connected in the shunt field circuit.
- One end of the handle is connected to the terminal L through the over-load release coil.
- The other end of the handle moves against a spiral spring and makes contact with each stud during starting operation, cutting out more and more starting resistance as it passes over each stud in clockwise direction.

Operation:

(i) To start with, the d.c supply is switched on with handle in the OFF position.

(ii) The handle is now moved clockwise to the first stud. As soon as it comes in contact with the first stud, the shunt field winding is directly connected across the supply, while the whole starting resistance is inserted in series with the armature circuit.

(iii) As the handle is gradually moved over to the final stud, the starting resistance is cut out of the armature circuit in steps. The handle is now held magnetically by the no-volt release coil which is energized by shunt field current.

(iv) If the supply voltage is suddenly interrupted or if the field excitation is accidentally cut, the no-volt release coil is demagnetized and the handle goes back to the OFF position under the pull of the spring.

(v) If no-volt release coil were not used, then in case of failure of supply, the handle would remain on the final stud. If then supply is restored, the motor will be directly connected across the supply, resulting in an excessive armature current.

(vi) If the motor is over-loaded (or a fault occurs), it will draw excessive current from the supply. This current will increase the ampere-turns of the over-load release coil and pull the armature C, thus short-circuiting the no volt release coil.

(vii) The no-volt coil is demagnetized and the handle is pulled to the OFF position by the spring. Thus, the motor is automatically disconnected from the supply.

Drawback

- In a three-point starter, the no-volt release coil is connected in series with the shunt field circuit so that it carries the shunt field current.

- While exercising speed control through field regulator, the field current may be weakened to such an extent that the no-volt release coil may not be able to keep the starter arm in the ON position.
- This may disconnect the motor from the supply when it is not desired. This drawback is overcome in the four point starter.

Four-Point Starter

- In a four-point starter, the no-volt release coil is connected directly across the supply line through a protective resistance R.
- Fig. (3.25) shows the schematic diagram of a 4-point starter for a shunt motor (over-load release coil omitted for clarity of the figure.
- Now the no-volt release coil circuit is independent of the shunt field circuit. Therefore, proper speed control can be exercised without affecting the operation of no volt release coil.
- Note that the only difference between a three-point starter and a four-point starter is the manner in which no-volt release coil is connected.

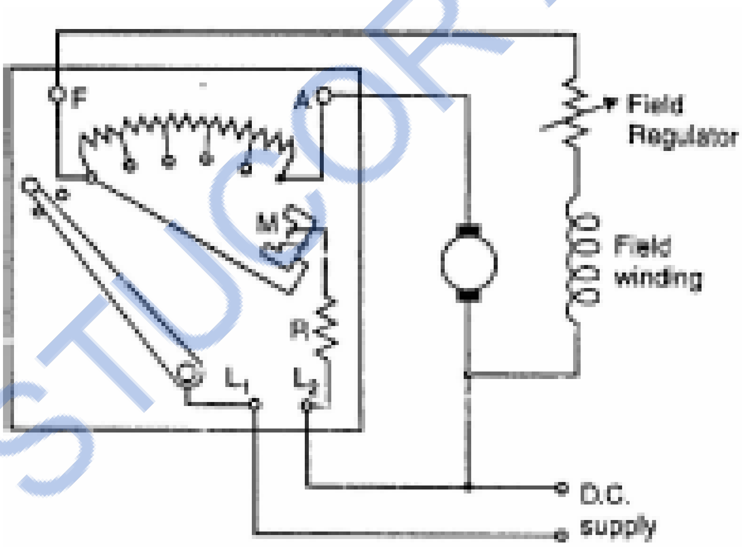


Fig 3.25Four point starter

- However, the working of the two starters is the same. It may be noted that the three point starter also provides protection against an open field circuit.
- This protection is not provided by the four-point starter.

Speed control of D.C. Motors:

14. Explain the different methods of speed control of dc motor.[NOV/DEC 2014]

- Different ranges of speeds are required for different applications. A single motor can be used for different speeds for various works.
- Smooth speed control is possible in D.C. Shunt motor.
- The speed of a D.C. motor can be expressed by the equation:

$N \propto \frac{E_b}{\emptyset}$

$N \propto \frac{(V - I_a R_a)}{\emptyset}$ ……………………..(i)

Where $R = R_a$ for shunt motor

$R = R_a + R_{se}$ for series motor

- From exp. (i), it is clear that there are three main methods of controlling the speed of a d.c. motor, namely:

(i) By varying the flux per pole (Φ). This is known as flux control method.

(ii) By varying the resistance in the armature circuit. This is known as armature control method.

(iii) By varying the applied voltage V. This is known as voltage control method.

Speed Control of D.C. Shunt Motors

15. Explain with a neat diagram, the Armature control and Flux controlmethods of speed control of dc shunt motor.[MAY 2018]

The speed of a shunt motor can be changed by

(i) Flux control method

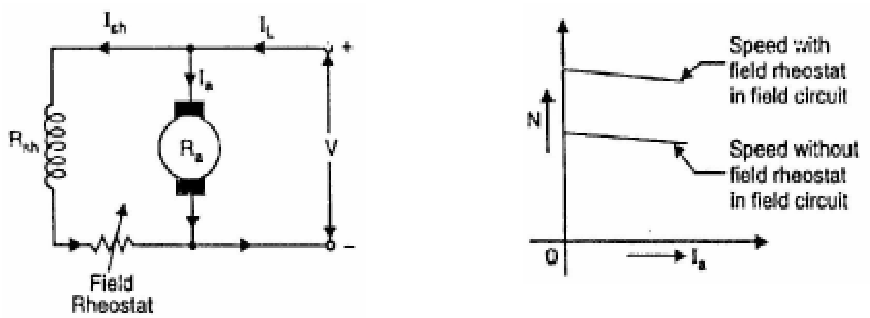
(ii) Armature control method

(iii) voltage control method.

The first method (i.e.Flux control method) is frequently used because it is simple and inexpensive.

Flux control method

- It is based on the fact that by varying the flux Φ, the motor speed $\left(N \propto \frac{1}{\Phi}\right)$ canbe changed and hence the name flux control method.
- In this method, a variableresistance (known as shunt field rheostat) is placed in series with shunt field winding as shown in Fig.



- The shunt field rheostat reduces the shunt field current I_{sh} and hence the flux Φ.
- Therefore, only raise the speed of the motor above the normal speed .

- Generally, this method permits to increase the speed in the ratio 3:1.Wider speed ranges tend to produce instability and poor commutation.

Advantages

- This is an easy and convenient method.
- It is an inexpensive method since very little power is wasted in the shuntfield rheostat due to relatively small value of I_{sh}.
- The speed control exercised by this method is independent of load on themachine.

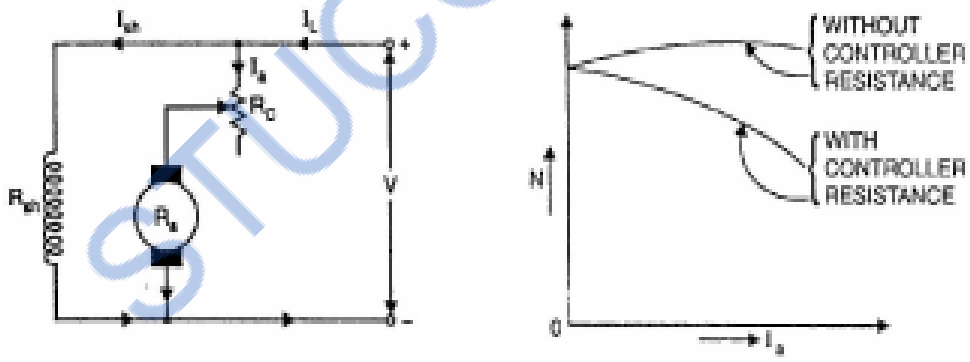
Disadvantages

- Only speeds higher than the normal speed can be obtained since the totalfield circuit resistance cannot be reduced below Rsh—the shunt fieldwinding resistance.
- There is a limit to the maximum speed obtainable by this method. It isbecause if the flux is too much weakened, commutation becomes poorer.

Note:The field of a shunt motor in operation should never be opened because itsspeed will increase to an extremely high value.

Armature control method

- This method is based on the fact that by varying the voltage available across thearmature, the back e.m.f and hence the speed of the motor can be changed.
- This is done by inserting a variable resistance RC (known as controller resistance) inseries with the armature as shown in Fig.



$N \propto V(R_a + R_c)$

where R_C = controller resistance

- Due to voltage drop in the controller resistance, the back e.m.f. (Eb) isdecreased. Since $(N \propto E_b)$, the speed of the motor is reduced.
- The highest speed obtainable is that corresponding to RC = 0 i.e., normal speed. Hence, this methodcan only provide speeds below the normal speed .

Disadvantages

- A large amount of power is wasted in the controller resistance since itcarries full armature current I_a.

- The speed varies widely with load since the speed depends upon thevoltage drop in the controller resistance and hence on the armature currentdemanded by the load.
- The output and efficiency of the motor are reduced.
- This method results in poor speed regulation.Due to above disadvantages, this method is seldom used to control the speed ofshunt motors.

Note:The armature control method is a very common method for the speedcontrol of d.c series motors. The disadvantage of poor speed regulation is notimportant in a series motor which is used only where varying speed service isrequired.

Voltage control method

- In this method, the voltage source supplying the field current is different fromthat which supplies the armature.
- This method avoids the disadvantages of poorspeed regulation and low efficiency as in armature control method. However, it is quite expensive.
- Therefore, this method of speed control is employed for largesize motors where efficiency is of great importance.

(i) Multiple voltage control:

In this method, the shunt field of the motor isconnected permanently across a-fixed voltage source.

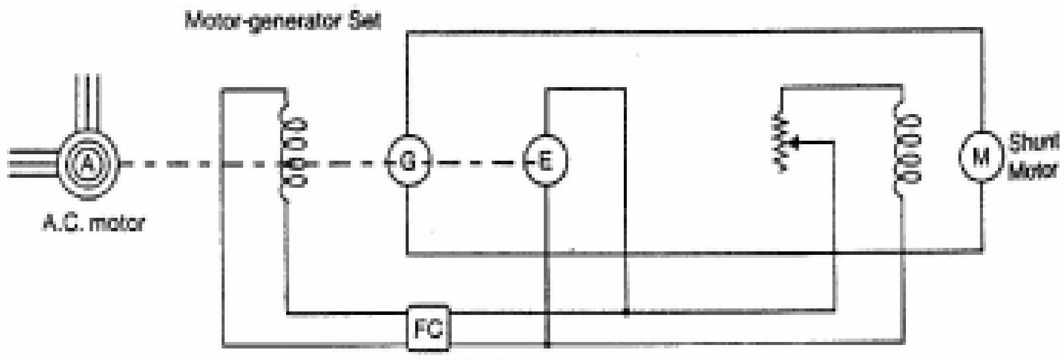
- The armature can beconnected across several different voltages through a suitable switchgear.
- In this way, voltage applied across the armature can be changed. The speedwill be approximately proportional to the voltage applied across thearmature.
- Intermediate speeds can be obtained by means of a shunt fieldregulator.

(ii) Ward-Leonard system:

In this method, the adjustable voltage for thearmature is obtained from an adjustable-voltage generator while the fieldcircuit is supplied from a separate source.

- This is illustrated in Fig. (5.5).The armature of the shunt motor M (whose speed is to be controlled) isconnected directly to a d.c. generator G driven by a constant-speed a.cmotor A.
- The field of the shunt motor is supplied from a constant-voltageexciter E. The field of the generator G is also supplied from the exciter E.
- The voltage of the generator G can be varied by means of its fieldregulator. By reversing the field current of generator G by controller FC,the voltage applied to the motor may be reversed.
- Sometimes, a fieldregulator is included in the field circuit of shunt motor M for additionalspeed adjustment.

- With this method, the motor may be operated at anyspeed upto its maximum speed.



Ward-Leonard speed-control system.

Advantages

(a) The speed of the motor can be adjusted through a wide range withoutresistance losses which results in high efficiency.

(b) The motor can be brought to a standstill quickly, simply by rapidlyreducing the voltage of generator G. When the generator voltage is reducedbelow the back e.m.f. of the motor, this back e.m.f. sends current throughthe generator armature, establishing dynamic braking. While this takes place, the generator G operates as a motor driving motor A which returnspower to the line.

(c) This method is used for the speed control of large motors when a d.c.supply is not available.

Disadvantage

- The disadvantage of the method is that a special motor-generator set is requiredfor each motor and the losses in this set are high if the motor is operating underlight loads for long periods.

Speed Control of D.C. Series Motors

16. Explain the different methods of speed control of dc shunt motor with neat circuit diagrams [or] Explain the speed control of dc shunt motor applying flux control technique. [MAY/JUNE 2014]

The speed control of d.c. series motors can be obtained by

(i) flux control method

(ii) armature-resistance control method.

The latter method is mostly used.

Flux control method

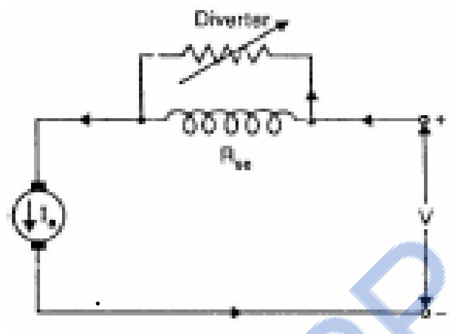
- In this method, the flux produced by the series motor is varied and hence the speed. The variation of flux can be achieved in the following ways:

(i) Field diverters

In this method, a variable resistance (called field diverter) is connected in parallel with series field winding as shown in Fig.

- Any desired amount of current can be passed through the diverter by adjusting its resistance.
- Hence the flux can be decreased and consequently the speed of the motor is increased. The minimum speed is obtained by completely removing the resistance in the diverter circuit.

$\left(N \propto \frac{1}{\Phi}\right)$



(ii) Armature diverter

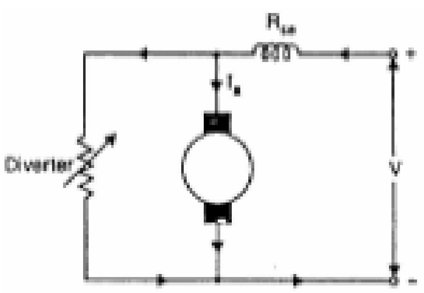
In order to obtain speeds below the normal speed, avariable resistance (called armature diverter) is connected in parallel withthe armature as shown in Fig

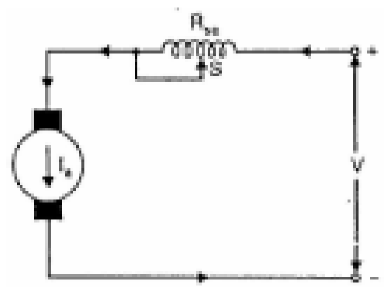
- The diverter shunts some of the linecurrent, thus reducing the armature current. Now for a given load, if Ia isdecreased, the flux Φ must increase $(T \propto \Phi I_a)$.Since$\left(N \propto \frac{1}{\Phi}\right)$, the motorspeed is decreased.
- By adjusting the armature diverter, any speed lowerthan the normal speed can be obtained.

(iii) Tapped field control

In this method, the flux is reduced (and hence speedis increased) by decreasing the number of turns of the series field winding as shown in Fig

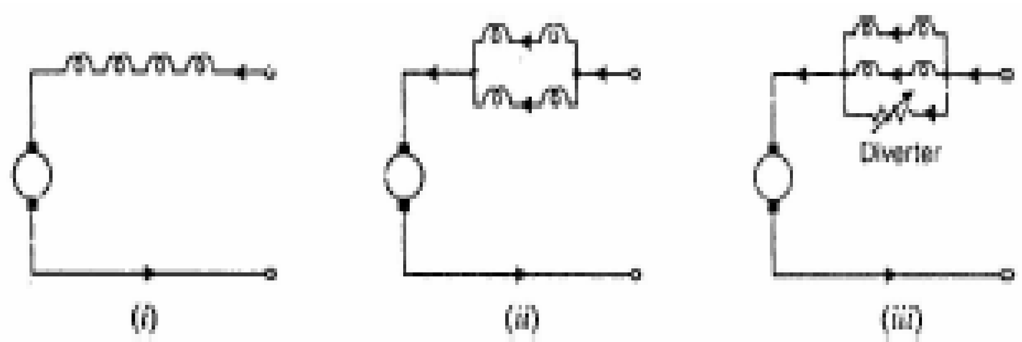
- The switch S can short circuit any part of the field winding, thus decreasing the flux and raising the speed.
- With full turns ofthe field winding, the motor runs at normal speed and as the field turns arecut out, speeds higher than normal speed are achieved.





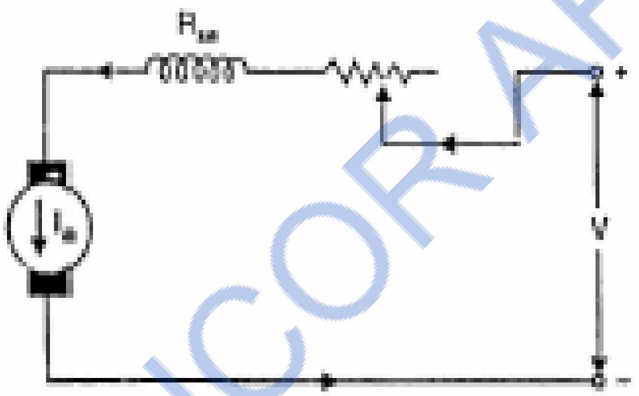
(iv) Paralleling field coils.

This method is usually employed in the case of fanmotors. By regrouping the field coils as shown in Fig. (5.9), several fixedspeeds can be obtained.



Armature-resistance control

- In this method, a variable resistanceis directly connected in series withthe supply to the complete motor asshown in Fig.



- This reducesthe voltage available across thearmature and hence the speed falls.
- By changing the value of variableresistance, any speed below thenormal speed can be obtained.
- Thisis the most common methodemployed to control the speed of d.c. series motors.
- when full load current of the motor passes through this resistance, there is a considerable loss of power in it.

Speed Control of Compound Motors:

- Speed control of compound motors may be obtained by any one of the methodsdescribed for shunt motors.
- Speed control cannot be obtained throughadjustment of the series field since such adjustment would radically change theperformance characteristics of the motor.

UNIVERSAL MOTOR

17. Explain the construction and working of an universal motor.

- An universal motor is a special type of motor which is designed to run on either DC or single phase AC supply.

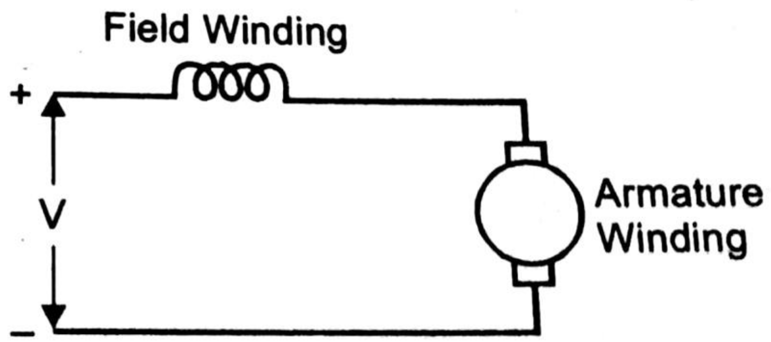
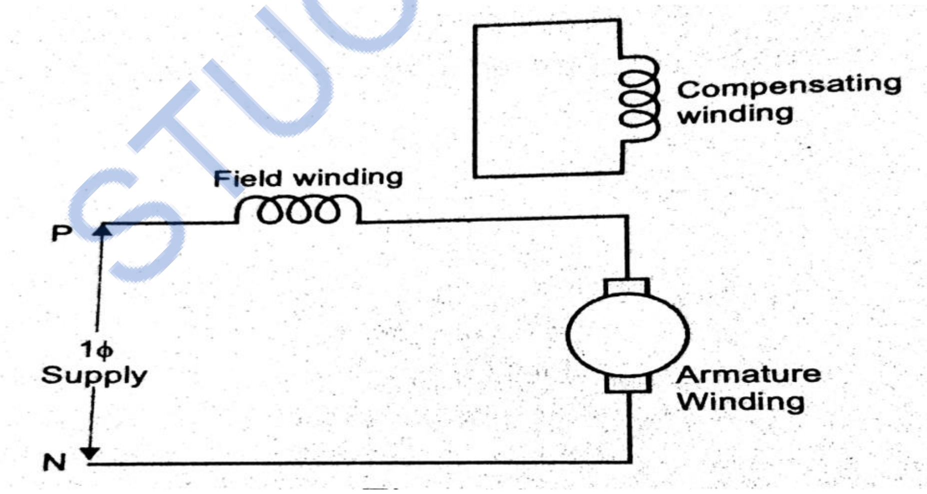


Fig 3.26 universal motor

- These motors are generally series wound (armature and field winding are in series), and hence produce high starting torque.
- They run at lower speed on AC supply than they run on DC supply of same voltage, due to the reactance voltage drop which is present in AC and not in DC.

Construction Of Universal Motor:

- Construction of a universal motor is very similar to the construction of a DC machine. It consists of a stator on which field poles are mounted. Field coils are wound on the field poles.



- However, the whole magnetic path (stator field circuit and also armature) is laminated. Lamination is necessary to minimize the eddy currents which induce while operating on AC.
- The rotary armature is of wound type having straight or skewed slots and commutator with brushes resting on it.
- The commutation on AC is poorer than that for DC, because of the current induced in the armature coils. For that reason brushes used are having high resistance.

Working Of Universal Motor

- A universal motor works on either DC or single phase AC supply. When the universal motor is fed with a DC supply, it works as a DC series motor.
- When current flows in the field winding, it produces an electromagnetic field. The same current also flows from the armature conductors.
- When a current carrying conductor is placed in an electromagnetic field, it experiences a mechanical force. Due to this mechanical force, or torque, the rotor starts to rotate. The direction of this force is given by Fleming's left hand rule.
- When fed with AC supply, it still produces unidirectional torque. Because, armature winding and field winding are connected in series, they are in same phase. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the same time.
- Thus, direction of magnetic field and the direction of armature current reverses in such a way that the direction of force experienced by armature conductors remains same. Thus, regardless of AC or DC supply, universal motor works on the same principle that DC series motor works.

Speed Torque Characteristics

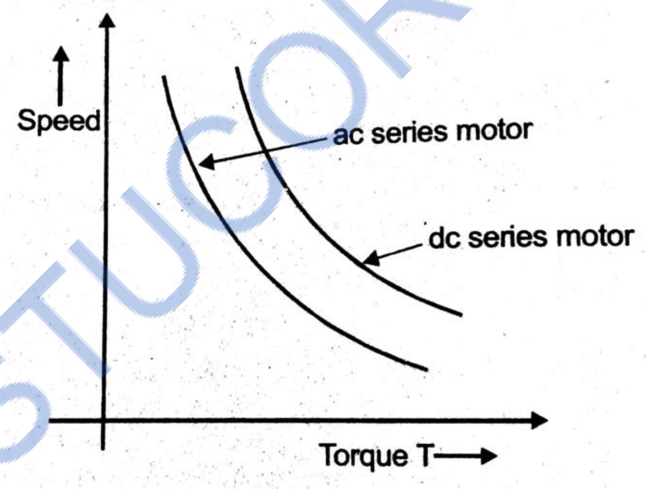


Fig 3.27 speed torque characteristics

- By increasing the torque, the motor speed can be decreased.

Applications Of Universal Motor

- Vacuum cleaners, drink and food mixers, domestic sewing machine etc.
- The higher rating universal motors are used in portable drills, blenders, railway systems etc.

STEPPER MOTOR

18. Explain the construction and working principle of different types of stepper motors. (MAY 2018)

- A stepper Motor is basically a synchronous Motor. In a stepper motor, there are no brushes.
- This motor does not rotate continuously; instead it rotates in the form of pulses or in discrete steps. That is why it is called stepper motor.
- There are different types of motors available on the basis of steps per rotation, for example-12 steps per rotation, 24 steps per rotation etc.
- We can control or operate Stepper motor with the feedback or without any feedback. A simple image of stepper motor is shown in above picture.

Types of Stepper Motor:

The Stepper Motors are of following types:

- Permanent Magnet
- Variable Reluctance.
- Hybrid Stepper Motor

Permanent Magnet Type Stepper Motor

- The Working and Construction of the Permanent Magnet Type Stepper Motor is given below:

Construction

- The permanent magnet type stepper motor has a stator, that is made of electromagnets.
- The rotor that is of Permanent Magnet, therefore this motor is called permanent magnet type stepper motor.

Working

- When supply is given to the stator, the winding of stator is energized and hence produces magnetic field.
- As described above, the rotor is made up of permanent magnet. That is why it tends to follow the revolving field. Thus, a stepper motor works.
- The speed or torque of a permanent magnet type motor is changed by the number of poles used in stator.
- If we use a large number of poles in stator then the speed of motor will increase and if we use a less number of poles then the speed will decrease.
- The diagram of Permanent Magnet Type Stepper Motor is given below:

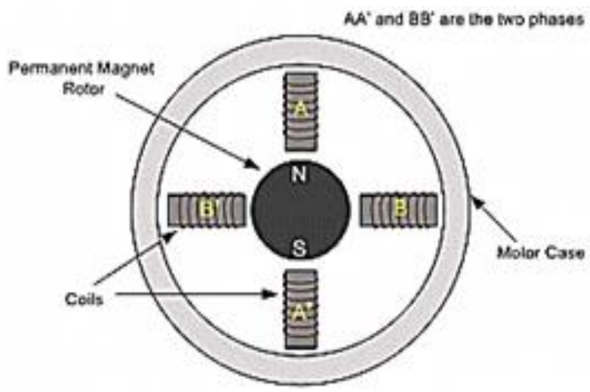


Figure.4.45 Permanent Magnet Type Stepper Motor

Variable Reluctance Motor:

- In Variable reluctance stepper motor, we use a nonmagnetic iron core rotor, which has winding on its surface.
- The stator is same as used in the Permanent Type Stepper Motor.

Working:

- When we give supply to the stator, a magnetic field is induced in the stator winding which causes an e.m.f. induction in the rotor's winding.
- Thus, a magnetic field is also set up in the rotor which tends to follow the magnetic field of stator.
- The diagram of Variable reluctance stepper motor is given below:

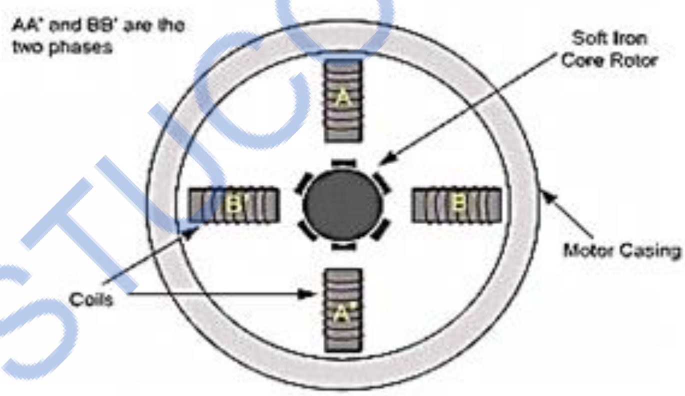


Figure 4.46 Variable Reluctance Motor

- The speed control method is almost same as in the permanent magnet type motor. In this motor, we can increase the speed by increasing the number of poles of stator as well as by increasing the number of teeth of rotor and vice versa.

Hybrid Type Stepper Motor:

- The Hybrid type motor, as the name suggests is a mixture of both the above types. This consists a rotor which is magnetic and as well as teethed. The diagram of the construction of this motor is shown below:

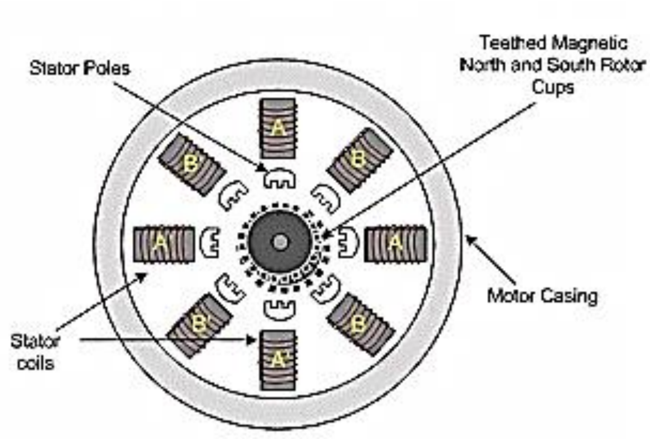


Figure 4.47 Hybrid Type Stepper Motor

- The rotor of this type of motor is made up of two rotors joining like a shaft of motor.
- One of them is for north and other is for South Pole. These poles arrange in alternative manner as they designed in such a manner.

Applications of stepper motors:

- Linear actuators, linear stages, rotation stages, goniometers, and mirror mounts
- Commercially, stepper motors are used in floppy disk drives, scanners, computer printers, plotters, slot machines, image scanners, compact disc drives, intelligent lighting, camera lenses, CNC machines and, more recently, in 3D printers.

<u>BRUSHLESS DC MOTOR</u>

19. Explain the construction and working principle of Brushless DC motor.

- Conventional dc motors are highly efficient and their characteristics make them suitable for use of servomotors.
- However their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance.
- When the functions of commutator and brushes were implemented by solid state switches, maintenance free motors were realized.
- These motors are known as brushless dc motors.

CONSTRUCTION:

- The construction of modern brushless motor is very similar to the ac motor known as the permanent magnet synchronous motor. The main parts of brushless dc motor are
- Stator
- Rotor

Stator:

- Stator is made up of silicon steel stampings with slots in its inner periphery.
- The slots are accommodated either in closed or open distributed armature winding.

- This winding is to be wound for a specified number of poles.
- The winding is connected to DC supply through power electronic switching circuits.

Rotor:

- Rotor is made up of permanent magnet. The number of poles of the rotor is same as the number of poles of the stator.
- The rotor shaft carries a rotor position sensor.
- A position sensor provides information about the position of the shaft at any instant for the controller which sends signals to the electronic commutator.

Principle of operation:

- The schematic diagram of the brushless dc motor is shown in the figure. It also shows the three phases of the stator and rotor with d and q axes.
- The stator is connected to a variable voltage current source through an indicator and an inverter comprising six SCRs (S1 to S6).
- Diodes are connected across SCRs to protect these from the voltage induced in the armature coil undergoing commutation position sensors placed on the rotor.
- Which cause the SCRs to be fired in sequence so as to be in synchronism with the rotors mechanical position.

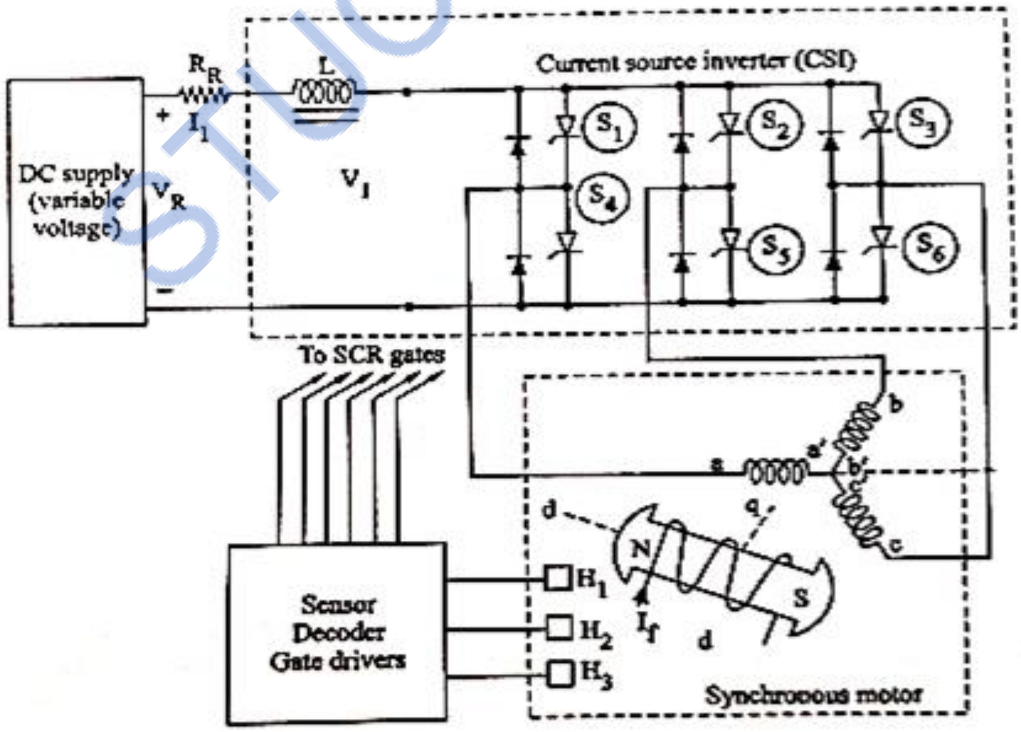


Fig 4.48: Brushless DC motor

- The armature winding of a stator draws the current from the inverter circuit. The current distributions in the stator winding depend upon rotor position and the devices turn on.
- The m.m.f perpendicular to the permanent magnet flux is setup. Then the armature conductor experiences a force. The reactive force develops a torque in the rotor.
- If the torque is more than the opposing fractional and load torque, the motor starts. It is self-starting motor.
- As the motor picks up, then there exists a relative speed between permanent field and armature conductors.
- As per faraday's law of electromagnetic induction, emf is induced in the conductors. This emf oppose a cause, as a result, the developed torque is reduced.
- Finally the rotor will attain a steady state when the developed torque is equal to the opposing load torque. Thus the motor attains steady state condition.

Advantages:

- They require little or no maintenance.
- They have a much larger operating life.
- No field winding.
- Better ventilation.
- Regenerative braking is possible.
- High speed operation.
- No mechanical commutator.

Disadvantages:

- Require rotor position sensors.
- Motor field cannot be controlled.
- Require power semiconductor switching circuits.

Applications:

- Laser printer
- Hard disk drive
- Automotive applications.
- Robotics applications.
- Textile and glass industries.

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2MARKS:

1. State the law of conservation of energy.

According to the law of conservation of energy, "Energy can neither be created nor destroyed, but it can be converted from one form to another form".

2. Classify the two types of DC machines.

DC machines can be classified into two types.

✓ DC generator

✓ DC motor

3. What is a DC generator?

A DC generator is an electromechanical device which converts mechanical energy into electrical energy.

4. What is the principle of generator?

When the armature conductor cuts the magnetic flux, emf is induced in the conductor.

5. State Faraday's first law of electromagnetic induction.

It states that "whenever the magnetic flux linking a conductor changes, an emf is always induced in it".

6. State Fleming's Right hand rule.

The thumb, forefinger & middle finger of right hand are held so that these fingers are mutually perpendicular to each other, then forefinger gives the direction of the lines of flux, thumb gives the direction of the relative motion of conductor and middle finger gives the direction of the emf induced.

7. How will you find the direction of force produced using Fleming's left hand rule?

The thumb, forefinger & middle finger of left hand are held so that these fingers are mutually perpendicular to each other, then forefinger gives the direction of magnetic field, middle finger gives the direction of the current and thumb gives the direction of the force experienced by the conductor.

8. The outer frame of a DC machine serves double purposes, what are they?

- It acts as a mechanical support for the machine
- Magnetic circuit is formed through the core

9. List the main constituents of stator of DC machine.

- Stator
- Rotor

Stator parts

1. Yoke
2. Pole core

3. Pole shoe
4. Field coils

Rotor parts

1. Armature
2. Commutator
3. Brushes

10. What is the purpose of yoke in DC machine?

- It acts as a protecting cover for the whole machine and provides mechanical support for the poles
- It carries magnetic flux produced by the poles

11. Express the emf equation of DC generator (OR) write the equation for emf induced DC machine.[MAY 2018]

EMF generated in DC generator $E_g = \frac{\Phi Z N}{60} \times \frac{P}{A}$

Where Φ-Flux/pole in Weber
Z- Total number of armature conductors
P- Number of poles
N- Speed in rpm
A - Number of parallel paths

12. What are the different methods of excitation of DC generator?

Depending upon the source from which the exciting current the DC machines is classified into two types.

- Separately excited DC generator
- Self-excited DC generator
  - Series generator
  - Shunt generator
  - Compound generator
- Long shunt Compound generator
- Short shunt Compound generator

13. Distinguish between shunt and series field coil construction in DC machine.

SHUNT FIELD	SERIES FIELD
Field winding is connected across the armature.	The field winding is connected in series with the armature.
It has more number of turns with thin wire.	It has less number of turns with thick wire.
It has high resistance.	It has low resistance.

14. What is a DC compound generator?

Compound generator is one of the self-excited DC generators. In that, there are two field windings, one of them is connected across the armature and other is connected in series with the armature winding.

15. List the conditions of self-excitation of DC generator.

There must be a sufficient residual flux in the field poles.

* The field terminals must be connected in such a way that the field current increases flux in the direction of residual flux.
* The field circuit resistance should be less than the critical field resistance.
* The generator should run at the rated speed.

16. State the conditions under which a DC shunt generator fails to excite.

* There may not be any residual magnetism in the field system.
* The field winding connection may be such that it may not assist the voltage to get build up.
* The total field circuit resistance is more than the critical field resistance.
* The break or opening in the field or armature circuit.

17. Compare lap winding and wave windings used for DC machine armature.

LAP WINDING	WAVE WINDING
It is suitable for high current, low voltage generator.	It is suitable for high voltage, low current generator.
Number of parallel paths A=P	Number of parallel paths A=2

18. Mention the application of a differentially compound generator.

It is a constant current generator and finds a useful application as an arc welding generator where the generator is practically short-circuited every time the electrode touches the metal plates to be welded.

19. Define commutation.

The process of reversal of current in the armature coils by means of brushes and commutator bars is called commutation.

20. Specify the functions of the commutator in a DC machine?[MAY 2018]

* Commutator is used for the rectification of the e.m.f induced in the armature conductors as they are alternating in nature.
* It is cylindrical in shape and is made up of copper and the copper segments are insulated from each other by a thin layer of mica.
* The commutator segment is connected to armature conductor with copper strip.

21. What is the purpose of Commutator?

Commutator is used to convert the alternating emf (AC) generated in the armature winding into direct voltage (DC).

22. Differentiate self and separately excited DC generators.

SELF EXCITED DC GENERATOR	SEPERATELY EXCITED DC GENERATOR
The field winding is excited by an emf induced in the armature conductors.	The field winding is excited by separate DC source.

23. Give the circuit model for DC shunt generator and write down the current and voltage equation.

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

$$E_g = V + I_aR_a + \text{Brush drop}$$

$$V = E_g - I_aR_a - \text{Brush drop}$$

24. What are the causes for drop in terminal voltage?

$$E_g = V + I_aR_a + \text{Brush drop}$$

$$V = E_g - I_aR_a - \text{Brush drop}$$

1. Armature circuit resistance drop.
2. Brush contact drop.
3. Demagnetizing effect of armature reaction.
4. Weakening of field current.

25. What is the function of carbon brush used in DC generators?

The function of the carbon brush is to collect current from commutator and supply to external load circuit and to load.

26. Why is the emf not zero when the field current is reduced to zero in DC generator?

Even after the field current is reduced to zero, the machine is left out with some flux as residue so emf is available due to residual flux.

27. Name any two application of DC series generator.

- Booster
- Constant illumination
- Constant current source

in determining heating, temperature rise, rating & efficiency of transformers, machines & other A.C run magnetic devices.

28. How does DC motor differ from DC generator in construction?

➢ Generators are normally placed in closed room and accessed by skilled operators only. Therefore on ventilation point of view they may be constructed with large opening in the frame.

- Motors have to be installed right in the place of use which may have dust, dampness, inflammable gases, chemical etc. to protect the motors against these elements the motor frames are used partially closed or totally closed or flame proof.

29. Define armature reaction in DC machines? What are its effects?

The interaction between the main flux and armature flux cause disturbance called as armature reaction.

30. Define pole pitch.

It is the distance measured in terms of number of armature slots (or armature conductors) per pole.

31. Define back pitch.

It is the distance measured in terms of armature conductors between the two sides of a coil at the back of the armature.

32. Define front pitch.

It is the distance measured in terms of armature conductors between the coil sides attached to any one commutator segment.

33. Define commutator pitch.

The commutator pitch is the number of commutator segments spanned by each coil of the winding. It is denoted by Y_C.

34. Why the external characteristics of DC shunt generator is more drooping than that of a separately excited generator?

In separately excited generator, $I_a = I_L$ and , I_{sh} is not supplied by armature. In DC shunt generator, $I_a = I_L + I_{sh}$ hence the drop I_aR_a is more than in separately excited generator. Hence the external characteristics of DC shunt generator is more drooping than that of a separately.

35. What is a DC motor?

A DC motor is an electromechanical device which converts electrical energy into mechanical energy.

36. What is the principle of motor?

When a current carrying conductor is placed in a magnetic field it experiences a force tending to move it.

37. How will you find the direction of force produced using Fleming's left hand rule?

The thumb, forefinger & middle finger of left hand are held so that these fingers are mutually perpendicular to each other, then forefinger gives the direction of magnetic field, middle finger gives the direction of the current and thumb gives the direction of the force experienced by the conductor.

38. Mention the significance of back emf.

$$E_g = V - I_a R_a.$$

$$Ia = \frac{V-Eb}{Ra}$$

i. Back emf in a DC motor makes the motor self-regulating.

ii. During no-load conditions, it makes the armature current to be low.

iii. During heavy load conditions, it makes the armature current to be high.

39. What do you mean by back emf in DC motor?

* While a machine is functioning as a motor, the conductors are cutting flux and that is exactly what is required for generator action to take place.

* This means that even when the machine is working as a motor, voltages are induced in the conductors.

* This emf is called as back emf or counter emf.

40. List the types of Dc motor.

* Separately excited Dc motor.

* Self-excited Dc motor.

a. Series motor.

b. Shunt motor.

* Compound motor.

i. Long shunt Compound motor.

ii. Short shunt Compound motor.

41. When a 4 point starter is required in DC motor?

* In a four-point starter, the circuits of no-volt release coil and shunt field are independent and so the operation of no volt release is affected due to variation of field current.

* Whenever the speed of the shunt motor is varied by field control method, there 4 point starter is required. 3 point starter is not suitable for this application.

42. What is the necessity of having starter with DC motor? What is the need for starter in Dc motor?

* Starters are used in DC motors to limit the starting current within about 2 to 3 times of the rated current.

In starters, 2 protective devices are also used.

* Over-load protection.

* No voltage protection.

43. List the different methods of speed control in D.C shunt motor.

* Armature control

* Flux or field control

* Applied voltage control

44. Write the expression for speed of a Dc motor.[NOV/DEC 2015]

$$\therefore N = K\frac{(V - I_a R_a)}{\varphi}$$

$$N \ \alpha \ \frac{E_b}{\varphi}$$

Where, (Φ)- Flux/pole

N-speed of the motor

V- input voltage

K-constant

I_a –armature current

R_a –armature resistance

Speed is directly proportional to back e.m.f(Eb) and inversely proportional to flux/pole (Φ)

45. What is a self-excited DC machine?

The excitation current is needed for producing magnetic field in DC machine.

If the exciting current is drawn from the same source (armature) itself, then it is called self excited Dc machine.

46. What for field coils are provided in DC machines?

In Dc machine, we are in need of magnetic field to produce e.m.f(generator) or force (motor) in the conductor. Permanent magnet is not employed for this purpose in Dc machines. Electromagnets are used.

47. How does a series motor develop high starting torque?

A dc series motor is always started with some load. Therefore the motor armature current increases. Due to this, series motor develops high starting torque.

48. What is the need for starter in dc motors?

* When a dc motor is directly switched on, at the time of starting, the motor back e.m.f is zero. Due to this, the armature current is very high.

* Due to the very high current, the motor gets damaged. To reduce the starting current of the motor a starter is used.

49. What is prime mover?

The basic source of mechanical power which drives the armature of the generator is called prime mover.

50. Mention the applications of series motor.

* Series motors are used where the load is directly attached to the shaft and where there is no danger of the load is being thrown off.

* It is used in electric trains, where the self weight of the train acts as load and for cranes, hoists, fans, blowers, conveyors, lifts etc.

51. Mention the applications of compound motor.

Compound motors are used for driving heavy machine tools for intermittent loads shears, punching machines.

52. State the various applications of DC motors.

Type of Motor	**Characteristics**	**Applications**
Shunt	Approximately constant speed. Speed can be controlled. Medium starting torque. (Up to 1.5 full load torque)	For driving constant speed line shafting lathes, centrifugal pumps, machine tools, Blowers and fans, Reciprocating pumps.
Series	Variable speed. Speed can be controlled. High Starting torque.	For traction work. i.e. electric locomotives rapid transit systems trolley cars etc. cranes and hoists Conveyors.
Cumulative	Compound Variable speed. Speed can be controlled. High Starting torque.	For intermittent high torque loads, for shears and punches, elevators, conveyors, heavy planners, rolling Mills, ice machines, printing press, air compressors .

53. Write the power balance equation of a motor.

Multiplying both sides of the voltage equation by I_a we get power equation as,

$$VI_a = E_b I_a + I_a^2 R_a$$

This equation is called power balance equation of a DC motor.

54. Write the torque equation of a DC motor.

The torque equation of DC motor is

$$T_a = \frac{1}{2\pi}\phi I_a \times \frac{PZ}{A}$$

$\phi = fluxperpole$

P= Number of poles.

Z = Number of conductors.

A= Number of parallel paths

I_a= Armature current.

55. Why a dc series motor used to start heavy loads? Why DC series motor is never started on no load?

* In case of a d.c. series motor, $\phi \propto I_a$ and on no load as I_a is small hence flux produced is also very small. According to speed equation,

$$N \propto \frac{1}{\phi}$$

As E_b is almost constant.

* So on very light load or no load as flux is very small, the motor tries to run at dangerously high speed which may damage the motor mechanically.

* This can be seen from the speed-armature current and the speed-torque characteristics that on low armature current and low torque condition motor shows a tendency to rotate with dangerously high speed.

56. State the function of no volt coil of the starter.

* As the handle is gradually moved over to the final stud, the starting resistance is cut out of the armature circuit in steps. The handle is now held magnetically by the no-volt release coil which is energized by shunt field current.

* The no-volt coil is demagnetized and the handle is pulled to the OFF position by the spring. Thus, the motor is automatically disconnected from the supply.

57. Mention the factor affecting the speed of DC motor.

The factors affecting the speed of a DC motor are,

* The flux Φ.

* The voltage across the armature.

* The applied voltage V.

58. State the advantages of flux control method used for controlling speed of DC shunt motor.

* This is an easy and convenient method.

* It is an inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value of I_{sh}.

* The speed control exercised by this method is independent of load on the machine.

59. State the disadvantages of flux control method used for controlling speed of DC shunt motor.

* Only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below R_{sh}—the shunt field winding resistance.

* There is a limit to the maximum speed obtainable by this method. It is because if the flux is too much weakened, commutation becomes poorer.

60. State the disadvantages of armature control method used for controlling speed of DC shunt motor.

* A large amount of power is wasted in the controller resistance since it carries full armature current I_a.
* The speed varies widely with load since the speed depends upon the voltage drop in the controller resistance and hence on the armature current demanded by the load.
* The output and efficiency of the motor are reduced.
* This method results in poor speed regulation. Due to above disadvantages, this method is seldom used to control the speed of shunt motors.

61. State the methods of speed control in DC series motor.

* Rheostat control.
* Applied voltage control.
* Flux control.
  i. Flux diverter.
  ii. Armature diverter.
  iii. Tapped field.
  iv. Series-parallel grouping of field coil.

62. Why DC series motor is not suitable for belt driven loads?

For belt driven loads, there is possibility of breaking of a belt causing no load condition for the series motor. But on no load, dc series motor tries to run at dangerously high speed and may get damaged. To avoid such situation, dc series motor is not suitable for belt driven loads.

63. What is stepper motor?

- A stepper Motor is basically a synchronous Motor. In a stepper motor, there are no brushes.
- This motor does not rotate continuously; instead it rotates in form of pluses or in discrete steps. So, it is called as stepper motor.

64. Define step angle.

Step angle is defined as the angle through which the motor rotates for each command pulse.it is denoted as β.

B = (Ns-Nr/Ns.Nr) 360

65. Define resolution

It is defined as the no.of steps needed to complete one revolution of the shaft.

Resolution = no. of steps /revolution

66. Mention some applications of stepper motor.

- Floppy disc drives

- Full step operation or single phase on mode is the one in which at a time only one Quartz watch
- Camera shutter operation
- Dot matrix and line printers
- Small tool application i.e. robotics

67. What are the advantages and disadvantages of stepper motor?

Advantages:

- It can be driven in open loop without feedback
- It is mechanically simple
- It requires little or no maintenance.

Disadvantages:

- Low efficiency
- Fixed step angle
- Limited power output

68. What is meant by full step operation?

Phase winding is energized, due to which one stator winding is energized and causes the rotor to rotate some angle.

69. What is meant by two phase mode of operation?

Two phase on mode is the one in which two phase windings are energized at a time, due to which two stator windings are energized and causes the rotor to rotate through some angle.

70. What is synchronism in stepper motor?

It is the one to one correspondence between the number of pulses applied to the stepper motor and the number of steps through which the motor has actually moved.

71. What are the types of stepper motor?

The Stepper Motors are of following types:

- Permanent Magnet
- Variable Reluctance.
- Hybrid Stepper Motor

72. What is meant by micro stepping in stepper motor?

The methods of modulating currents through stator windings so as to obtain rotation of stator magnetic field through a small angle to obtain micro stepping action are known as micro stepping.

73. What are the advantages of micro stepping?

- Improvement in resolution.
- Dc motor like performance.
- Elimination of mid frequency resonance.

- Rapid motion at micro stepping rate..

74. What are the advantages of brushless dc motors drives?

- They require little or no maintenance.
- They have a much larger operating life.
- No field winding.
- Better ventilation.
- Regenerative braking is possible.
- High speed operation.
- No mechanical commutator.

75. What are the disadvantages of brushless dc motors drives?

- Require rotor position sensors.
- Motor field cannot be controlled.
- Require power semiconductor switching circuits.

76. What are the applications of brushless dc motors?

- Laser printer
- Hard disk drive
- Automotive applications.
- Robotics applications.
- Textile and glass industries.

77. Define mechanical commutators.

- Its arrangement is located in the rotor.
- No of commutator segments are very high.

78. Define electronic commutators.

- Its arrangement is located in the stator.
- No of switching devices limited to six.

79. Why the BLDC motor is called electronically commutated motor?

The BLDC motor is also called electronically commutated motor because the phase windings of BLDC motor is energized by using power semiconductor switching circuits. Here the power semiconductor switching circuits act as a commutator.

80. What are the two types of rotor position sensors?

- Optical position sensor
- Hall effect position sensor

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UNIT-III

AC ROTATING MACHINES

Principle of operation of three-phase induction motors – Construction –Types – Equivalent circuit, Speed Control - Single phase Induction motors -Construction–Types–starting methods. Alternator: Working principle–Equation of induced EMF – Voltage regulation, Synchronous motors- working principle-starting methods – Torque equation.

THREE PHASE INDUCTION MOTOR

1. Describe the construction and principle of operation of a 3-phase induction with neat sketch. (MAY 2018)

- A 3-phase induction motor has two main parts,

  (i) Stator **(ii)Rotor**

- The rotor is separated from the stator by a small air-gap which ranges from 0.4 mm to 4 mm, depending on the power of the motor.

1. Stator

- It consists of a steel frame. It encloses a hollow cylindrical core. It is made up of thin laminations of silicon steel. Lamination reduces the hysteresis and eddy current losses.
- A number of evenly spaced slots are provided on the inner periphery of the laminations [See Fig. (4.l)].

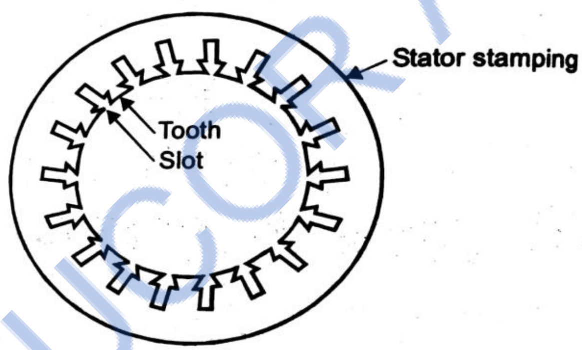


Figure 4.1 Stator of a three-phase induction motor

- The insulated slots are housing the winding and it is connected to form a balanced 3-phase star or delta connected circuit.
- The 3-phase stator winding is wound for a definite number of poles as per requirement of speed.
- Greater the number of poles, lesser is the speed of the motor and vice-versa.

2. Rotor

- The rotor is mounted on a shaft. It has a hollow laminated core. Core has slots on its outer periphery. The winding may be one of the following two types:
  (i) Squirrel cage rotor
  (ii) Slipring (or) Wound rotor

(i) Squirrel cage rotor.

- It consists of a laminated cylindrical core having parallel slots on its outer periphery. One copper or aluminum bar is placed in each slot.

- All these bars are joined at each end by metal rings called end rings. This forms a permanently short-circuited winding.
- The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator.

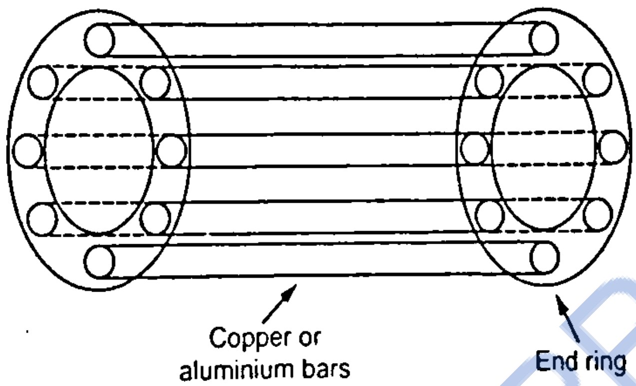


Figure 4.2 Squirrel cage rotor

- Those induction motors which employ squirrel cage rotor are called squirrel cage induction motors. Most of 3-phase induction motors use squirrel cage rotor.
- It has a remarkably simple and robust construction. It enables it to operate in the most adverse circumstances.
- It suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited.
- It is not possible to add any external resistance to the rotor circuit to have a large starting torque.

(ii) Slipring (or) Wound rotor

- It consists of a laminated cylindrical core and carries a 3- phase winding, similar to the one on the stator [See Fig. (4.3)]. The rotor winding is uniformly distributed in the slots and is usually star-connected.
- The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring.

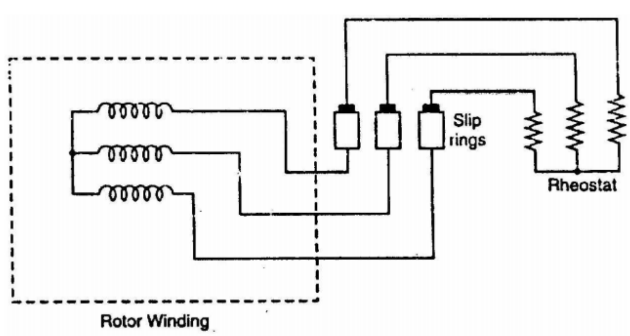


Figure 4.3 external resistor connected to wound rotor

- The three brushes are connected to a 3-phase star-connected rheostat as shown in Fig. (4.3). At starting, the external resistances are included in the rotor circuit to give a large starting torque.
- These resistances are gradually reduced to zero as the motor runs up to speed.

Advantages of Induction Motor

i) It has simple and rugged construction.

ii) It is relatively cheap.

iii) It requires little maintenance.

iv) It has high efficiency and reasonably good power factor.

v) It has self-starting torque.

Disadvantages of Induction Motor

i) It is essentially a constant speed motor and its speed cannot be changed easily.

ii) Its starting torque is inferior to a d.c. shunt motor.

PRINCIPLE OF OPERATION

Consider a portion of 3-phase induction motor as shown in Fig. (4.4). The operation of the motor can be explained as under,

(i) When 3-phase stator winding is energized fiom a 3-phase supply, a rotating magnetic field is set up which rotates round the stator at synchronous speed ($N_S = \frac{120f}{P}$).

(ii) The rotating field passes through the air gap and cuts the stationary rotor conductors.Due to the relative speed between the rotating flux and the stationary rotor, e.m.f.s are induced in the rotor conductors. Since the rotor circuit is short-circuited, currents start flowing in the rotor conductors.

(iii) The current-carrying rotor conductors are placed in the magnetic field produced by the stator. Mechanical force acts on the rotor conductors. The sum of the mechanical forces on all the rotor conductors produces a rotating torque.It moves the rotor in the same direction as the rotating field.

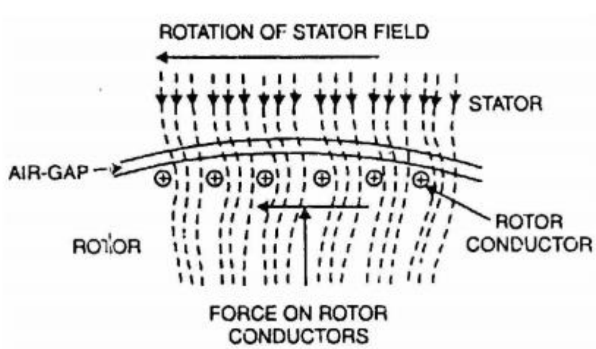


Figure 4.4 Operation of induction motor

(iv) According to Lenz's law, the direction of rotor currents will be such that they tend to oppose the cause producing them. Now, the cause producing the rotor currents is the relative speed between the rotating field and the stationary rotor conductors.

To reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch it.

2. Explain the principle of operation of 3-phase induction motor and explain how the rotating magnetic field is produced by three- phase currents.

PRODUCTION OF ROTATING MAGNETIC FIELD

- If a balanced 3 phase supply is given to a balanced 3 phase winding, it produces rotating magnetic field of constant amplitude. This speed is called as synchronous speed.
- The speed of the rotating magnetic field is given by

$$N_S = \frac{120\,f}{P}$$

Where, f = frequency of the supply

P = number of poles

- Stator of induction motor can be star or delta connected. The three phase windings are displaced from each other by 120^0.

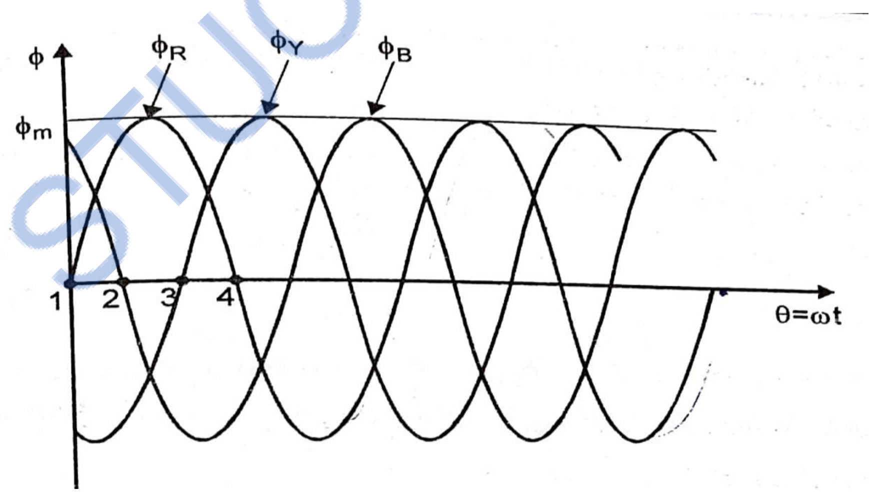
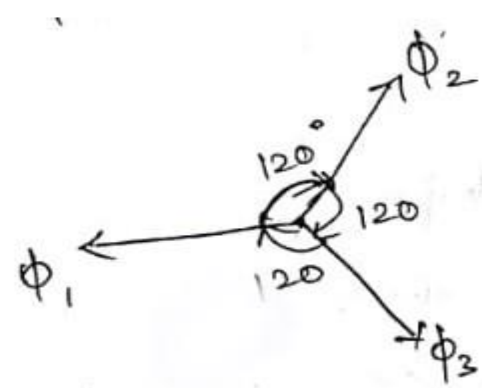


Fig 4.5 three phase waveform



Case 1 :-

At position 1, $\omega t = 0°$

$\phi_1 = \phi_m \sin\omega t = \phi_m \sin(0)$

$\phi_1 = 0$

$\phi_2 = \phi_m \sin(\omega t - 120)$

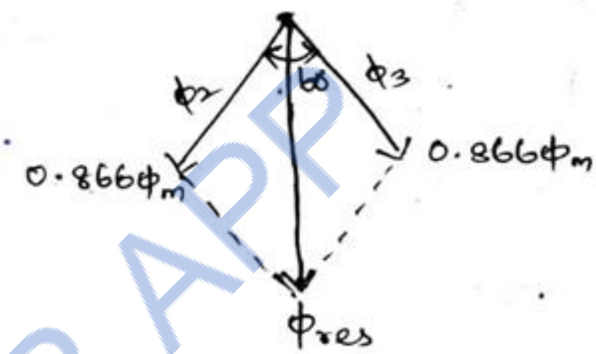
$= \phi_m \sin(0 - 120)$

$\phi_2 = -0.866\phi_m$

$\phi_3 = \phi_m \sin(\omega t - 240)$

$= \phi_m \sin(0 - 240)$

$\phi_3 = 0.866\phi_m$



By using parallelogram formula,

If the two vectors are equal in magnitude.

$\phi_{res} = 2a \cos\frac{\alpha}{2}$

$= 2(0.866\phi_m) \cos\frac{60}{2}$

$\phi_{res} = 1.499\phi_m \simeq 1.5\phi_m$

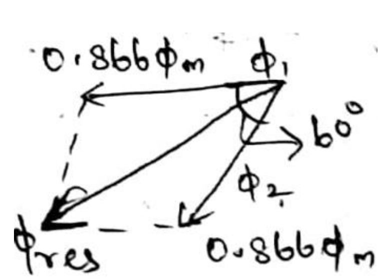
Case 2 :-

At position 2, $\omega t = 60°$

$\phi_1 = \phi_m \sin 60° = 0.866\phi_m$

$\phi_2 = \phi_m \sin(-60) = -0.866\phi_m$

$\phi_3 = \phi_m \sin(60 - 240) = 0$



$\phi_{res} = 2a \cos\frac{\alpha}{2}$

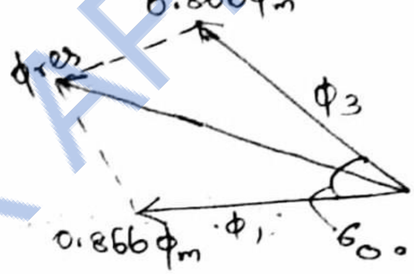
$= 2a \cos\frac{60}{2} = 2 \times 0.866\phi_m \cos 30°$

$\phi_{res} = 1.499\phi_m \simeq 1.5\phi_m$

Compared to Case 1, Magnitude of ϕ_{res} is rotated through 60° in clockwise direction.

Case 3:-

At position 3, $\omega t = 120°$;



$\phi_1 = \phi_m \sin 120° = 0.866\phi_m$

$\phi_2 = \phi_m \sin 0 = 0$

$\phi_3 = \phi_m \sin(-120°) = -0.866\phi_m$

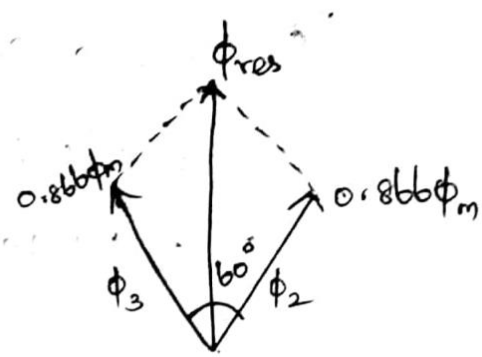
$\phi_{res} = 2a \cos\frac{\alpha}{2} = 2 \times 0.866\phi_m \cos\frac{60}{2}$

$\phi_{res} = 1.499\phi_m \simeq 1.5\phi_m$

Compared to Case 1, Magnitude is rotated through 120° in space in clockwise direction.

Case 4:-

At position 4, $\omega t = 180°$



$\phi_1 = \phi_m \sin 180° = 0$

$\phi_2 = \phi_m \sin 60° = 0.866\phi_m$

$\phi_3 = \phi_m \sin(-60°) = -0.866\phi_m$

$\phi_{res} = 2a \cos\frac{\alpha}{2} = 2 \times 0.866\phi_m \cos\frac{60}{2}$

$\phi_{res} = 1.499\,\phi_m \simeq 1.5\phi_m$

Magnitude of ϕ_{res} is rotated through 180 degree in space in clockwise direction compared to case 1.

RRemarks:

i) The resultant flux ϕ_r is of constant value. $i.e$ $0.866\ \phi_m$.

ii) The resultant flux rotates at the synchronous speed given by $N_s = \frac{120f}{P}$.

3. Write short notes on slip.

- In practice, the rotor never succeeds in 'catching up' with the stator field.
- If it really did so, then there would be no relative speed between the two and no rotor e.m.f., no rotor current and so no torque to maintain rotation.
- That is why the rotor runs at a speed which is always less than the speed of the stator field. The difference in speeds depends upon the load on the motor.
- The difference between the synchronous speed Ns and the actual speed N of the rotor is known as slip.
- It is usually expressed as a percentage of the synchronous speed.
- Actually, the term 'slip' is descriptive of the way in which the rotor 'slips back' from synchronism.

$$\%\ \ \text{Slip} = \frac{N_s - N}{N_s} \times 100$$

- Sometimes, $N_s - N$ is called the slip speed.
- Obviously, rotor (or motor) speed is $N = N_s(1 - s)$.

4. Explain in detail the equivalent circuit of 3-phase induction motor. (OR) Develop an approximate equivalent circuit of a 3-phase induction motor.

- The three phase induction motor is generally treated as rotating transformer.
- The transformer has two windings one is primary and the other is secondary windings. Similarly in induction motor, stator acts as a primary and the rotor acts as a secondary.
- The transformer as well the induction motor operates same principle of mutual induction.

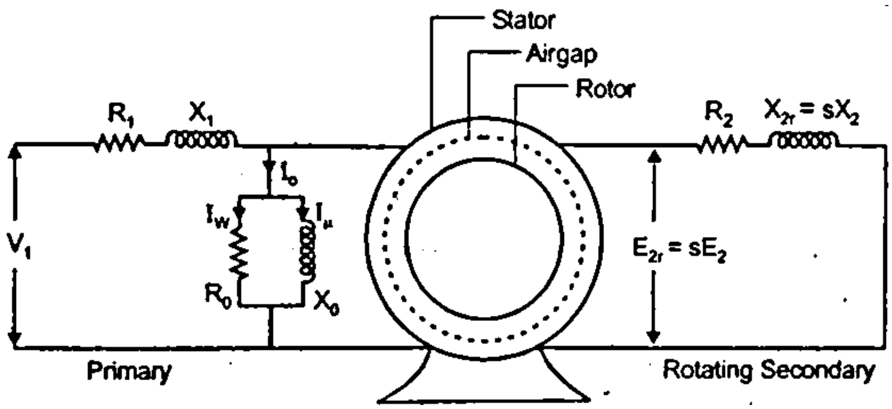


Fig.4.6

- The secondary is connected to the load, which draws electrical power. But in case of induction motor the secondary / rotor is short circuited.
- The stator of the induction motor is represented by an equivalent circuit as shown in above fig.

From fig,

V_1 – supply voltage per phase

E_1 – induced EMF in stator

E_2 – induced EMF in rotor

R_1 – stator resistance/ phase

X_1 – stator reactance/ phase

X_{2r} – rotor reactance / phase

R_{2r} – rotor induced EMF in running condition/phase

When the induction motor operates under no load condition, it draws some current from the supply.

It is to produce the flux in the air gap and to supply iron losses. Normally the no load current consists of two components, (i.e) I_w and I_μ.

$$\overline{I_0} = \overline{I_W} + \overline{I_\mu}$$

Where,

I_w – working component which supplies no load losses.

I_μ - magnetizing component which sets up the flux in core and air gap

R_0 – no load resistance/ phase $= \frac{V_1}{I_W}$

X_0 – no load reactance/ phase $= \frac{V_1}{I_\mu}$

I_{2r} – rotor current under running condition = $\frac{E_{2r}}{Z_{2r}} = \frac{SE_2}{\sqrt{R_2^2+(SX_2)^2}}$

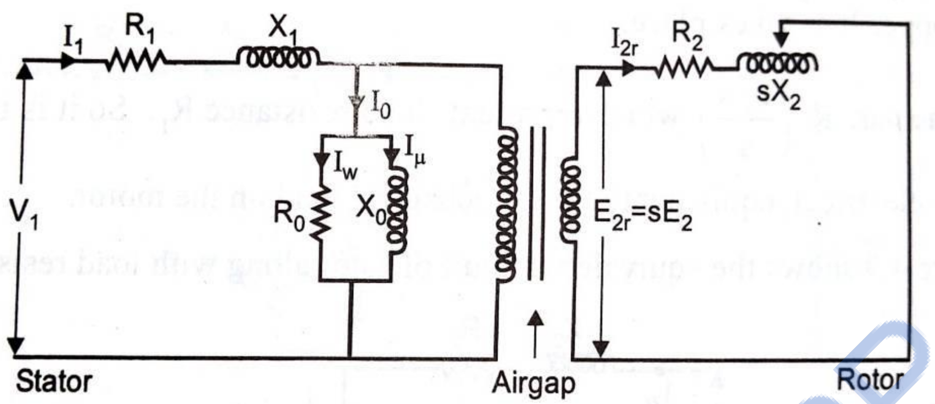


Fig.4.7. Equivalent circuit of an induction motor

- When the induction motor load changes, the motor speed also changes. Correspondingly slip also changes. Due to this reactanceX_{2r} changes. So it is indicated as variable element.

Equivalent circuit of rotor:

- The rotor current under running condition is given by,

$$I_{2r} = \frac{SE_2}{\sqrt{R_2^2+(SX_2)^2}}$$

$$= \frac{E_2}{\sqrt{\left(\frac{R_2}{S}\right)^2+X_2{}^2}}$$

- From this equation, rotor circuit consists of fixed reactance X_2 in series with variable resistance $\frac{R_2}{S}$and supplied with fixed voltage E_2 as shown in fig.

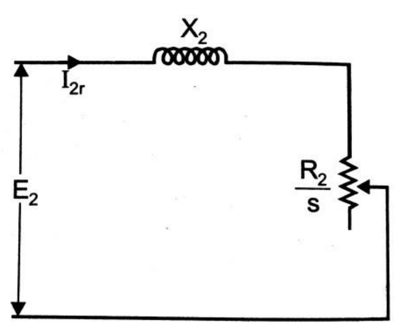


Fig.4.8. Equivalent circuit of rotor

- Now, the variable resistance can be written as,

$$\frac{R_2}{S} = R_2 + \frac{R_2}{S} - R_2$$

$$= R_2 + R_2\left(\frac{1}{S} - 1\right) = R_2 + R_2\left(\frac{1-S}{S}\right)$$

- Now, the variable resistance $\frac{R_2}{S}$ consists of two parts (i.e) R_2 and $R_2\left(\frac{1-S}{S}\right)$
  - i) The part R_2 is rotor resistance itself which represents that part where rotor copper loss takes place.
  - ii) The part $R_2\left(\frac{1-S}{S}\right)$ which represents load resistance R_L. So it is indicated as an electrical equivalent of the mechanical load on the motor.
  - iii) Fig shows the equivalent circuit of rotor along with load resistance R_L.

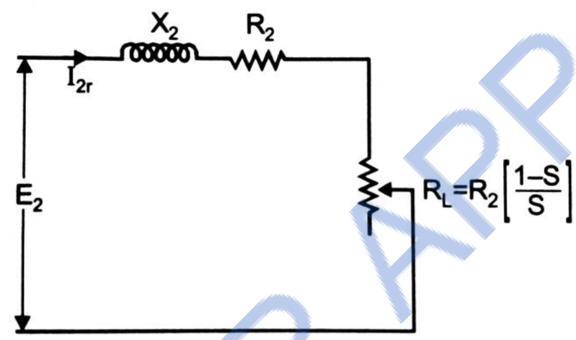


Fig.4.9. Equivalent circuit of rotor

Equivalent circuit referred to stator:

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

- Rotor parameters are transferred to stator,

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

- Rotor current referred to stator

$$I_{2r}' = KI_{2r} = \frac{KSE_2}{\sqrt{(R_2)^2 + (SX_2)^2}}$$

- Rotor reactance referred to stator (R_2')

$$R_2' = \frac{R_2}{K^2}$$

- Load resistance R_L referred to stator,

$$R_L' = \frac{R_L}{K^2} = \frac{R_2}{K^2}\left(\frac{1-S}{S}\right) = R_2'\left(\frac{1-S}{S}\right)$$

- The below fig shows the equivalent circuit referred to stator.

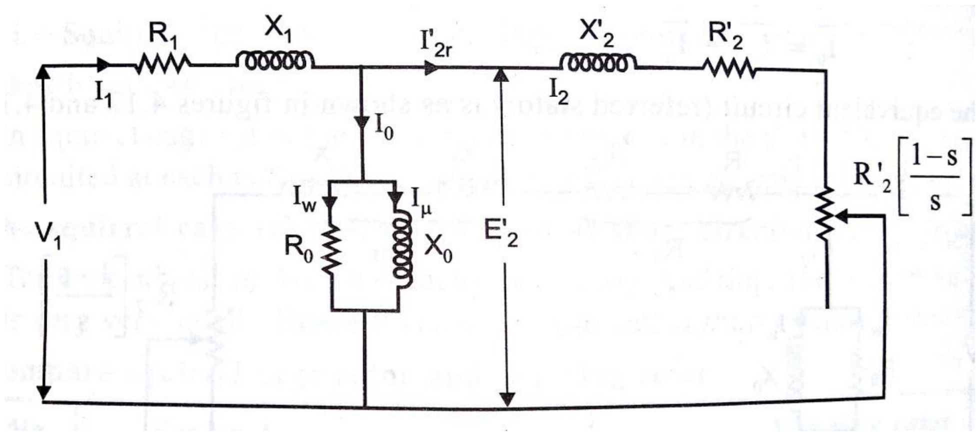


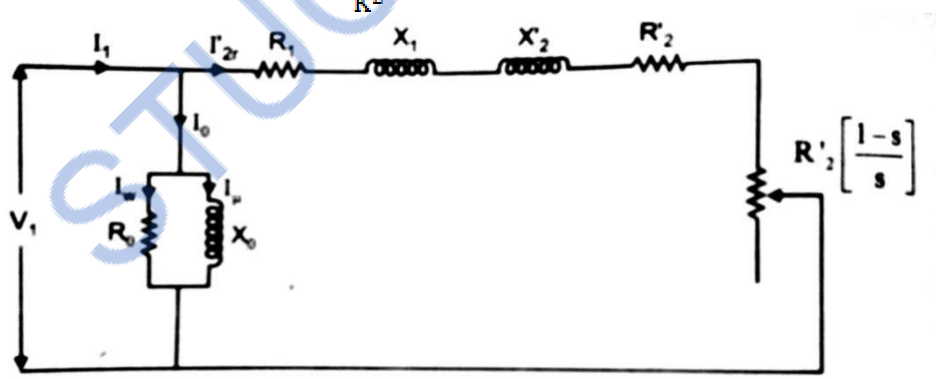
Fig.4.10. Equivalent circuit referred to stator

Approximate Equivalent circuit:

- The exciting circuit consists of R_0 and X_0. This exciting current is transferred to the left of R_1 and X_1.
- The inaccuracy involved due to this is negligible. Here the calculations are very simple. This is known as approximate equivalent circuit. It is shown in below fig.
- Now the circuit is further simplified,
- Combined resistance R_1 and R_2' similarly reactance X_1 and X_2'

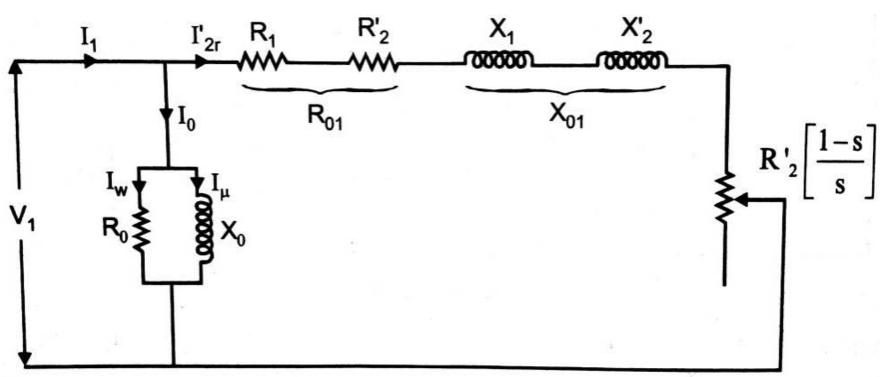
R_{01} = equivalent resistance referred to stator $= R_1 + R_2'$

$$= R_1 + \frac{R_2}{K^2}$$



X_{01}= equivalent reactance referred to stator

$$= X_1 + X_2'$$



$$= X_1 + \frac{X_2}{K^2}$$

$$\overline{I_1} = \overline{I_0} + \overline{I'_{2r}}$$

$$\overline{I_0} = \overline{I_W} + \overline{I_\mu}$$

The equivalent circuit (referred stator) is shown in below figures.

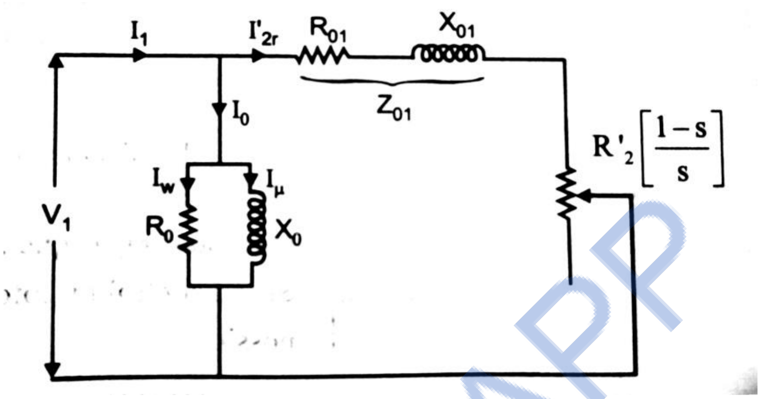


Fig.4.12 Approximate Equivalent circuit

5. Derive the expression for running torque of an induction motor.

In DC motor, torque is proportional to the product of the armature and flux per pole i.e., $\mathbf{T} \propto \boldsymbol{\varphi} \mathbf{I_a}$.

Incase of induction motor, the flux and rotor current, the rotor power factor has also been taken into account. Hence,

$$\mathbf{T \propto \phi I_{2r} \cos\phi_{2r}} \quad \ldots\ldots\ldots\ldots(1)$$

Where, ϕ = flux responsible to produce induced emf.

I_{2r} = rotor current under running condition

$\cos\phi_{2r}$ = rotor power factor under running condition

let E_2 be the rotor induced emf per phase under standstill condition and X_2 be the rotor reactance per phase under standstill condition.since the rotor frequency at a slip is f_r = sf.

$$X_2 = sX_2$$

$$\text{Also } E_2 \propto \phi \ \ldots\ldots\ldots(2)$$

$$E_{2r} = sE_2$$

$$I_{2r} = \frac{E_{2r}}{Z_{2r}} = \frac{sE_2}{\sqrt{[R_2^2 + (sX_2)^2]}} \ldots\ldots\ldots(3)$$

$$cos\phi_{2r} = \frac{R_2}{\sqrt{[R_2^2 + (sX_2)^2]}} \ldots\ldots(4)$$

Substitute equations (2),(3),(4) in eqn. (1),

$$T \propto E_2 * \frac{sE_2}{\sqrt{[R_2^2 + (sX_2)^2]}} * \frac{R_2}{\sqrt{[R_2^2 + (sX_2)^2]}}$$

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

$$T = \frac{KsE_2^2 R_2}{R_2^2 + (sX_2)^2} \, N-m \ldots\ldots\ldots (5)$$

Equation (5) is known as torque equation of a three phase induction motor.

Where,K= constant of proportionality.

$K = \frac{3}{2\pi n_s}$ and n_s = synchronous speed in rps = $\frac{Ns}{60}$

At standstill s =1 and hence,

$$T_{st} = \frac{KE_2^2 R_2}{R_2^2 + X_2^2} N-m \ldots\ldots\ldots (6)$$

Equation (6) is known as starting torque of a three phase induction motor.

Condition for Maximum Torque Under Running Conditions:

Torque under running condition,

$$T = \frac{KsE_2^2 R_2}{R_2^2 + (sX_2)^2} = \frac{u}{v}$$

Torque T for a fixed input voltage will be maximum when $\frac{dT}{ds} = 0$.

$$\frac{u}{v} = \frac{vu' - uv'}{v^2}$$

$$\frac{dT}{ds} = 0 = \frac{(R_2^2 + (sX_2)^2)(KE_2^2 R_2) - KsE_2^2 R_2 (0 + 2s{X_2}^2)}{(R_2^2 + (sX_2)^2)^2}$$

$$0 = (R_2^2 + (sX_2)^2)(KE_2^2 R_2) - KsE_2^2 R_2 (2s{X_2}^2)$$

$$(R_2^2 + (sX_2)^2)(KE_2^2 R_2) = KsE_2^2 R_2 (2s{X_2}^2)$$

$$R_2^2 + (sX_2)^2 = s(2s{X_2}^2)$$

$$R_2^2 + s^2{X_2}^2 = 2s^2{X_2}^2$$

$$R_2^2 = 2\,s^2{X_2}^2 - s^2{X_2}^2$$

$$R_2^2 = s^2{X_2}^2$$

$$\frac{R_2^2}{X_2^2} = s^2$$

$$s = \frac{R_2}{X_2} \dots\dots\dots (7)$$

Running torque is maximum when slip, $s = \frac{R_2}{X_2}$

Substitute equation (7) in (5),

$$T_{max} == \frac{K(R_2/X_2)E_2^2 R_2}{R_2^2 + (R_2/X_2)^2 X_2^2}$$

$$T_{max} = \frac{k_1(R_2/X_2)E_2^2 R_2}{R_2^2 + (R_2^2/X_2^2)^2 X_2^2}$$

$$T_{max} = \frac{KE_2^2}{2X_2}\ N-m \dots\dots\dots (8)$$

Equation (8) is known as maximum torque of a three phase induction motor.

TORQUE-SLIP CHARACTERISTICS

6. Draw and explain the torque-Slip characteristics of a 3 phase induction motor.

$$T = \frac{KsE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

- When the supply voltage V is constant, E_2 is also constant and running torque is given by,

  $$T = \frac{KsR_2}{R_2^2 + (sX_2)^2}$$

- If a curve is drawn between the torque and slip for a particular value of rotor resistance R_2, the graph thus obtained is called torque-slip characteristic.

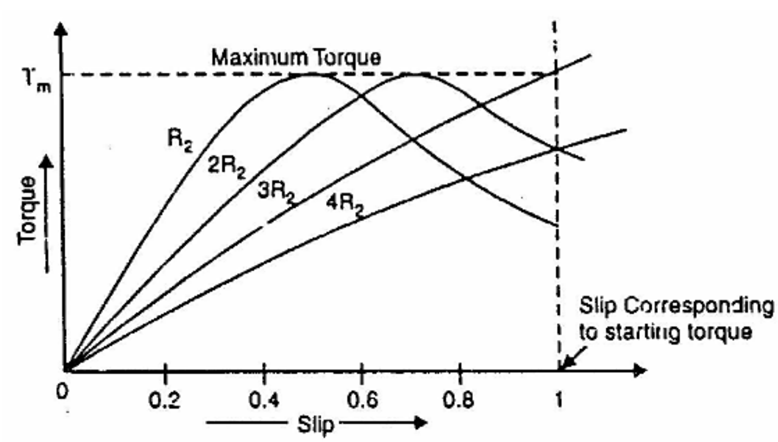


Figure 4.13 Torque-Slip characteristics

- Fig. (4.13) shows a family of torque-slip characteristics for a slip-range from s = 0 to s = 1 for various values of rotor resistance.

  The following points may be noted carefully:

(i) At s = 0, T = 0 so that torque-slip curve starts from the origin.

(ii) At normal speed, slip is small so that sX_2 is negligible as compared to R_2.

$$T \propto \frac{s}{R_2}$$

$$T \propto s \qquad \because \qquad \ldots..R_2 \quad is\ constant$$

Hence, torque slip curve is a straight line from zero slip to a slip that corresponds to full-load.

(iii)As slip increases beyond full load slip, the torque increases and becomes maximum at s = R_2/X_2. This maximum torque in an induction motor is called pull-out torque or break-down torque.

Its value is at least twice the full-load value when the motor is operated at rated voltage and fiequency.

When is X_2 maximum, term $s^2X_2^2$ increases rapidly so that R_2^2 may be neglected.

$$T \propto \frac{s}{s^2X^2}$$

$$T \propto {}^1/_s \qquad \ldots as\ X_2\ is\ constant$$

The torque is now iversely proportional to slip. Th torque-slip characteristics is a retcangular hypebola.

(iv)The maximum torque remains the same and is independent of the value of rotor resistance.

Therefore, the addition of resistance to the rotor circuit does not change the value of maximum torque.

It only changes the Value of slip at which maximum torque occurs.

STARTING METHODS OF THREE PHASE INDUCTION MOTOR

NEED FOR STARTERS:

- An induction motor is similar to a poly-phase transformer whose secondary is short circuited.
- Thus, at normal supply voltage, like in transformers, the initial current taken by the primary is very large for a short while.
- If an induction motor is directly switched on from the supply, it takes 5 to 7 times its full load current and develops a torque which is only 1.5 to 2.5 times the full load torque.

- This large starting current produces a large voltage drop in the line, which may affect the operation of other devices connected to the same line.
- Hence, it is not advisable to start induction motors of higher ratings (generally above 25kW) directly from the mains supply.

Types of starters:

- DOL(Direct On Line) starter
- Rotor resistance starter.
- Autotransformer starter.
- Star to Delta starter.

7. Describe with a neat sketch, the principle and working of a DIRECT ON LINE starter of a 3-phase induction motor. (16) (NOV/DEC 2011)

- This method is also known as the DOL method for starting the three-phase squirrel cage induction motor**.**
- In this method, we directly switch the stator of the three-phase squirrel cage induction motor on to the supply mains.
- The motor at the time of starting draws very high starting current (about 5 to 7 times the full load current) for the very short duration.
- Such a high value of current causes sudden undesirable voltage drop in the supply voltage.
- A live example of this sudden drop of voltage is the dimming of the tube lights and bulbs in our homes at the instant of starting of refrigerator motor.
- The buttons which may be installed in a convenient place away from the starter. The start button is held open by a spring.
- On pressing the star pushbutton S_1, the contactor C is energized from two line conductors L_1 and L_2.
- The three main contacts M and the auxiliary contact A are closed. The terminals a and b are short-circuited. The motor is then connected to the supply mains.
- The S_1 button moves back under the spring action as soon as the pressure is released. The coil C remains energized through ab.
- Thus, the main contact M remains closed, and the motor continues to get supplies.
- Therefore, contact A is known as Hold-On-Contact. The stop button S_2 is normally held closed by the spring.
- If the S_2 button is pressed to stop the motor, the supply through the contactor coil C is disconnected.

- As the coil C is de-energized, the main contacts M and the auxiliary contact A are opened. The supply to the motor is disconnected, and the motor is stopped.

Under voltage Protection

- When the voltage falls below a certain value or when the supply fails or disrupted during the operation of the motor, the coil C is de-energized.
- Hence, the motor is disconnected from the supply overload Protection
- The motor is overloaded one or all the overload coils (O.L.C) are energized.
- The normally closed contact D is opened, and the contactor coil C is de-energized to disconnect the supply from the motor. Fuses are provided in the circuit for short circuit protection.
- In Direct on line starting the starting current may be as large as ten times the full load current, and the starting torque is equal to full load torque.
- Such a large starting current produces an excessive voltage drop in the line which supplies power to the motor.

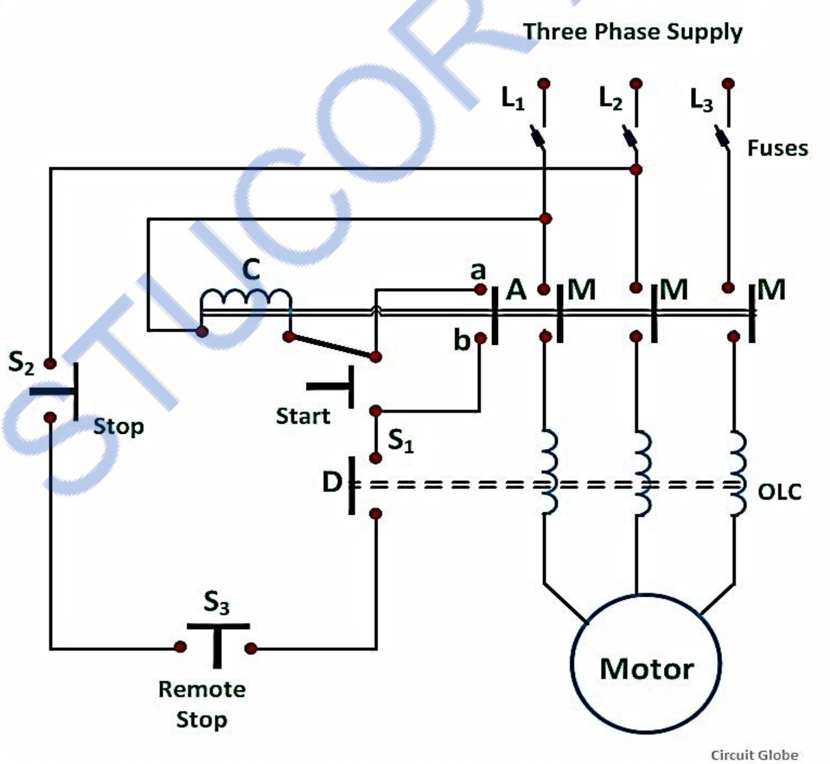


Fig 4.14 DOL starter

8. Explain the rotor rheostat control of 3 phase slip ring induction motor.

- We have discussed everything on squirrel cage induction motors including its disadvantages.
- To overcome these disadvantages, slip ring induction motors have been developed, with better starting characteristics and better current drawing characteristics.

- In this article, we will discuss on the starting method and characteristics of slip ring induction motors with its applications.
- Unlike cage motors, the speed of the slipring motor can be controlled.
- The stators of the slipring motors are same as those of squirrel cage motors.
- But the rotor of a slipring motor consists of a three-phase winding formed out of copper conductors, and set into a laminated soft iron core.
- The rotor sliprings are connected to three terminals through three sets of brushes. A starter unit, connected to the terminals, completes the rotor circuit externally.
- The starter unit consists of three variable resistances connected in star.
- It is connected to the three slipring terminals so that each phase of the rotor winding has variable resistance in series with it, as shown in Fig.

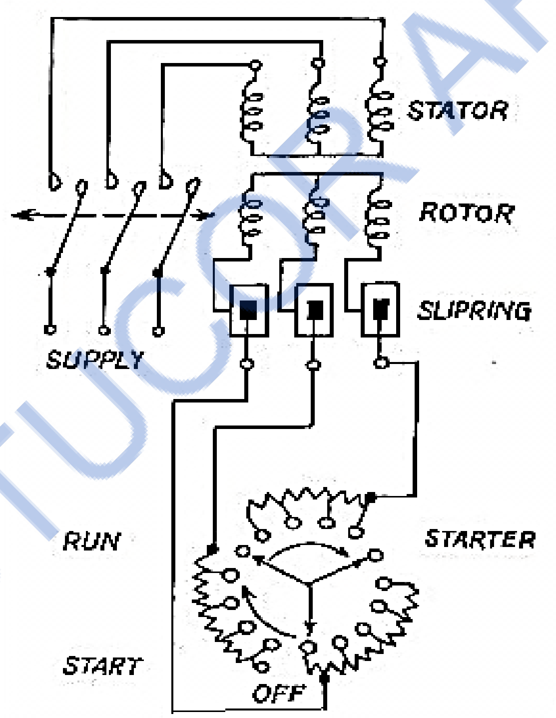


Fig 4.15 Rotor resistance starter

- The resistance of the rotor circuit can therefore, be varied by an external control.
- To start the motor, the resistances are set at their highest value.
- When the supply to the stator winding is switched on, the motor starts slowly with a high torque and relatively low stator current.
- The resistances are progressively reduced, thereby permitting the motor to speed up, until the three terminals are, in effect, short circuited and the motor runs at full speed.

- A slipring motor can be made to run below its maximum speed by leaving parts of the external resistances in series with the rotor windings.
- These motors are usually started with full line voltage applied across its terminals.
- As these motors have external resistance connected to its rotor circuit, the value of starting current is adjusted or kept minimum, by increasing the resistance of the rotor circuit.
- This external resistance can be assumed to be a form of rheostat, connected in star.
- The rheostat is at its maximum when the motor starts and gradually cut-out as the motor gathers speed.
- The controlling rheostat may be of either stud or contactor type. It may be either hand operated or sometimes automatic.
- The 3-phase supply to the stator has a switching contactor along with over-load and no or low-voltage protective devices.
- There might be also an interlock provided to ensure the proper sequential operation of the control gear and starting devices.

9. With neat diagrams, explain the working of (i) Auto Transformer Starter (ii) Star-Delta Starter for 3 phase induction motor. (16) (NOV/DEC 2016)

Auto Transformer Starter:

- A three-phase star connected autotransformer can be used to reduce the voltage applied to the stator. Such a starter is called an autotransformer starter.
- The schematic diagram of autotransformer starter. The schematic diagram of autotransformer starter is shown in the Fig.
- It consists of a suitable change over switch.
- When the switch is in the start position, the stator winding is supplied with reduced voltage. This can be controlled by tappings provided with autotransformer.
- The reduction in applied voltage by the fractional percentage tappings x, used for an autotransformer.
- When motor gathers 80% of the normal speed, the changeover switch is thrown into run position.
- Due to this, rated voltage gets applied to stator winding.
- The motor starts rotating with normal speed. Changing of switch is done automatically by using relays.

- The power loss is much less in this type of starting. It can be used for both star and delta connected motors. But it is expensive than stator resistance starter.

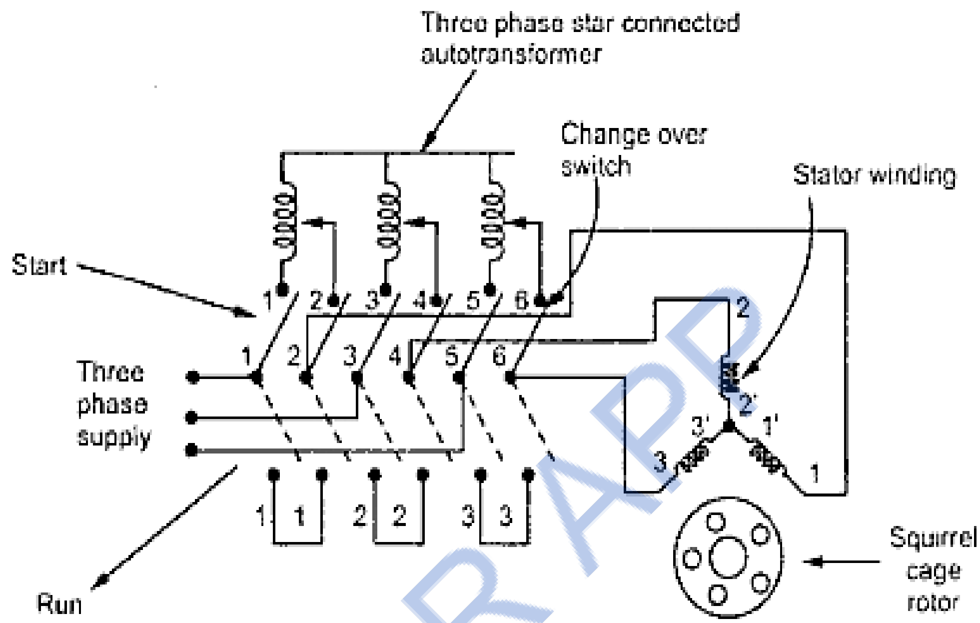


Figure 4.16 Autotransformer starter

Star-Delta Starter:

- It is the most commonly used reduced voltage starter as it is the cheapest starter among all.

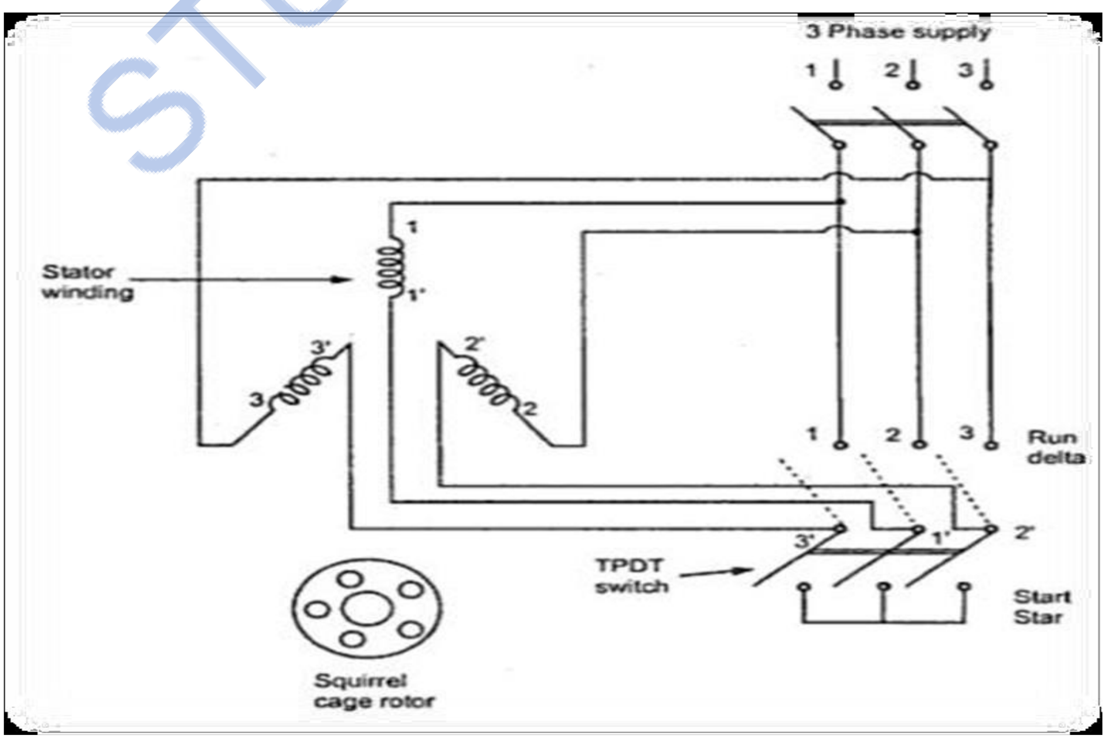


Figure 4.17 Star-delta starter

- In this method, induction motor is connected in star during start and delta while running with rated speeds.
- These starters are designed to run on delta connected stator of an induction motor. The schematic diagram of this starter is shown in Figure.
- This starter uses a TPDT (triple pole double throw) switch and it connects the stator winding in star during the starting condition.
- Due to this star connection, the applied voltage to the motor is reduced by the factor $1/\sqrt{3}$. This reduced voltage results the less current through the motor.
- When the motor picks up the speed, the TPST switch is thrown automatically on the other side by using relays such that the winding is now connected in delta across the supply.
- So, the normal voltage is applied to the motor (because in delta connection voltage is same, ($V_L = V_P$) and hence the motor runs at normal speed.
- This method is cheap and maintenance free as compared to other methods.
- However, this is suitable only for delta connected motors and also the factor by which starting voltage reduced, i.e., $1/\sqrt{3}$ cannot be altered.

SINGLE PHASE INDUCTION MOTOR

- The motors which work on single phase a.c. supply is very popularly in use in shops, offices, houses, schools etc. These a.c. motors are called single phase induction motors.
- The numerous domestic applications use single phase motors. The power rating of such motors is very small.
- Some of them are even fractional horse power motors, which are used in applications like small toys, small fans, hair dryers etc.

10. Explain with neat diagram the construction of single phase Induction Motors.

- Similar to a d.c. motor, single phase induction motor has basically two main parts. One is rotating and other is stationary.
- The stationary part in single phase induction motors is called stator while the rotating part is called rotor.
- The stator has laminated construction, made up of stampings. The stampings are slotted on its periphery to carry the winding called stator winding or main winding.
- This is excited by a single phase a.c. supply. The laminated construction keeps iron losses to minimum.

- The stampings are made up of material like silicon steel which minimizes the hysteresis loss. The stator winding is wound for certain definite number of poles means when excited by single phase a.c. supply, stator produces the magnetic field which creates the effect of certain definite number of poles.
- The number of poles for which stator winding is wound, decides the synchronous speed of the motor.
- The synchronous speed is denoted as N_s and it has a fixed relation with supply frequency f and number of poles P. The relation is given by,

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

- The induction motor never rotates with the synchronous speed but rotates at a speed which is slightly less than the synchronous speed.
- The rotor construction is of squirrel cage type. In this type, rotor consists of uninsulated copper or aluminum bars, placed in the slots.
- The bars are permanently shorted at both the ends with the help of conducting rings called end rings.
- The entire structure looks like cage hence called squirrel cage rotor. The construction and symbol is shown in the Fig.4.18.

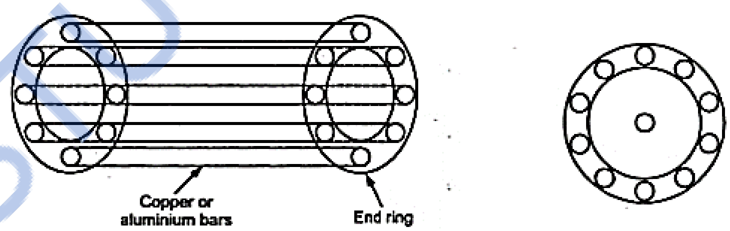


Figure. 4.18 Cage type rotor

- As the bars are permanently shorted to each other, the resistance of the entire rotor is very small. The air gap between stator and rotor is kept uniform and as small as possible.
- The main feature of this rotor is that it automatically adjusts itself for same number of poles as that of the stator winding.
- The schematic representation of two pole single phase induction motor is shown in the Fig 4.19.

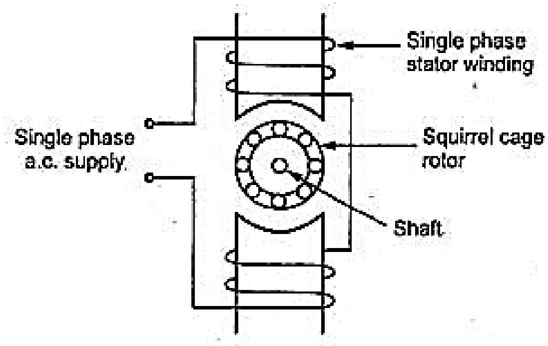
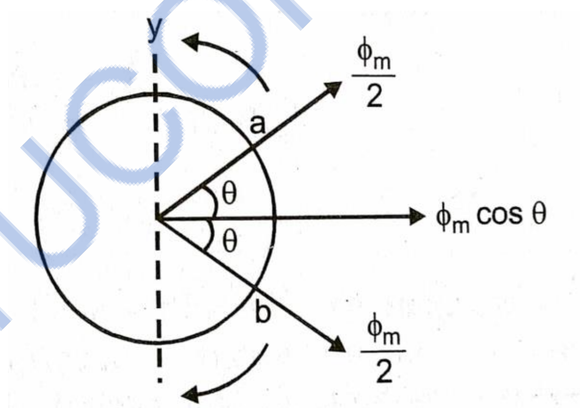


Figure 4.19 Two pole motor

11. Explain the operation of a single-phase induction motor using double field revolving theory.

- From fundamental principle i.e., any alternating quantity can be resolved into two quantities which rotate in opposite directions and have half of the magnitude.
- The alternating flux (Φ_m) produced in the 1Φ induction motor can be represented by two resolving fluxes each equal to the half the value of ($\frac{\varphi_m}{2}$) the alternating flux



and each rotating synchronously $N_S = \frac{120f}{P}$ in opposite direction.

Fig 4.20

- Fig 4.20 shows the vectors when they have been rotated by an angle $+\theta$ to $-\theta$.

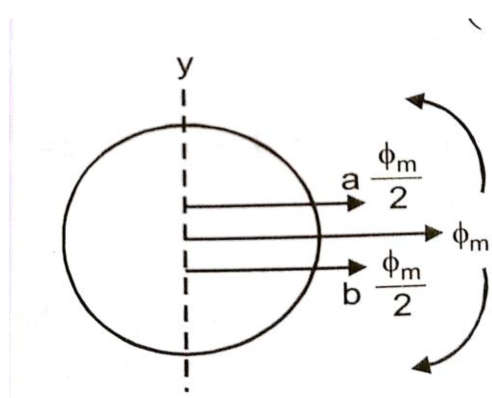


Fig 4.21

The resultant flux is $2*(\frac{\varphi_m}{2}) = \varphi_m$

- After a quarter cycle of rotation, fluxes a and b will be oppositely directed. The resultant flux now zero.

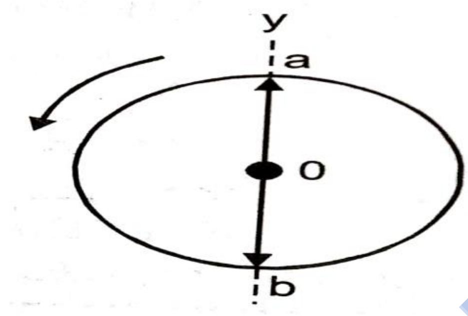


Fig 4.22

- After a half cycle of rotation, fluxes a and b will have resultant of $-2*(\frac{\varphi_m}{2}) = -\varphi_m$

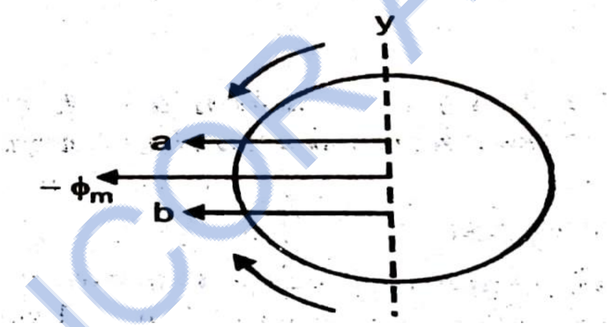


Fig 4.23

- After three quarters of cycle of, again the resultant is zero.

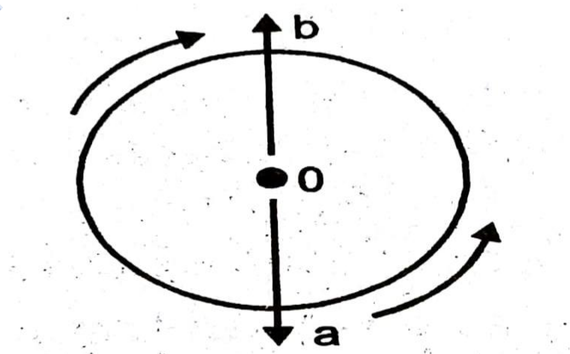


Fig 4.24

- So flux variation is φ_m,0,- φ_m,0.the flux variation with respect to θ is plotted which is shown in the figure below.

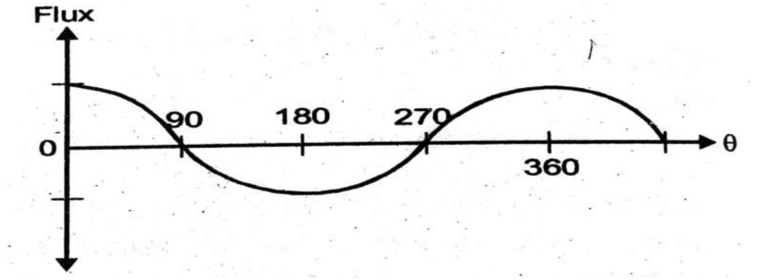


Fig 4.25

- The slip of the rotor is given by $s_f = \frac{N_s - N}{N_s}$
- With respect to the forward rotating flux (i.e., one which rotates in the same direction as rotor).
- The slip with respect to the backward flux is

$$S_b = \frac{N_s-(-N)}{N_s} = 1+\frac{N}{N_s} = 1+1\text{-}s = 2\text{-}s$$

$$S_b = 2\text{-}s$$

- Each of the two component fluxes while revolving around the stator cuts the rotor induces an emf and produces its own torque. The two torques are oppositely directed so that the net torque is zero i.e., resultant torque is equal to their differences.

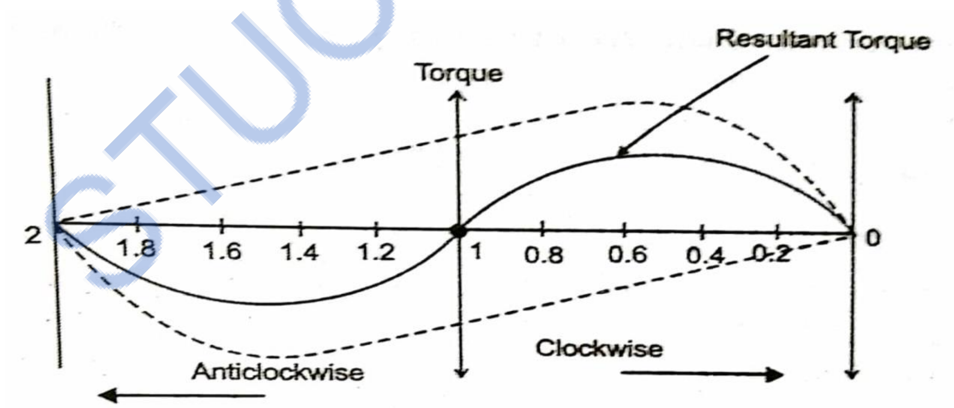


Fig 4.26 torque-slip characteristics

STARTING METHODS OF SINGLE PHASE INDUCTION MOTOR

12. Discuss in detail, the different methods of starting of single-phase induction motors.(OR) Explain in detail the operation of capacitor start and run induction motor.

- The single phase induction motors are made self-starting by providing an additional flux by some additional means.

- Now depending upon these additional means the single-phase induction motors are classified as:
  - (i) Split phase induction motor.
  - (ii) Capacitor start induction motor.
  - (iii) Capacitor start capacitor run induction motor (two value capacitor method).
  - (iv) Shaded pole induction motor.

Split Phase Induction Motor:(8M)

- In addition to the main winding or running winding, the stator of single phase induction motor carries another winding called auxiliary winding or starting winding.
- A centrifugal switch is connected in series with auxiliary winding. The purpose of this switch is to disconnect the auxiliary winding from the main circuit when the motor attains a speed up to 75 to 80% of the synchronous speed.
- We know that the running winding is inductive in nature. Our aim is to create the phase difference between the two winding and this is possible if the starting winding carries high resistance.
- Let us say I_{run} is the current flowing through the main or running winding, I_{start} is the current flowing in starting winding, and V is the supply voltage.

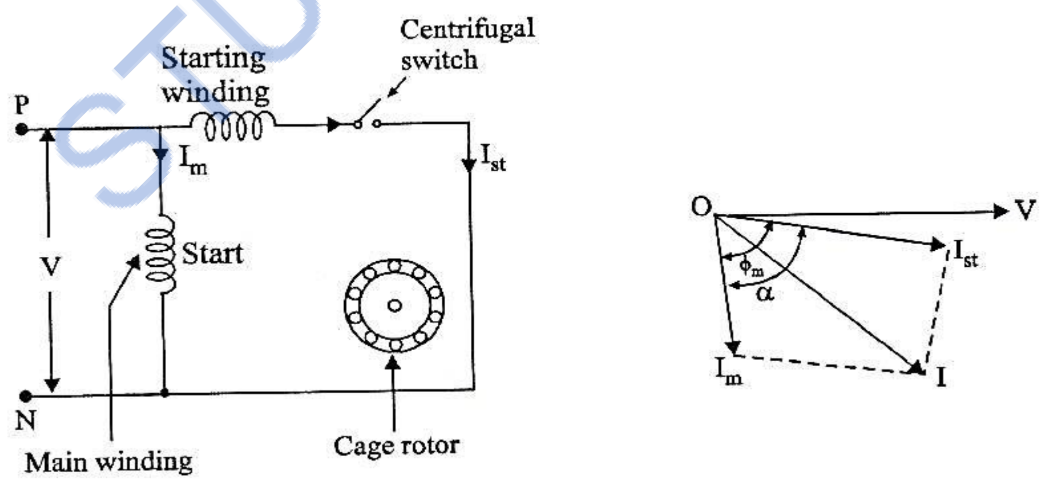


Fig 4.27 Split phase induction motor

- We know that for highly resistive winding the current is almost in phase with the voltage and for highly inductive winding the current lag behind the voltage by large angle.
- The starting winding is highly resistive so, the current flowing in the starting winding lags behind the applied voltage by very small angle and the running

winding is highly inductive in nature so, the current flowing in running winding lags behind applied voltage by large angle.

- The resultant of these two currents is I. The resultant of these two currents produces rotating magnetic field which rotates in one direction.
- In split phase induction motor the starting and main current get split from each other by some angle so this motor got its name as split phase induction motor.

Applications:

- Fans,
- Blowers,
- Centrifugal pumps,
- Washing machine,
- Grinder,
- Lathes,
- Air conditioning fans, etc.

Capacitor-Start Induction run Motor: (8M)

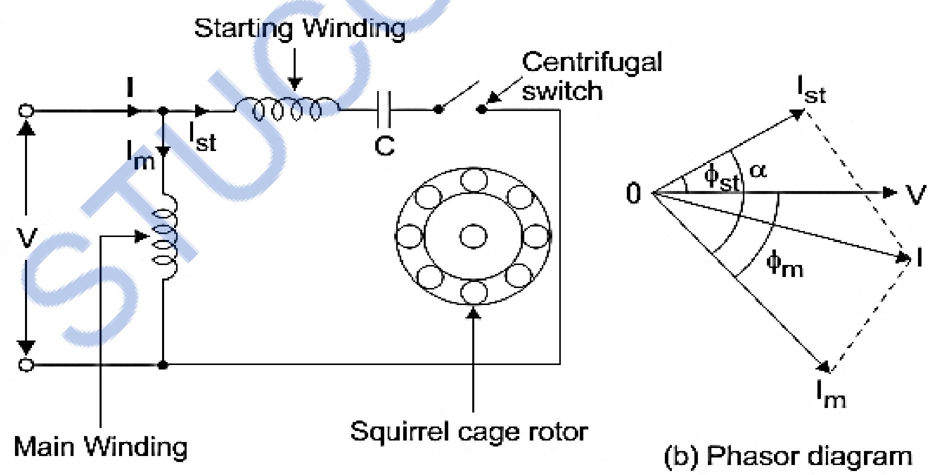


Fig 4.28 Capacitor-Start Induction run Motor

- The working principle and construction of Capacitor start inductor motors and capacitor start capacitor run induction motors are almost the same.
- We already know that single phase induction motor is not self-starting because the magnetic field produced is not rotating type.
- In order to produce rotating magnetic field there must be some phase difference. In case of split phase induction motor we use resistance for creating phase difference but here we use capacitor for this purpose.

- We are familiar with this fact that the current flowing through the capacitor leads the voltage. So, in capacitor start inductor motor and capacitor start capacitor run induction motor we are using two winding.
- They are the main winding and the starting winding. With starting winding we connect a capacitor so the current flowing in the capacitor i.e I_{st} leads the applied voltage by some angle, φ_{st}.
- The running winding is inductive in nature so, the current flowing in running winding lags behind applied voltage by an angle, φ_m.
- Now there occur large phase angle differences between these two currents which produce a resultant current, I and this will produce a rotating magnetic field.
- Since the torque produced by these motors depends upon the phase angle difference, which is almost 90^o. So, these motors produce very high starting torque.
- In case of capacitor start induction motor, the centrifugal switch is provided so as to disconnect the starting winding when the motor attains a speed up to 75 to 80% of the synchronous speed.

Applications:

- Conveyors,
- Grinder,
- Air conditioners,
- Compressor, etc

Capacitor-Start Capacitor-Run Motor: (8M)

- This motor is identical to a capacitor-start motor except that starting winding is not opened after starting. Both the windings remain connected to the supply when running as well as at starting. Two types of designs are generally used.
- In one design, a single capacitor C is used for both starting and running as shown in Fig.(4.29 (i)).
- This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.

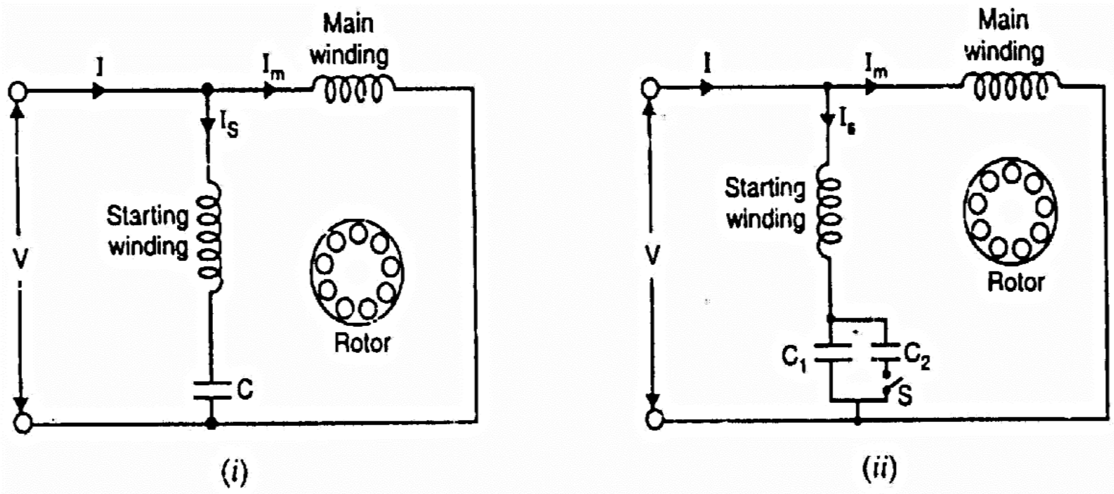


Fig 4.29 Capacitor-Start Capacitor-Run Motor

- In the other design, two capacitors C_1 and C_2 are used in the starting winding as shown in Fig. (4.29 (ii)). The smaller capacitor C_1 required for optimum running conditions is permanently connected in series with the starting winding.
- The much larger capacitor C_2 is connected in parallel with C_1 for optimum starting and remains in the circuit during starting.
- The starting capacitor C_1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.

Characteristics

- The starting winding and the capacitor can be designed for perfect 2-phase operation at any load.
- The motor then produces a constant torque and not a pulsating torque as in other single-phase motors.
- Because of constant torque, the motor is vibration free and can be used in, hospitals (b) studios and (c) other places where silence is important.

Applications:

- Conveyors,
- Grinder,
- Air conditioners,
- Compressor, etc.

<u>Shaded pole induction motor:</u> (13M)

13. Explain the operation of shaded pole induction motor with neat diagram.

- The shaded-pole motor is very popular for ratings below 0.05 H.P. (~ 40 W).It is extremely simple in construction.

- It has salient poles on the stator excited by single-phase supply and a squirrel cage rotor as shown in Fig. (4.30).
- A portion of each pole is surrounded by a short-circuited turn of copper strip called shading coil.

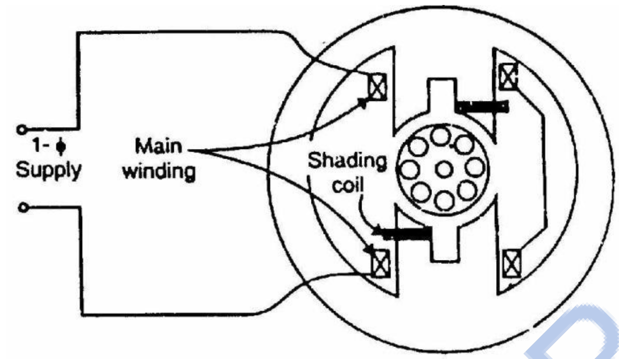


Fig 4.30 Shaded pole motor

Operation

- The operation of the motor can be understood by referring to Fig. (4.31) which shows one pole of the motor with a shading coil.
- During the portion OA of the alternating-current cycle [See Fig. (4.31)], the flux begins to increase and an e.m.f is induced in the shading coil.
- The resulting current in the shading coil will be in such a direction (Lenz's law) so as to oppose the change in flux.
- Thus, the flux in the shaded portion of the pole is weakened while that in the un shaded portion is strengthened as shown in Fig. (4.31 (ii)).
- During the portion AB of the alternating-current cycle, the flux has reached almost maximum value and is not changing.
- Consequently, the flux distribution across the pole is uniform [See Fig. (4.31 (iii))] since no current is flowing in the shading coil.
- As the flux decreases (portion BC of the alternating current cycle), current is induced in the shading coil so as to oppose the decrease in current.
- Thus, the flux in the shaded portion of the pole is strengthened while that in the unshaded portion is weakened as shown in Fig. (4.31 (iv)).

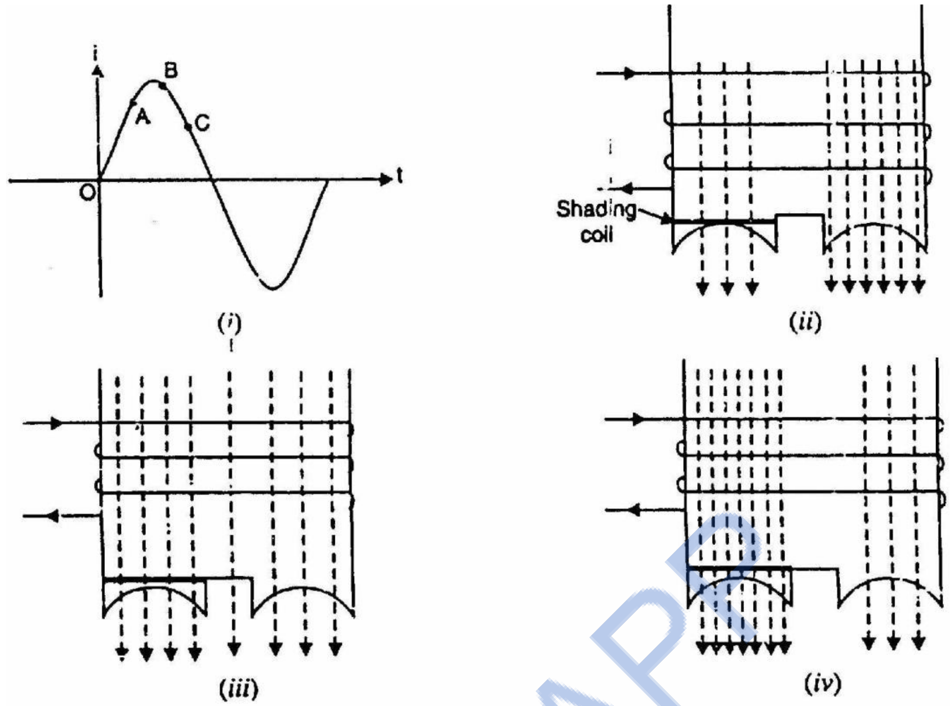


Fig 4.31 Shaded poles

- The effect of the shading coil is to cause the field flux to shift across the pole face from the unshaded to the shaded portion.
- This shifting flux is like a rotating weak field moving in the direction from unshaded portion to the shaded portion of the pole.
- The rotor is of the squirrel-cage type and is under the influence of this moving field. Consequently, a small starting torque is developed.
- As soon as this torque starts to revolve the rotor, additional torque is produced by single-phase induction-motor action.
- The motor accelerates to a speed slightly below the synchronous speed and runs as a single-phase induction motor.

Characteristics

- The salient features of this motor are extremely simple construction and absence of centrifugal switch.
- Since starting torque, efficiency and power factor are very low, these motors are only suitable for low power applications e.g., to drive: (a) small fans (b) toys (c) hair driers (d) desk fans etc.
- The power rating of such motors is upto about 30 W.

Applications:

- Hair dryers,
- Toys,

- Record players,
- Small fans,
- Electric clocks etc.

THREE PHASE ALTERNATOR (OR) SYNCHRONOUS GENERATOR

14. Describe construction and working of an alternator (or) synchronous generator.

- An alternator has 3-phase winding on the stator and a DC field winding on the rotor.

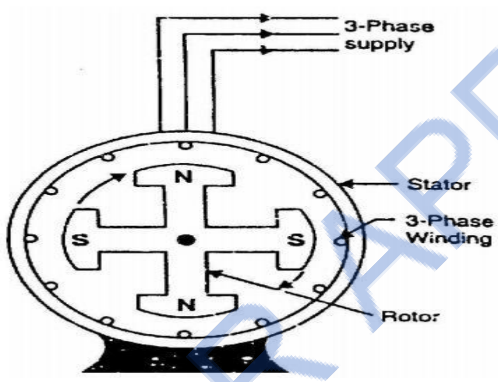


Fig 4.32 three phase alternator

Stator

- It is the stationary part of the machine and is built up of sheet-steel laminations having slots on its inner periphery.
- A 3-phase winding is placed in these slots and serves as the armature winding of the alternator.
- The armature winding is always connected in star and the neutral is connected to ground.

Rotor

- The rotor carries a field winding which is supplied with direct current through two slip rings by a separate D.C. source.
- This D.C. source (called exciter) is generally a small D.C. shunt or compound generator mounted on the shaft of the alternator.

Rotor construction

- Salient (or projecting) pole type
- Non-salient (or cylindrical) pole type

Salient pole type

- Salient or projecting poles are mounted on a large circular steel frame which is fixed to the shaft of the alternator.

- The individual field pole windings are connected in series in such a way that when the field winding is energized by the D.C. exciter, adjacent poles have opposite polarities.

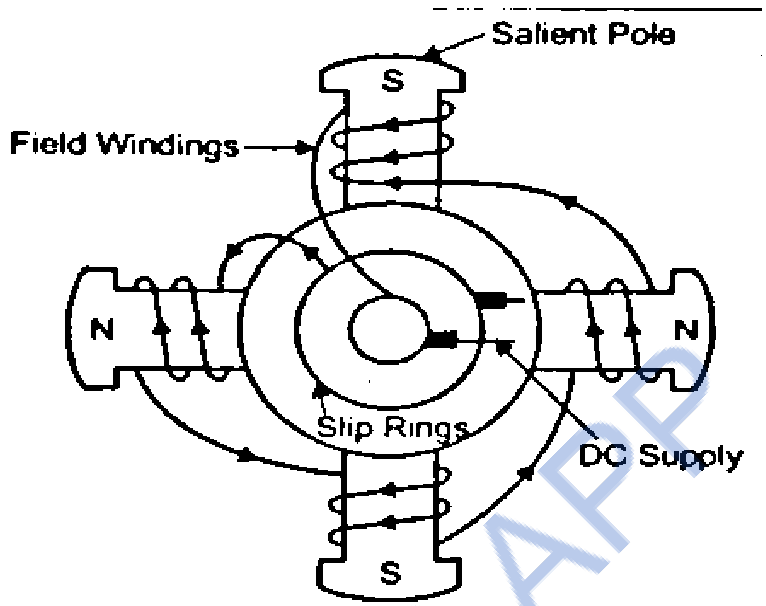


Fig 4.33 Salient pole rotor

- Used for Low and medium-speed alternators (120-400 r.p.m.)

Non-salient pole type

- In this type, the rotor is made of smooth solid forged-steel radial cylinder having a number of slots along the outer periphery.
- The field windings are embedded in these slots and are connected in series to the slip rings through which they are energized by the DC exciter.
- The regions forming the poles are usually left unslotted. It is clear that the poles formed are non-salient i.e., they do not project out from the rotor surface.
- Used for high-speed alternators (1500 or 3000 rpm).

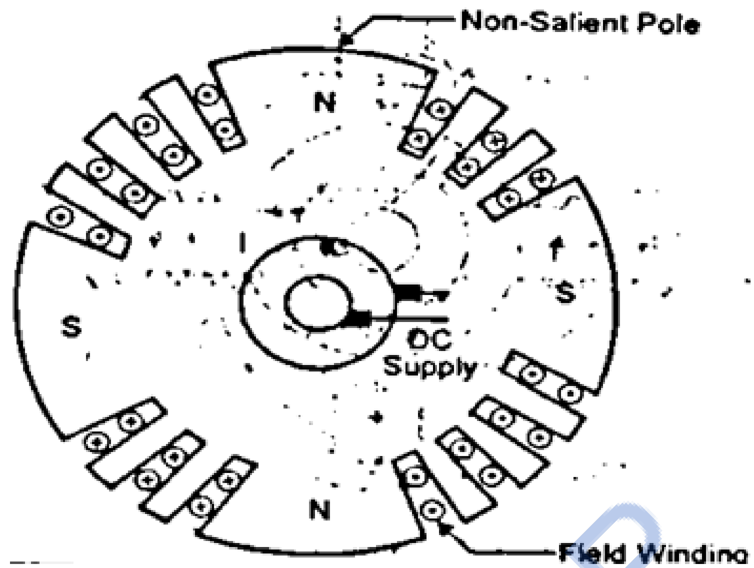


Fig 4.34 Non- salient pole rotor

15. Derive the e.m.f. equation of an alternator. Explain pitch factor and distribution factor.

Let Z = No. of conductors or coil sides in series per phase

ϕ = Flux per pole in webers

P = Number of rotor poles

N = Rotor speed in r.p.m.

In one revolution (i.e. 60/N second), each stator conductor is cut by Pφ webers i.e.,

$$d\phi = P\phi; \qquad dt = 60/N$$

∴ Average e.m.f. induced in one stator conductor

$$= \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \text{ volts}$$

Since there are Z conductors in series per phase,

$$\therefore \text{ Average e.m.f./phase} = \frac{P\phi N}{60} \times Z$$

$$= \frac{P\phi Z}{60} \times \frac{120\,f}{P} \qquad \left(\because N = \frac{120\,f}{P}\right)$$

$$= 2f\phi Z \text{ volts}$$

R.M.S. value of e.m.f./phase = Average value/phase x form factor

$$= 2f\phi Z \times 1.11 = 2.22\, f\phi Z \text{ volts}$$

$$\therefore \quad E_{r.m.s.}/\text{phase} = 2.22\, f\phi Z \text{ volts}$$

If K_p and K_d are the pitch factor and distribution factor of the armature winding, then,

$$E_{r.m.s.}/\text{phase} = 2.22 K_p K_d f\phi Z \text{ volts}$$

Sometimes the turns (T) per phase rather than conductors per phase are specified, in that case, eq. becomes:

$$E_{r.m.s.}/\text{phase} = 4.44 K_p K_d f\phi T \text{ volts}$$

where,

$$k_p = \cos\frac{\alpha}{2}$$

$$k_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}}$$

$$\beta = \frac{180^\circ}{n}$$

The line voltage will depend upon whether the winding is star or delta connected.

i.e., $E_L = \sqrt{3} E_{r.m.s/phase}$

Distribution factor (K_d):

The distribution factor is defined as the ratio of resultant emf when coils are distributed to the resultant emf when coils are concentrated. It is less than unity.

$$K_d = \frac{\text{emf with distributed winding}}{\text{emf with concentrated winding}}$$

$$k_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}}$$

Pitch factor (K_c):

The pitch factor is defined as the ratio of resultant emf when coil is short pitch to the resultant emf when coil is full pitched.

$$K_p = \frac{\text{emf induced in short pitch coil}}{\text{emf induced in full pitch coil}}$$

$$k_p = \cos\frac{\alpha}{2}$$

<u>PROBLEM :</u> A 3-phase, 12-pole, 500 rpm star connected alternator has 144 slots with 8 conductors per slot. The coils are full pitched and flux per pole is 0.08wb.

Determine the phase and line EMF's. What will be the phase voltage if the coils are connected to form a balanced two-phase winding?(15)(NOV/DEC 2018)

Solution:

Emf per phase $E_{ph} = 4.44 f\phi T_{ph} K_p K_d$

$$f = \frac{NP}{120} = \frac{12 \times 500}{120} = 50Hz$$

No. of turns per phase,

$$T_{ph} = \frac{Z_{ph}}{2}$$

Total no.of conductors = No.of slots X No. of conductors per slot

No. of conductors per phase,

$$Z_{ph} = \frac{\text{Total no.of.conductors}}{\text{No.of phases}}$$

$$Z_{ph} = \frac{8 \times 144}{3} = 384$$

$$T_{ph} = \frac{384}{2} = 192$$

Since the coils are full pitched i.e, the coil span factor $k_p = 1$

$$k_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}}$$

No. of slots/pole/phase,

$$m = \frac{144}{12 \times 3} = 4$$

No. of slots/pole,

$$n = \frac{144}{12} = 12$$

Angular displacement β,

$$\beta = \frac{180°}{n} = \frac{180°}{12} = 15°$$

$$k_d = \frac{\sin\frac{4 \times 15}{2}}{4\sin\frac{15}{2}}$$

$$k_d = 0.95776$$

$$E_{ph} = 4.44 \times 50 \times 0.08 \times 192 \times 1 \times 0.95776$$

Emf/Phase, $E_{ph} = 3265.88$ V

$$\text{Line Emf}, E_L = \sqrt{3}E_{ph} = \sqrt{3} \times 3265.88$$

$$E_L = 5656.67 \text{ V}$$

VOLTAGE REGULATION

16. Define Voltage regulation. Explain the two methods used to determine voltage regulation of alternators.

- The voltage regulation of an alternator is defined as the rise in voltage when full load is thrown off, assuming field current and speed remaining the same.
- The percentage regulation is defined as the ratio of change in terminal voltage from full load to no load terminal voltage.

$$\% \text{ Regulation} = \frac{E_0 - V}{V} * 100$$

E_0 – no load terminal voltage

V – full load rated terminal voltage

Determination of voltage regulation

- The alternator is driven at synchronous speed and the terminal voltage is adjusted to its rated value.
- The load is varied until the wattmeter sand ammeter indicates the rated value at desired pf.
- Then the entire load is thrown off while the speed and field excitation are kept constant. Then the open circuit or no load voltage E_0 is noted.

a) Synchronous impedance or EMF method

b) The ampere turn or MMF method

c) Zero power factor method or potier method.

All these methods require,

1. Armature resistance R_a.
2. Open load / no load characteristics
3. Short circuit characteristics

1. Armature resistance R_a:

- Armature resistance R_a/phase can be measured directly by voltmeter and ammeter method or by using Wheatstone bridge.

2. Open load / no load characteristics:

- As in DC machine, here it is plotted by running the machine on No load and by noting the values of induced voltage and field excitation current.

3. Short circuit characteristics:

- It is obtained by short circuiting, the armature windings through a low resistance ammeter.
- The excitation is so adjusted as to give 1.5 to 2 times the full load current.

a) Synchronous impedance or EMF method:

The following steps are involved in this method,

- OCC is plotted from the given data.
- Similarly SCC is drawn from the data given by short circuit test it is the straight line passing through the origin. Both the curves are drawn on common field current base.
- Consider field current I_f. The open circuit voltage corresponding to the field current is E_1. When the winding is short circuited the terminal voltage is zero.
- Hence it is assumed that the whole of this voltage E_1 is being used to circulate the armature short circuit current I_1 against the synchronous impedance Z_S.

$$E_1 = I_1 Z_S$$

$$Z_S = \frac{E_1(\text{open circuit})}{I_1(\text{short circuit})}$$

Since R_a can be found, $X_S = \sqrt{Z_S^2 - R_a^2}$

From below diagram, $OD = E_0$

$$E_0 = \sqrt{(OB^2 + BD^2)}$$

$$E_0 = \sqrt{(V\cos\emptyset + IR_a)^2 + (V\sin\emptyset + IX_S)^2}$$

$$\%\ \text{Regulation} = \frac{E_0 - V}{V} * 100$$

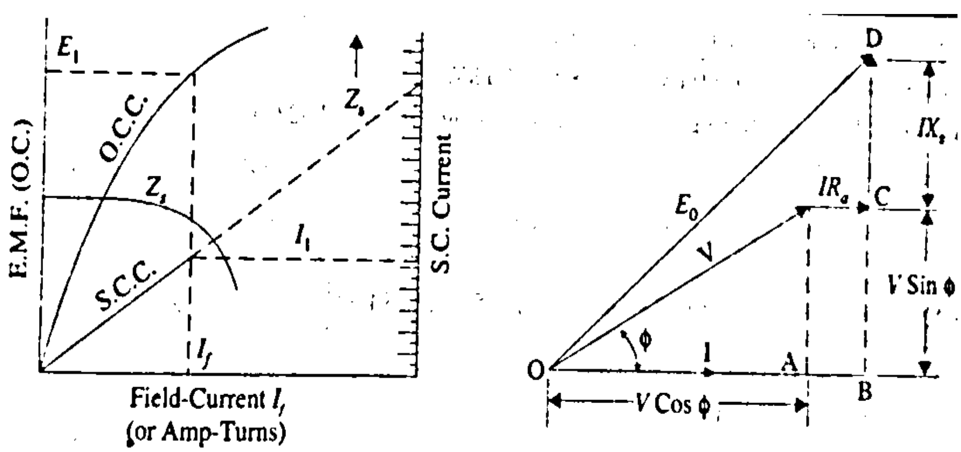


Fig.4.35

b) The ampere turn or MMF method

- This method of finding voltage regulation considers the opposite view to the synchronous impedance method. It assumes the armature leakage reactance to be additional armature reaction.
- Suppose the alternator is supplying full-load current I_a at operating voltage V and p.f. cos ϕ lagging. The procedure for finding Voltage regulation for AT method is as under:
  - (i) From the O.C.C., field current OA required to produce the operating load voltage V (or V + I_aR_a cos ϕ) is determined [See Fig. (4.36)]. The field current OA is laid off horizontally as shown in Fig. (4.36).

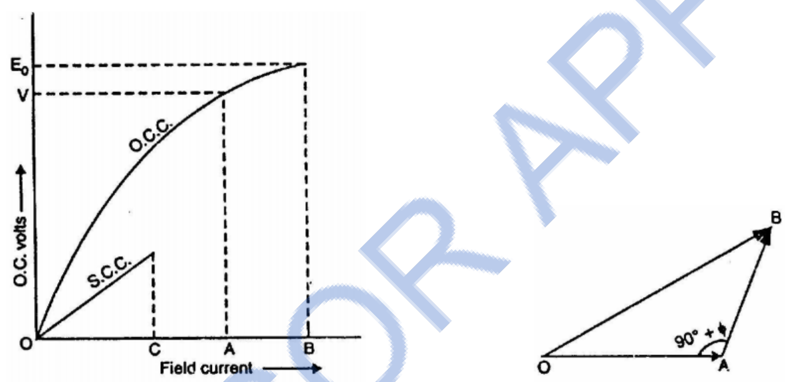


Fig 4.36 Total field current

  - (ii) From S.C.C., the field current OC required for producing full-load current I_a on short-circuit is determined. The phasor AB (= OC) is drawn at an angle of (90° + ϕ) i.e., ∟OAB = (90° + ϕ) as shown in Fig. (4.36).
  - (iii) The phasor sum of OA and AB gives the total field current OB required. The O.C. Voltage EO corresponding to field current OB on O.C.C. is the no-load e.m.f.

$$\%\,Voltage\ regulation = \frac{E_0 - V}{V} \times 100$$

  - (iv) This method gives a regulation lower than the actual performance of the machine. For this reason, it is known as Optimistic Method.

c) <u>Zero power factor method or portier method:</u>

- This method is based on the separation of armature leakage reactance drop and the armature reactance effect.
- The experimental data required are, no load curve, full load zero power factor curve also called wattles load characteristics.

- It is the curve of terminals volts against excitation, when armature is delivering full load current at zero pf. The reduction in voltage due to armature reaction is found from the above.
- Voltage drop due to armature leakage reactance X_L is found from both by combining these two, E_0 can be calculated if we vectorially add to V the drop due to resistance and leakage reactance X_L. We get E.
- I_f to E is further added the drop due to armature reaction then we get E_0.
- The zero power factor lagging curves can be obtained.
- If a similar machine is available this may be driven at no load as a synchronous motor at practically zero pf or by adding alternator with pure reactors.
- By connecting the alternator with pure reactors.
- By connecting the alternator to a three phase line with ammeter and wattmeter connected for measuring current and power.
- By so adjusting the field current that we get full load armature current with zero wattmeter reading.
- Point B was obtained when wattmeter was reading zero.
- Point A is obtained from short circuit test with full load armature current.
- Hence OA represents field current which is equal and opposite to the demagnetizing armature reaction ands for balancing.

$$\% \text{ Regulation} = \frac{E_0 - V}{V} * 100$$

Procedural Steps

- Suppose we are given V the terminal Voltage.
- We will be given or else we can calculate Armature leakage reactance X_L and hence can calculate IX_L.
- Adding IX_L vectorially to V, we get voltage E.
- We will next find N-L curves, field excitation for voltage E. Let it be If_1.

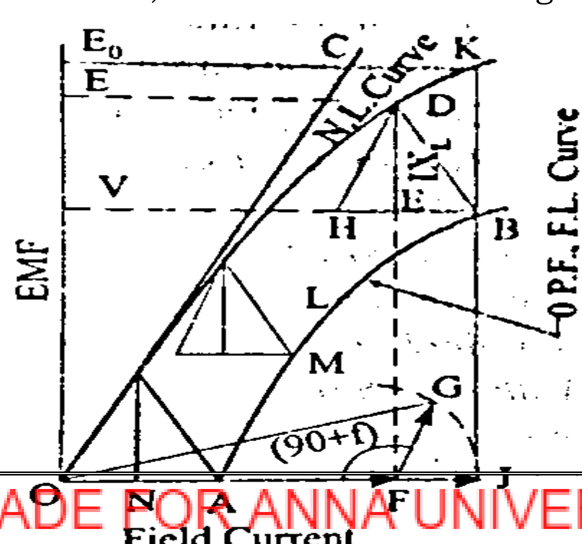


Fig.4.37 Potier Method

- Further field current I_{f2} is necessary for balancing armature reaction is found from potier triangle.
- Combine I_{f1} & I_{f2} vectorially to get I_f.
- Read from NL curve, the e.m.f corresponding to I_f. This gives in E_0. Hence regulation can be found.

SYNCHRONOUS MOTOR

17. Explain briefly principle operation of synchronous motor?

- Consider a 3-phase synchronous motor having two rotor poles N_R and S_R. Then the stator will also be wound for two poles N_S and S_S. The motor has direct voltage applied to the rotor winding and a 3-phase voltage applied to the stator winding.
- The stator winding produces a rotating field which revolves round the stator at synchronous speed N_S (= 120 f/P). The direct (or zero frequency) current sets up a two-pole field which is stationary so long as the rotor is not turning.
- Thus, we have a situation in which there exists a pair of revolving armature poles (i.e., N_S - S_S) and a pair of stationary rotor poles (i.e., N_R-S_R).
- Suppose at any instant, the stator poles are at positions A and B as shown in Fig. (4.38 (i)). It is clear that poles N_S and N_R repel each other and so do the poles S_S and S_R.
- Therefore, the rotor tends to move in the anti- clockwise direction. After a period of half-cycle (1/2 f = 1/100 second), the polarities of the stator poles are reversed but the polarities of the rotor poles remain the same as shown in Fig. (4.38 (ii)).

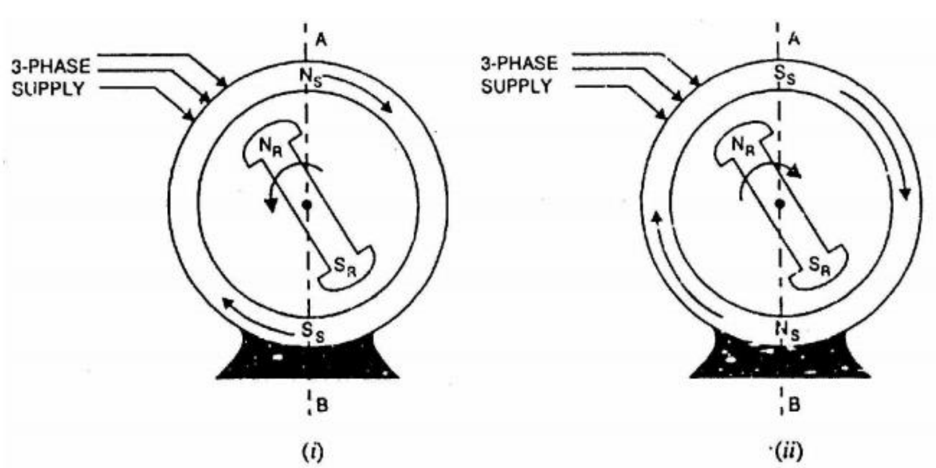


Figure 4.38 Synchronous motor

- Now S_S and N_R attract each other and so do N_S and SR. Therefore, the rotor tends to move in the clockwise direction.
- Since the stator poles change their polarities rapidly, they tend to pull the rotor first in one direction and then after a period of half-cycle in the other. Due to high inertia of the rotor, the motor fails to start.
- Hence, a synchronous motor has no self-starting torque i.e., a synchronous motor cannot start by itself.
- If the rotor poles are rotated by some external means at such a speed that they interchange their positions along with the stator poles, then the rotor will experience a continuous unidirectional torque.
- Suppose the stator field is rotating in the clockwise direction and the rotor is also rotated clockwise by some external means at such a speed that the rotor poles interchange their positions along with the stator poles.
- Suppose at any instant the stator and rotor poles are in the position shown in Fig. (4.39 (i)). It is clear that torque on the rotor will be clockwise.
- After a period of half-cycle, the stator poles reverse their polarities and at the same time rotor poles also interchange their positions as shown in Fig. (4.39 (ii)).
- The result is that again the torque on the rotor is clockwise. Hence a continuous unidirectional torque acts on the rotor and moves it in the clockwise direction.
- Under this condition, poles on the rotor always face poles of opposite polarity on the stator and a strong magnetic attraction is set up between them.

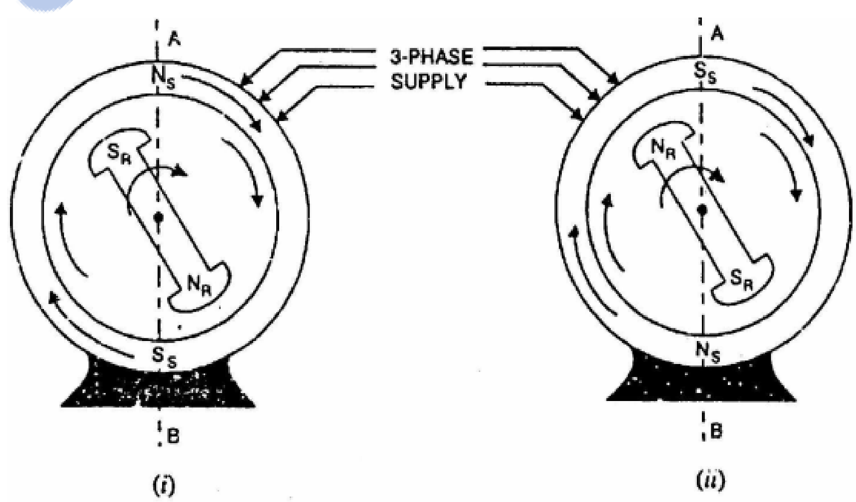


Figure 4.39 Alternating torque in a synchronous motor

- This mutual attraction locks the rotor and stator together and the rotor is virtually pulled into step with the speed of revolving flux (i.e., synchronous speed).
- If now the external prime mover driving the rotor is removed, the rotor will continue to rotate at synchronous speed in the clockwise direction because the rotor poles are magnetically locked up with the stator poles.
- It is due to this magnetic interlocking between stator and rotor poles that a synchronous motor runs at the speed of revolving flux i.e., synchronous speed.

18. Explain the operation of torque equation of synchronous motor.

- Except for very small machines, the armature resistance of synchronous motor is negligible as compared to its synchronous reactance.
- Hence, the equivalent circuit for the motor becomes as shown in Fig. 4.40 (a). From the phasor diagram of Fig. 4.40 (b). It is seen that

$$AB = E_b \sin\alpha \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\cos\phi = \frac{AB}{I_a X_s}$$

$$AB = I_a X_s \cos\phi \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Equating the equations (2) & (1),

$$E_b \sin\alpha = I_a X_s \cos\phi \ldots\ldots\ldots\ldots\ldots (3)$$

$$I_a \cos\phi = \frac{E_b}{X_s} \sin\alpha$$

$$P_{in} = V I_a \cos\phi$$

Now $VI_a \cos\phi$ = motor power input/phase

$$\therefore P_{in} = \frac{E_b V}{X_s} \sin\alpha \quad \text{for single phase}$$

$$P_{in} = \frac{3E_b V}{X_s} \sin\alpha \quad \text{for three phase}$$

Since stator Cu losses have been neglected, P_{in} also represents the gross mechanical power (P_m) developed by the motor.

$$P_m = \frac{3E_bV}{X_s}\sin\alpha$$

The gross torque developed by the motor is

$$P_m = T\omega_m$$

$$T = \frac{P_m}{\omega_m} = \frac{3E_bV}{\omega_m X_s}\sin\alpha$$

$$T = \frac{9.55\ Pm}{Ns} N\text{—}m$$

Ns in rpm.

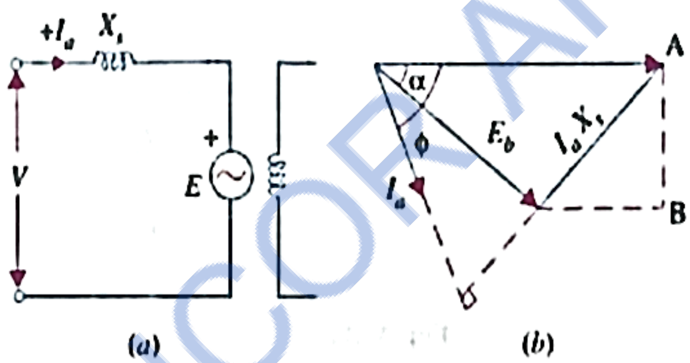


Figure 4.40 Synchronous motor- power developed

19. Discuss the methods of starting and procedure for starting synchronous motor.

Various methods to start the synchronous motor are,

1. Using pony motors
2. Using damper winding
3. As a slip ring induction motor
4. Using small d.c. machine coupled to it.

1. Using pony motors

- In this method, the rotor is brought to the synchronous speed with the help of some external device like small induction motor.
- Such an external device is called 'pony motor.

- Once the rotor attains the synchronous speed, the d.c. excitation to the rotor is switched on.
- Once the synchronism is established pony motor is decoupled.
- The motor then continues to rotate as synchronous motor.

2. Using Damper Winding

- In a synchronous motor, in addition to the normal field winding, the additional winding consisting of copper bars placed in the slots in the pole faces.
- The bars are short circuited with the help of end rings. Such an additional winding on the rotor is called damper winding.
- This winding as short circuited, acts as a squirrel cage rotor winding of an induction motor. The schematic representation of such damper winding is shown in the Fig.4.41.

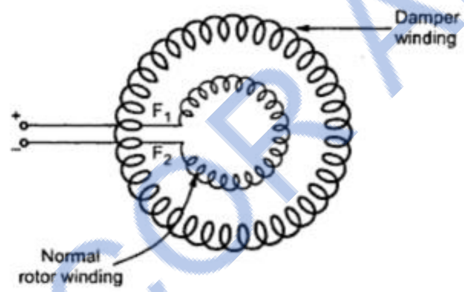


Figure 4.41 Starting as a squirrel cage I.M.

- Once the rotor is excited by a three-phase supply, the motors starts rotating as an induction motor at sub synchronous speed.
- Then d.c. supply is given to the field winding. At a particular instant motor gets pulled into synchronism and starts rotating at a synchronous speed.
- As rotor rotates at synchronous speed, the relative motion between damper winding and the rotating magnetic field is zero.
- Hence when motor is running as synchronous motor, there cannot be any induced e.m.f. in the damper winding.
- So, damper winding is active only at start, to run the motor as an induction motor at start. Afterwards it is out of the circuit.
- As damper winding is short circuited and motor gets started as induction motor, it draws high current at start so induction motor starters like star-delta, autotransformer etc. used to start the synchronous motor as an induction motor.

3. As a Slip Ring Induction Motor

- The above method of starting synchronous motor as a squirrel cage induction motor does not provide high starting torque. So, to achieve this, instead of shorting the damper winding, it is designed to a form a three-phase star or delta connected winding.
- The three ends of this winding are brought out through slip rings. An external rheostat then can be introduced in series with the rotor circuit.
- So, when stator is excited, the motor starts as a slip ring induction motor and due to resistance added in the rotor provides high starting torque.
- The resistance is then gradually cut off, as motor gathers speed. When motor attains speed near synchronous. d.c. excitation is provided to the rotor, then motors gets pulled into synchronism and starts rotating at synchronous speed.
- The damper winding is shorted by shorting the slip rings.
- The initial resistance added in the rotor not only provides high starting torque but also limits high inrush of starting current. Hence it acts as a motor resistance starter.
- The synchronous motor started by this method is called a slip ring induction motor is shown in the Fig 4.42.

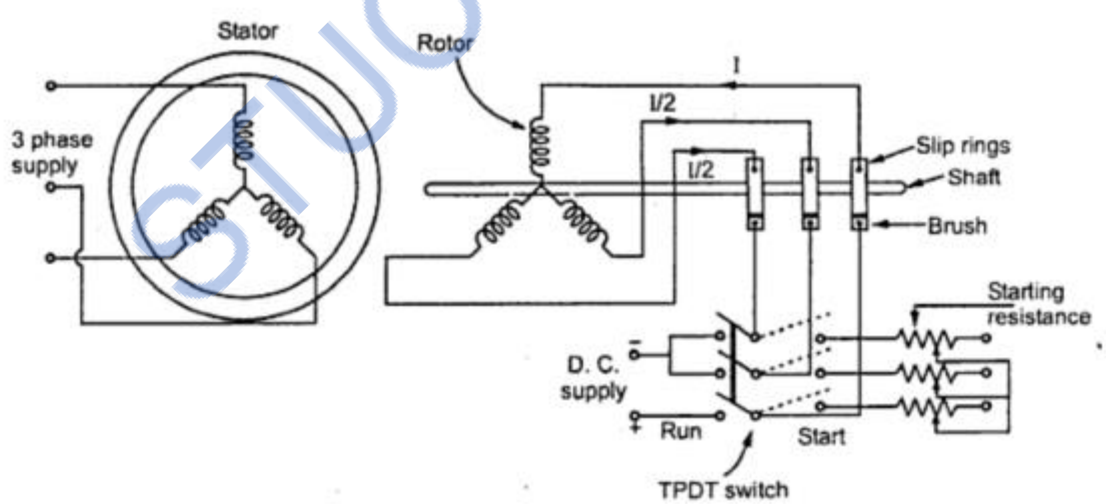


Figure 4.42 Starting as a slip ring I.M.

- It can be observed from the Fig. 4.42 that the same three phase rotor winding acts as a normal rotor winding by shorting two of the phases.
- From the positive terminal, current I flow in one of the phases, which divides into two other phases at start point as 1/2 through each, when switch is thrown on d.c. supply side.

4. Using Small D.C. Machine

- Many a times, a large synchronous motor is provided with a coupled d.c. machine. This machine is used as a d.c. motor to rotate the synchronous motor at a synchronous speed.
- Then the excitation to the rotor is provided. Once motor starts running as a synchronous motor, the same d.c. machine acts as a d.c. generator called exciter. The field of the synchronous motor is then excited by this exciter itself.

20. Explain V and inverted V curves.

- Excitation can be increased by increasing the field current passing through the field winding of synchronous motor.
- If the graph of armature current drawn by the motor (I_a) against field current (If) is plotted, then its shape looks like English alphabet letter V.
- If such graphs are obtained at various load conditions we get family of curves, all looking like V. such curves are called as V-curves of synchronous motor.

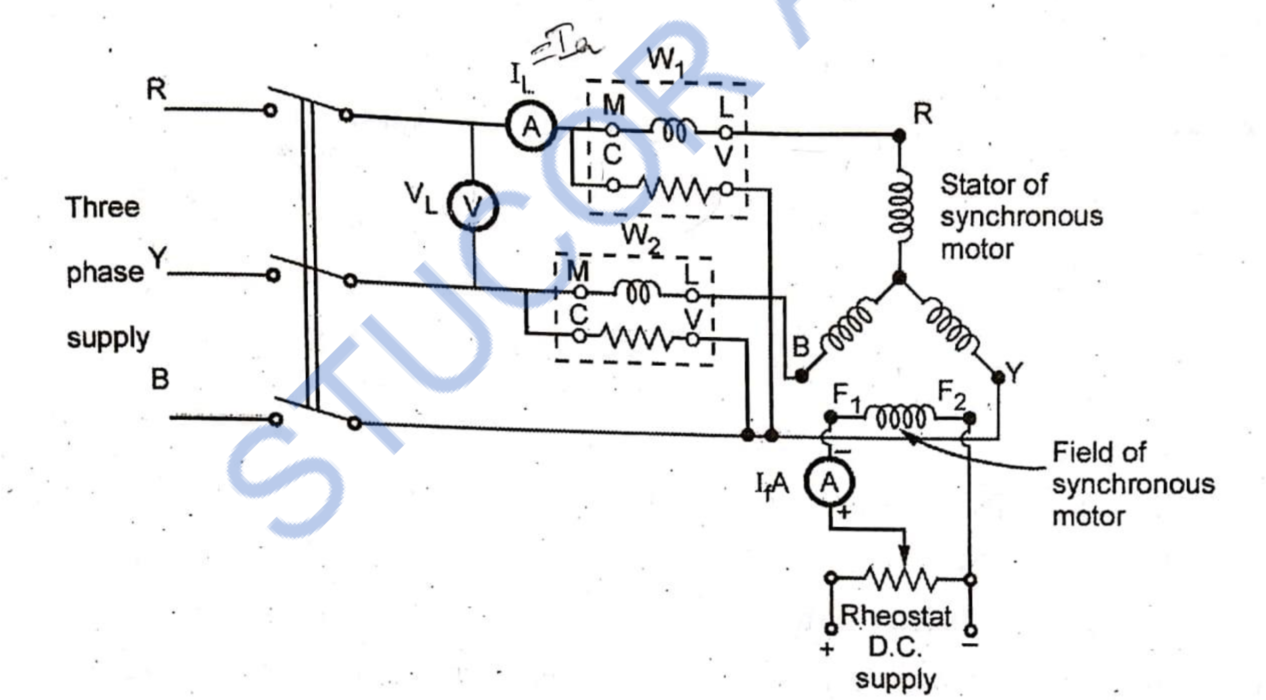


Fig 4.43 Experimental set up for V-curves

- If power factor ($\cos\varphi$) is plotted against field current (I_f), then the shape of the graph looks like an inverted V. such curves are called as inverted V-curves of synchronous motor.

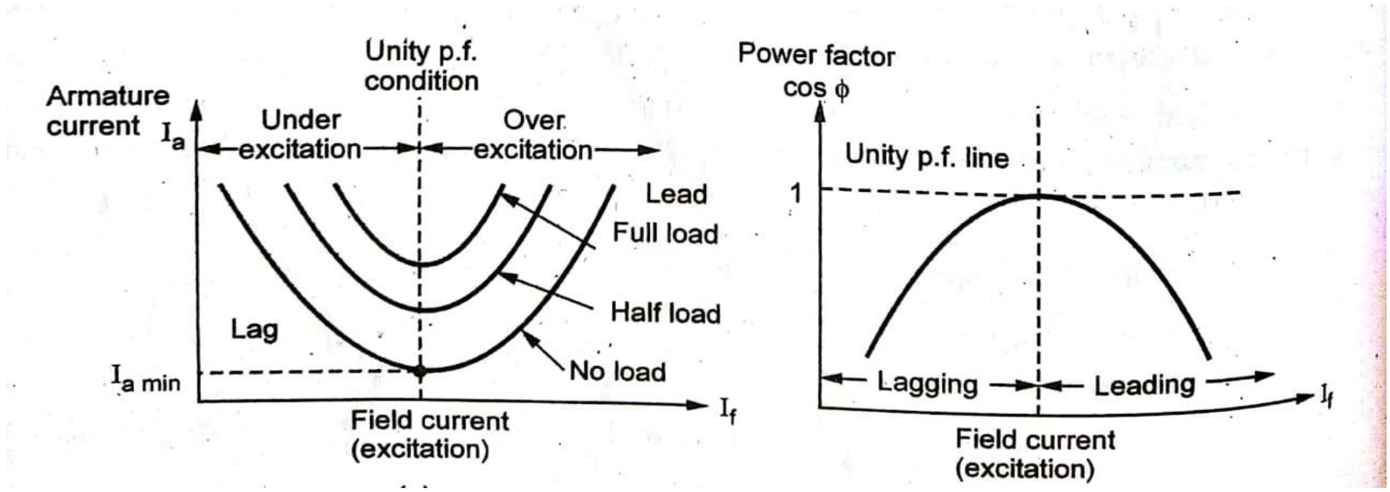


Fig 4.44 (i) V-curves (ii) inverted V-curves

Observation table:

S.No	V_L (V)	I_L (A)	W_1(W)	W_2(W)	(I_f) excitation(A)
1					
2					
3					

Now $I_L = I_a$, per phase value can be determined, from the stator winding connections.

$I_L = I_{aph}$ for star connection

$\frac{I_L}{\sqrt{3}} = I_{aph}$ for delta connection

The power factor can be obtained as

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

Result table:

S.No	I_f (A)	I_a (A)	cos ϕ (p.f)	Nature of p.f
1				
2				
3				

The graph can be plotted from this result table.

1) I_a Vs I_f ⟶ V – Curve

2) $\cos\phi$ Vs I_f → Inverted V – Curve

****

TWO MARKS

THREE PHASE INDUCTION MOTOR

1. What are the types of AC machines?

Synchronous machines:

- Synchronous Generator.
- Synchronous Motor.

Asynchronous (Induction) Machines:

- Induction motors.
- Induction generator.

2. What is an induction motor?

- It is an electric motor that works on the principle of electromagnetic induction.

3. State the principle of 3-phase induction motor.

- When starting rotor conductors are stationary and they cut the revolving magnetic field and so an emf is induced in them by electromagnetic induction.
- This induced emf produces a current if the circuit is closed.
- This current opposes the cause by Lenz's law and hence the rotor starts revolving in the same direction as that of the magnetic field.

4. What are the types of 3-phase induction motors?

Types of induction motor are:

- Squirrel cage induction motor
- Slip ring or wound rotor induction motor

5. What are the advantages of skewing of the rotor slots? (NOV/DEC 2016) (NOV/DEC 2015) (APR/MAY 2016) (APR/MAY 2011) or Why are the slots on the cage rotor of induction motor usually skewed? (NOV/DEC 2013) (NOV/DEC 2010) (APR/MAY 2017)

The rotor slots of a three-phase induction motor are skewed,

- To make the motor run quietly by reducing the magnetic hum
- To reduce the locking tendency of the rotor

6. Why the induction motor is called asynchronous motor?

Since the induction motor runs always at a speed lesser than synchronous speed, it is called asynchronous (not synchronous) motor.

7. Define Synchronous speed in a 3-phase IM? [APRIL/May-2004]

The speed at which the revolving flux rotates is called synchronous speed Ns and is given by

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

Where, f – Supply Frequency

P- Number of poles on the stator.

8. State the difference between slip ring rotor and cage rotor of an induction motor.(or) compare squirrel cage rotor and slip ring rotor.

SQUIRREL CAGE ROTOR	SLIP RING ROTOR
Low starting torque	High starting torque
Sliprings, brushes are not present	Sliprings, brushes are present
External resistance cannot be added	External resistance can be added
Minimum maintenance	High maintenance
Low cost	High cost

9. Write an expression for the slip of an induction motor. Define slip of induction motor. (NOV/DEC 2010) (NOV/DEC 2013) (NOV/DEC 2012)

Slip of an induction motor is the speed difference between synchronous speed and motor speed expressed as percentage of synchronous speed.

$$\text{Percent slip} = \frac{N_s - N_r}{N_s} \times 100$$

Where, N_s and N_r are synchronous and rotor speeds in r.p.m.

10. What is cogging of an induction motor?

When the number of stator tooth are equal or integral multiple of rotor tooth, they have a tendency to align themselves exactly to minimum reluctance position. Thus the rotor may refuse to accelerate. This phenomenon is known as cogging.

11. What does crawling of induction motor mean?

Squirrel cage motor, sometimes exhibit a tendency to run stably at speeds as low as1/7 of its synchronous speed because of the harmonics. This phenomenon is known as crawling.

12. What are the advantages of cage type motor?

- Since the rotor has very low resistance, the copper loss is low.
- Efficiency is high on account of simple construction of rotor.
- It is mechanically robust.

- Initial cost is low.
- Maintenance cost is low.
- Simple stating arrangement

13. Write the torque equation of the induction motor?

The torque developed by an induction motor is given by,

$$T = \frac{KsE_2^2R_2}{R_2^2 + (sX_2)^2} \text{ N} - \text{m}$$

Where, E_2 = rotor emf per phase at standstill

R_2 = rotor resistance per phase

X_2 = rotor reactance per phase at standstill

14. Give expression for starting torque of an induction motor.

The starting torque of an induction motor,

At standstill s =1 and hence,

$$T_{st} = \frac{KE_2^2R_2}{R_2^2 + X_2^2} \text{ N} - \text{m}$$

15. Write down the condition to get maximum torque under running condition? (APR/MAY 2016) (NOV/DEC 2015)

The rotor resistance and rotor reactance should be equal for developing maximum torque

i.e. $R_2 = sX_2$

Where s is the slip under running conditions.

R_2 and X_2 are the rotor resistance and reactance.

16. What are the advantages and disadvantages of three phase induction motor?(MAY 2018)

Advantages:

- It has simple and rugged construction.
- It is relatively cheap.
- It requires little maintenance.
- It has high efficiency and reasonably good power factor.
- It has self-starting torque.

Disadvantages:

- It is essentially a constant speed motor and its speed cannot be changed easily.
- Its starting torque is inferior to a d.c. shunt motor.

17. What are the applications of three phase induction motors?

Some of the common applications of three phase induction motor are

- Lifts
- Cranes
- Hoists
- Large capacity exhaust fans
- Driving lathe machines
- Oil extracting mills, Textiles and etc.

18. Why is a starter needed for starting a large capacity induction motor? (NOV/DEC 2016)

- If an induction motor is directly switched on from the supply, it takes 5 to 7 times its full load current and develops a torque which is only 1.5 to 2.5 times the full load torque.
- This large starting current produces a large voltage drop in the line, which may affect the operation of other devices connected to the same line.

19. What are the types of starters for three phase induction motor?(or) What are the starting methods of three phase induction motor? (NOV/DEC 2016), (NOV/DEC 2013), (NOV/DEC 2011), (APR/MAY 2011)

- DOL starter.
- Autotransformer starter.
- Star to Delta starter.
- Rotor resistance starter.

20. What is the effect of change in supply voltage on starting torque of induction motor? (NOV/DEC 2015), (APR/MAY 2017), (NOV/DEC 2010), (MAY/JUNE 2016)

Starting torque is proportional to square of the supply voltage. The change in supply voltage greatly affects the starting torque.

21. List out the methods of speed control of three phase induction motor.

Stator side control:

- Stator voltage control
- Stator frequency control
- V/f control
- Pole changing method

Rotor side control:

- Adding external resistance in the rotor circuit
- Cascade control

- Slip power recovery scheme

22. List out the methods of speed control of cage type 3 phase induction motor. (NOV/DEC 2015)

- Stator frequency control
- Pole changing method
- Cascade control

23. Mention different types of speed control of slip ring induction motor?

- Stator frequency control
- Pole changing method
- Adding external resistance in the rotor circuit
- Cascade control

24. What are the advantages of rotor resistance starter?

As these motors have external resistance connected to its rotor circuit, the value of starting current is adjusted or kept minimum, by increasing the resistance of the rotor circuit. The starting torque is also improved.

25. What is the advantage and disadvantage of auto transformer starter?

This stator can be connected to both star and delta connected three–phase motors. However, these starters are more expensive than stator resistance starter.

26. What is the advantage and disadvantage of star-delta starter?

This method is cheap and maintenance free as compared to other methods.

SINGLE PHASE INDUCTION MOTOR

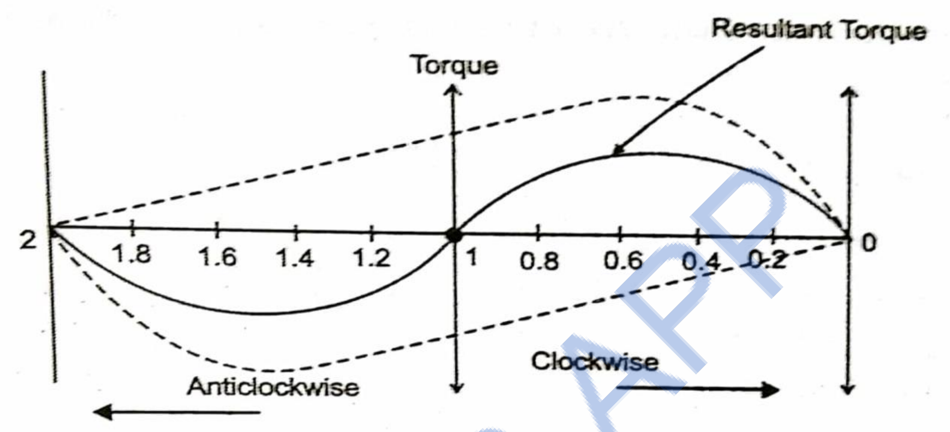
27. State the double revolving field theory. (NOV/DEC 2013), (APR/MAY 2017)

- Any alternating quantity can be resolved into two quantities which rotate in opposite directions and have half of the magnitude.
- Each of the two component fluxes while revolving around the stator cuts the rotor induces an emf and produces its own torque.

28. Why single-phase induction motor is not self-starting? Mention any one method of starting. (NOV/DEC 2015), (MAY/JUNE 2016), (APR/MAY 2011), (APR/MAY 2017)

- A single-phase supply produces alternating torque, not a rotating torque. That is why a single-phase motor is not self-starting.
- The motor can be made self-starting by splitting the current into two components - split phase induction motor.

29. Draw the torque-slip characteristics of single phase induction motors.[APRIL/May-2013]



30. Why an induction motor is called as rotating transformer?

The rotor receives same electrical power in exactly the same way as the secondary of a two winding transformer receiving its power from primary. That is why induction motor is called as rotating transformer.

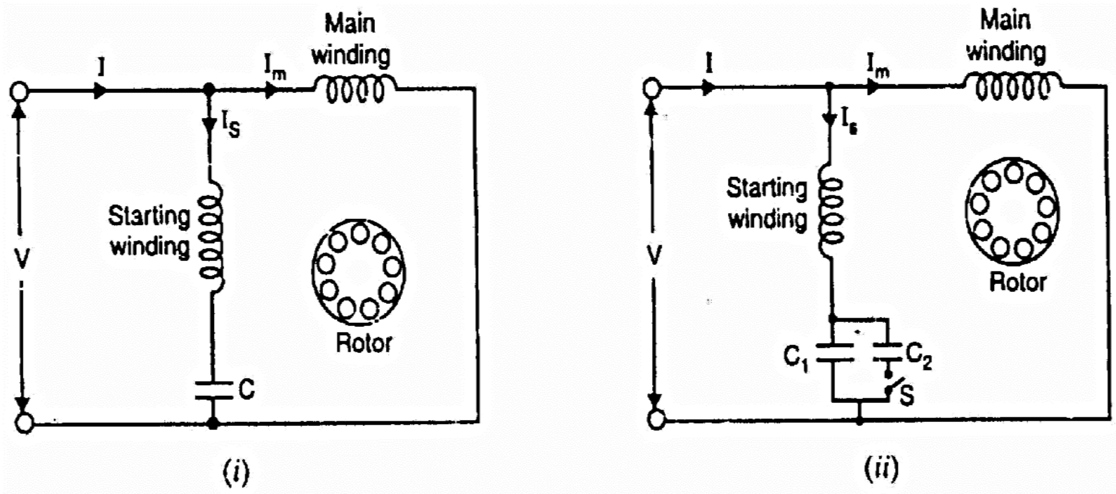
31. Name the methods of starting single induction motors. (NOV/GEC 2012)

- Split phase induction motor.
- Capacitor start induction run motor.
- Capacitor start capacitor run induction motor (two value capacitor method).
- Shaded pole induction motor.

32. Name the motor being used in ceiling fans. (MAY/JUNE 2016), (MAY/JUNE 2014), (NOV/DEC 2011)

Capacitor start and run induction motors are used in ceiling fans.

33. Draw the basic circuit of capacitor start capacitor run induction motor.(MAY 2018)



34. List the applications of single phase induction motors? (APR/MAY 2011)

Some of the common applications of single phase induction motor are

- Motor of refrigerator
- Water pump motor
- Cooler motor
- Drilling machines
- Small fans
- Used in small toys, hair dryers, ventilators, clock etc.

35. What are the advantages of retaining the capacitor in the circuit?

- It improves the running torque.
- It improves the overall power factor of the motor.

36. Mention the applications of split phase induction motor.

- Fans,
- Blowers,
- Centrifugal pumps,
- Washing machine,
- Grinder,
- Lathes,
- Air conditioning fans, etc.

37. List out the applications of capacitor start capacitor run induction motor.

- Conveyors,
- Grinder,
- Air conditioners,
- Compressor, etc.

38. State the application of shaded pole motor.

- Hair dryers,
- Toys,
- Record players,
- Small fans,
- Electric clocks etc.

39. State the limitations of shaded pole motors. [APRIL/MAY-2015]

- Starting torque is poor
- Power factor is very low.
- Due to copper losses in the shading ring the efficiency is very low.
- Speed reversal is very difficult
- Size and power rating is very small.

THREE PHASE ALTERNATOR

40. What is an synchronous generator?

An alternator or AC generator is a synchronous machine which converts mechanical energy into electrical energy and producing alternating emf.

41. What is principle of alternator (or) synchronous generator?

The alternator works on the principle of Faradays law of electromagnetic induction. whenever a conductor links with a magnetic field either the conductor is moving or the field is moving ,an emf is induced in the conductor.

42. Why a 3-phase synchronous motor will always run at synchronous speed?

Because of the magnetic coupling between the stator poles and rotor poles the motor runs exactly at synchronous speed.

43. Write down the equation for frequency of emf induced in an alternator.

frequency $f = \frac{PN_s}{120}$ Hz

Where, $P =$ No of poles

$N_s =$ Synchronous speed in r.p.m.

44. What are the two types of synchronous machines? (OR) What are the types of rotor in alternator

The classification synchronous machines are:

- Salient pole or projecting pole rotor type
- Non-salient pole or Cylindrical rotor type

45. Why the stator core is laminated? (APR/MAY 2011)

Stator core is laminated to reduce the eddy currents loss.

46. How can you distinguish between the two types of large synchronous generator from their appearance?

S.NO	Salient Pole Type	Smooth Cylindrical Type
1	Poles are projecting out from the surface	Poles are non-projecting
2	Air gap is non-uniform	Air gap is uniform
3	Large diameter and small axial length	Small diameter and large axial length
4	Mechanically weak	Mechanically strong
5	Preferred for low speed alternator	Preferred for high speed alternator

47. What are the advantages of salient pole type of construction used for synchronous machines?

- They allow better ventilation.
- The pole faces are so shaped radial air gap length increases from the pole center to the pole tips so that flux distribution in the air gap is sinusoidal in shape which will help to generate sinusoidal emf.
- Due the variable reluctance, the machine develops additional reluctance power, which is independent of excitation.

48. Write the emf equation of the synchronous generator (OR) alternator.

Emf per phase $E_{ph} = 4.44 f \phi T_{ph} K_p K_d$

Where, f = frequency of supply in Hz,

ϕ = flux per pole in wb,

T_{ph} = turns per phase,

K_p = Pitch factor,

K_d = distribution factor.

49. Define voltage regulation.

The percentage regulation is defined as the ratio of change in terminal voltage from full load to no load terminal voltage.

$$\% \text{ Regulation} = \frac{E_0 - V}{V} * 100$$

E_0 – no load terminal voltage

V – full load rated terminal voltage

50. Why EMF method is called Pessimistic method? [APRIL/MAY-2011]

The value of voltage regulation obtained by EMF method is always more than the actual value, therefore it is called Pessimistic method.

51. Why MMF method is called Optimistic method?

The value of voltage regulation obtained by MMF method is less than the actual value, therefore it is called Optimistic method.

SYNCHRONOUS MOTOR

52. What is a synchronous motor?

A synchronous electric motor is an AC motor which, at steady state, the rotation of the shaft is synchronized with the frequency of the supply current; the rotation period is exactly equal to an integral number of cycles.

53. What are the advantages of synchronous motor?[APRIL/MAY 2011]

- The speed is constant and independent of load.
- These motor usually operate at higher efficiencies.
- Electromagnetic power varies linearly with the voltages.

54. What are the disadvantages of synchronous motor?

- Higher cost.
- Necessity of a DC excitation source.
- Greater initial cost
- High maintenance cost.

55. Give the torque equation of a synchronous motor.

The torque developed by the motor is,

$$T = \frac{9.55P_m}{N_s} \quad N-m$$

Where, P_m=Mechanical power developed

N_s=Synchronous speed in r.p.m.

56. What is V curve?

- If the graph of armature current drawn by the motor (I_a) against field current (If) is plotted, then its shape looks like English alphabet letter V.
- If such graphs are obtained at various load conditions we get family of curves, all looking like V. such curves are called as V-curves of synchronous motor.

57. What is an inverted V curve?

- If power factor ($\cos\varphi$) is plotted against field current (I_f), then the shape of the graph looks like an inverted V. such curves are called as inverted V-curves of synchronous motor.

58. What are the starting methods of synchronous motor?

The various methods to start the synchronous motor are,

- Using pony motors
- Using damper winding
- As a slip ring induction motor
- Using small d.c. machine coupled to it.

59. What are the various functions of damper winding provided with synchronous motor? (NOV/DEC 2016) (NOV/DEC 2013)

It serves two purposes,

- It provides starting torque in motoring mode
- It provides damping torque in motoring mode

60. Write the applications of synchronous motor.

- Used for power factor improvement in sub-stations and in industries.
- Used in industries for power applications.
- Used for constant speed drives such as motor-generator set, pumps and compressors.

61. List the inherent disadvantages of synchronous motor. (MAY/JUNE 2016) (NOV/DEC 2010)

- Requires d.c. excitation at the rotor
- No self-starting torque.
- Construction is complicated

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UNIT-IV

MEASUREMENTS AND INSTRUMENTATION

Functional elements of an instrument, Standards and calibration, Operating Principle, types Moving Coil and Moving Iron meters, Measurement of three phase power, Energy Meter, Instrument Transformers-CT and PT, DSO- Block diagram- Data acquisition.

MEASUREMENT:

A measurement of any quantity either physical or electrical gives meaning when it is compared with predefined standard quantity.

The basic requirements of the measurement:

- The standard used for comparison purposes must be accurately defined and should be commonly accepted.
- The apparatus used and the method must be provable.

The two methods of measurement are:

- Direct method
- Indirect method

Direct method of measurement:

The unknown quantity which is known as measurand is directly compared against a standard. The result is expressed as a numerical number and unit.

Indirect method of measurement:

The unknown quantity is converted into some other form and then it is compared against a standard.

The types of measurement are:

- Primary measurement
- Secondary measurement
- Tertiary measurement

Primary measurements:

Primary measurements are direct method of measurements without involving conversion of the measured quantity. E.g.: measurement of length of a bar using scale.

Secondary measurements:

Secondary measurements are the indirect method of measurements which involve one conversion of the quantity to be measured. Eg: Measurement of pressure of manometers.

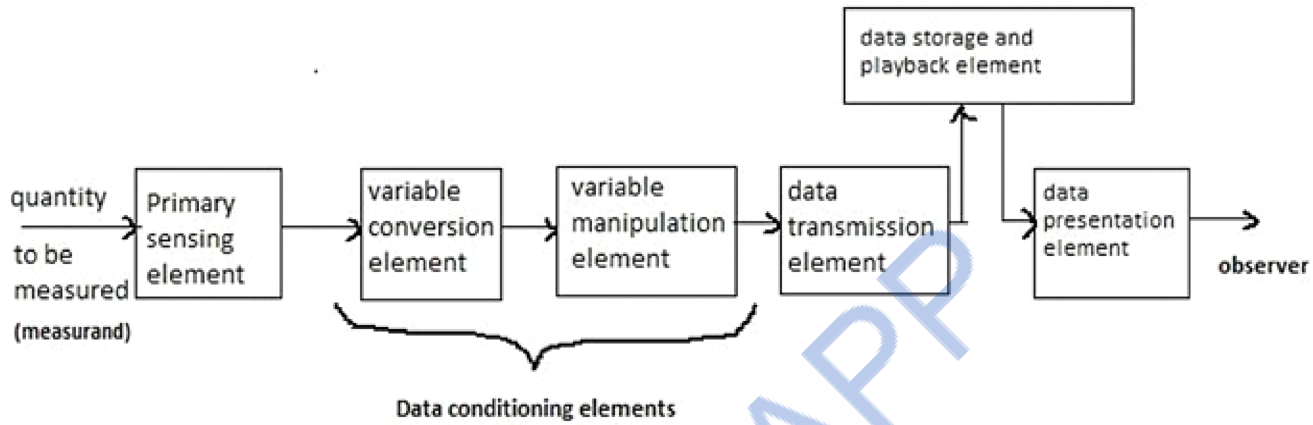
Tertiary measurements:

Tertiary measurements are the indirect method of measurements which involve two conversions of the quantity to be measured.

First conversion **Second conversion**

1. Explain the functional elements of an instrument with a neat block diagram. (May/June 2014) (or) Draw and explain the general block diagram of measurement system with an example.

Functional elements of an Instrument



Primary sensing element:

- The measurement first comes into contact with primary sensing element where the conversion takes place.
- This is first done by a transducer which converts the measurement or measured quantity into usable electrical output.
- The transduction may be from mechanical, electrical or optical to any related form.

Variable conversion element:

- The output of the primary sensing element is in the electrical form suitable for control, recording and display.
- For the instrument to perform the desired function, itis necessary to convert this output to some other suitable output for preserving the original information.

Variable manipulation element:

- The signal gets manipulated here preserving the original nature of it.
- Example: - an amplifier accepts a small voltage signal as input and produces a voltage of greater magnitude.
- The output is same voltage but of higher value, acting as a voltage amplifier.
- Here the output voltage amplifier acts as a variable manipulation element since it amplifies the voltage.
- The element that follows the primary sensing element in a measurement system is called signal conditioning element.

- Here the variable conversion element and variable manipulation element are collectively called as data conditioning element.

Data transmission element:

- The transmission of data from one another is done by the data transmission element.
- In case of space crafts the control signals are sent from the control stations by using radio signals.
- The stage that follows the signal conditioning element and data transmission element collectively is called the intermediate stage.

Data presentation element:

- The display or readout devices which display the required information about the measurement, forms the data presentation element.
- The information of the measurand has to be conveyed for monitoring, control process.

✓In case of data to be monitored, visual display devices are needed like ammeters, voltmeters.

✓In case of data to be recorded, recorders like magnetic tapes, TV equipment and storage type CRT, printers are used.

- The final stage in a measurement system is known as terminating stage.
- When a control device is used for the final measurement stage, it is necessary to apply some feedback to the input signal to accomplish the control objective.

Example: Bourdon tube pressure gauge

- Due to pressure, closed end of tube is displaced. Pressure is converted to displacement.
- The closed end is linked to mechanical linkage to a gearing arrangement.
- The gearing arrangement amplifies the small displacement and makes the pointer to rotate through a large angle.

2. Discuss the static and dynamic characteristics of measuring instrument.(MAY 2018) (13 marks)

<u>STATIC CHARACTERISTICS:</u>

- The static characteristics of an instrument are, in general, considered for instruments which are used to measure an unvarying process condition.
- All the static performance characteristics are obtained by one form or another of a process called calibration.
- Desirable static characteristics are:

i. Accuracy

ii. Reproducibility

iii. Sensitivity

iv. Linearity

- Undesirable static characteristics are:

i. Drift

ii. Dead zone

iii. Static error

iv. Hysteresis

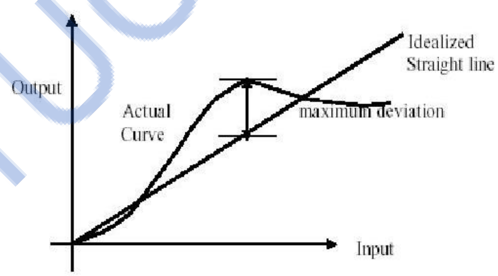
Accuracy:

- It is the degree of closeness of a measurement compared to true value.
- The accuracy of any instrument system is measured in terms of its error.
- It is the ability of instrument to indicate true value. It is calibration against a standard.

Static sensitivity:

- Static sensitivity is defined as the ratio of the magnitude of the output signal to the magnitude of input signal to be measured.
- Low sensitivity meter produces more loading effect.
- Meter with high sensitivity will give more reliable result. Eg: Milli-ammeter, Galvanometer.

Linearity:



$$\% \text{ non-linearity} = \frac{\text{Max. deviation of output from idealized straight line}}{\text{Full scale reading}}$$

Fig 4.1

- The ability to produce the input characteristics symmetrically is known as Linearity.
- It can be expressed as straight line.
- It is a measure of maximum deviation of any one of the calibration points from straight line which is drawn by using the method of least square from the given calibration data.
- Any departure from straight line relationship is known as non-linearity.

Reproducibility:

- It is defined as the degree of closeness with which a given value may be repeatedly measured.

- It is specified in terms of scale readings over a given period of time.
- Perfect reproducibility means that the instrument has no drift.

Drift:

- It is defined as for a given input, the measured values do not vary with time.

Factors that cause the drift are:

- Mechanical vibrations
- High mechanical stress
- Wear and tear
- Stray electric and magnetic fields

Drift may be classified as

- Zero drift
- Span drift
- Zonal drift

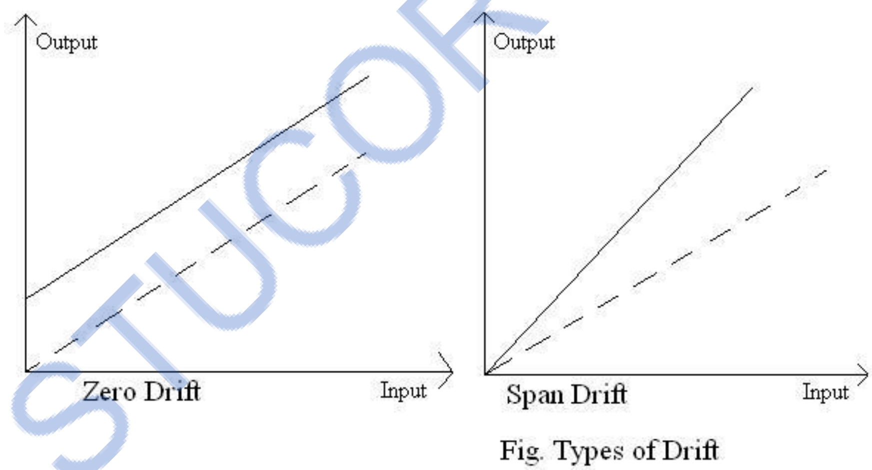


Fig 4.2 types of drift

Zero drift:

The whole instrument calibration may gradually shifts due to slippage or due to undue warming up of electronic tube circuits; the drift is called zero drift.

Span drift:

There is a proportional change in the indication all along the upward scale; the drift is called as span drift.

Zonal drift:

The drift occurs over a span of an instrument, it is called as zonal drift.

Precision:

A measure of the consistency or repeatability of measurements, i.e. successive readings does not differ. (Precision is the consistency of the instrument output for a given value of input).

Expected value:

The design value, i.e. the most probable value that calculations indicate one should expect to measure.

Error:

The deviation of the true value from the desired value.

Dead zone:

It is defined as the largest change of input quantity for which there is no output of the instrument. The dead zone occurs due to friction, backlash and hysteresis in the instrument.

Backlash:

It is defined as the maximum distance through which a part of a mechanical system can be moved in one direction without applying appreciable force or motion to the next part in a mechanical system.

Threshold:

It is defined as the minimum value of the input at which the output starts changing / increasing from zero.

Resolution:

It is the smallest change in measured value to which the instrument will respond.

Signal to noise ratio:

It is defined as the ratio of desired signal to the unwanted noise is called signal to noise ratio.

The noise can be broadly classified as:

i. Generated noise: The possible sources of noise are an account of internal components of the amplifier like resistors, capacitors and transistors.
ii. Conducted noise: The power supply to the amplifier is the source of this noise. It may be caused due to spikes, ripples or random deviations which are presented in the amplifier circuit through power wiring.
iii. Radiated noise: The unwanted signals may be electric or magnetic fields on the environment around the amplifier which are radiated into the interior of the amplifier.

DYNAMIC CHARACTERISTICS:

- Instruments rarely respond to changes in the measured variables.

- The dynamic behavior of an instrument is determined by subjecting its primary element (sensing element) to some unknown and predetermined variations in the measured quantity.
- **The three most common variations in the measured quantity are as follows:**

✓ Step change: In this case the input is changed suddenly to a finite value and then remains constant.

✓ Linear change: In this case the input changes linearly with time.

✓ Sinusoidal change: In this case the magnitude of the input changes in accordance with a sinusoidal function of constant amplitude.

The dynamic characteristics of an instrument are:

Speed of Response:

It is the rapidity with which an instrument responds to changes in the input.

Lag:

✓ It is the retardation or delay in the response of an instrument to changes in the input.

✓ The measuring lag can be of two types

Retardation type: The response of the instrument begins immediately after a change in input.

Time delay type: here response begins after a dead time. This causes dynamic error.

Fidelity:

- It is the degree to which an instrument indicates the changes in the measured variable without dynamic error (faithful reproduction).

Dynamic Error:

- It is the difference between the true values of a quantity changing with time and the value indicated by the instrument, if no static error is assumed.

3. What are the different types of errors? Explain how to eliminate errors in instrument. May 2014 (10m) May 2016, 2017 (16m)

The static error of a measuring instrument is the numerical difference between the true value of a quantity and its value as obtained by measurement, i.e. repeated measurement of the same quantity give different indications.

- Static errors are categorized as Gross errors, Systematic errors and Random errors.

Gross Errors:

- This error is mainly due to human mistakes in reading or in using instruments or errors in recording observations.
- Errors may also be occurring due to incorrect adjustments and computational mistakes.

- The complete elimination of gross errors is not possible.
- The error can be minimized by taking proper care in reading and recording the measurement parameter.

Systematic Errors:

- These errors occur due to defective or worn parts or ageing effects of the environment on the instrument.
- There are basically three types of systematic errors,

  i. Instrumental Error

  ii. Environmental Error

  iii. Observational Error

(i) Instrumental Errors:

- These are inherent in measuring instruments, because of their mechanical structure.
- Instrumental errors can be avoided by

a) Selecting a suitable instrument for the particular measurement applications.

b) By applying correction factors after determining the amount of instrumental error.

c) Calibrating the instrument against a standard.

(ii) Environmental Errors:

- Environmental errors are due to conditions external to the measuring device.
- Such as the effects of change in temperature, humidity, barometric pressure or of magnetic or electrostatic fields.
- These errors can be avoided by

(i) air conditioning,

(ii) hermetically sealing certain components in the instruments

(iii) using magnetic shields.

(iii) Observational Errors:

- Observational errors are introduced by the observer.
- The most common error is the parallax error introduced in reading a meter scale, and the error of estimation when obtaining a reading from a meter scale.
- For example, an observer may always introduce an error by consistently holding his head too far to the left while reading a needle and scale reading.

(iv) Random errors:

- After calculating all systematic errors, it is found that there are still some errors in measurement are left.
- These errors are known as random errors.

- Some of the reasons of the appearance of these errors are known but still some reasons are unknown.
- Hence, we cannot fully eliminate these kinds of errors.

Sources of Errors:

- Noise
- Design limitations
- Weakening of measuring system.

Limiting Error:

- The accuracy and precision of an instrument depends upon its design, material used and workmanship. The choice depends upon accuracy.
- The manufacturer has to specify the deviations from the nominal value of a particular quantity.
- The limits of these deviations from specified value are defined as Limiting errors.
- Relative limiting error $\varepsilon_r = \frac{\delta A}{A_s} = \frac{\varepsilon_o}{A_s}$
- **Absolute error** is the difference between true value and measured value of a company.

$e = R_O - R_T$

Where, e is Absolute error

R_O is the Observed reading

R_T is the true reading

- **Relative error** is defined as the ratio of the error to the specified magnitude of a quantity.

$$\varepsilon_r = \frac{A_a - A_s}{A_s}$$

Where, ε_r is the Relative limiting error.

4. Discuss the different types of standards of measurements. Nov 2010, Apr 2015 (8m)

A standard is defined as the physical representation of a unit of measurements.

CLASSIFICATION OF STANDARDS:

- International standards
- Primary standards
- Secondary standards
- Working standards

International standards of instruments:

International standards are defined on the basis of International agreement. They are regularly evaluated and checked by absolute measurements in terms of fundamental units. The standardized units are:

1) International ohm.
2) International amperes.

Primary standards:

- They are maintained at National standards laboratories in different countries.
- The function of primary standards is the calibration and verification of secondary standards.
- The standardized units are:

✓ Quite stable.
✓ Independent.
✓ Invariant.

- The following points are considered in primary standards:

✓ Accuracy of machining.
✓ Rigidity of construction.
✓ Low temp Coefficient.

Secondary standards:

- They are basic reference standards used by measurement and calibration laboratories in industries.
- Each laboratory sends its secondary standards to national standard laboratory standard for calibration and compare with primary standards.
- Then the secondary standards are sent back to the industrial user by the national laboratories with a certification as regards their measured value in terms of primary standards.

Working standards:

- These standards are used to check and calibrate laboratory instrument for accuracy and performance.

5. Give an introduction about measuring instruments.

Electrical instruments may be divided into two categories, which are,

i. Absolute instruments
ii. Secondary instruments

Absolute instruments: These give the quantity to be measured in terms of instrument constant and its deflection.

Secondary instruments: The deflection gives the magnitude of electrical quantity to be measured directly. These instruments are required to be calibrated by comparing with another standard instrument before putting into use.

The three types of secondary instruments are:

i. Indicating instruments
ii. Recording instruments
iii. Integrating instruments

Indicating instruments:

It indicates the magnitude of an electrical quantity at the time when it is being measured. The indications are given by a pointer which moves over a graduated scale.

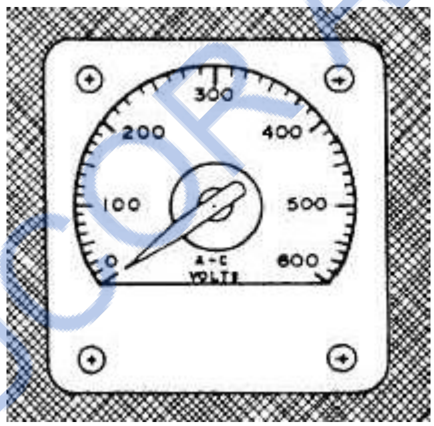


Figure 4.3 Indicating instruments

Recording instruments:

These instruments keep a continuous record of the variations of the magnitude of an electrical quantity to be observed over a defined period of time.

Integrating instruments:

These instruments which measure the total amount of either quantity of electricity or electrical energy supplied over a period of time. Example: energy meters.

ESSENTIALS OF INDICATING INSTRUMENTS:

- Indicating instruments are those which indicate the value of quantity that is being measured at the time at which it is measured.
- Such instruments consist essentially of a pointer which moves over a calibrated scale and which is attached to a moving system pivoted in bearing.
- The moving system is subjected to the following three torques:

- ✓ A deflecting (or operating) torque.
- ✓ A controlling (or restoring) torque.
- ✓ A damping torque.

SPRING CONTROL:

- When the pointer is deflected one spring unwinds itself while the other is twisted.
- This twist in the spring produces restoring (controlling) torque, which is proportional to the angle of deflection of the moving systems.

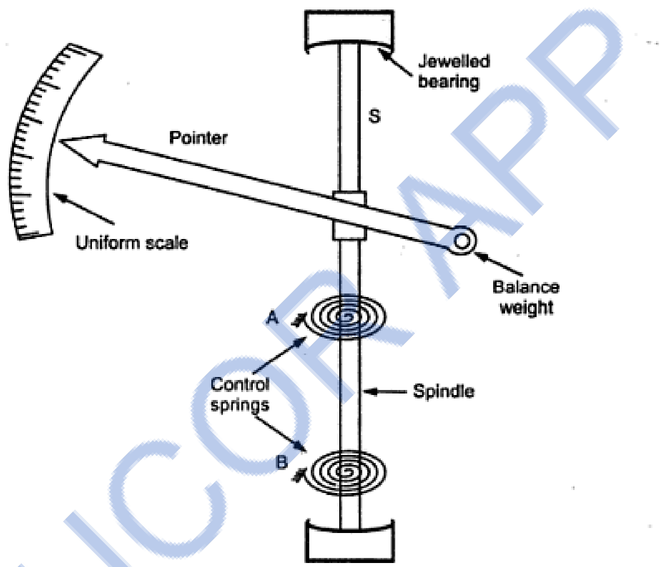


Figure 4.4: Spring control

GRAVITY CONTROL:

- In gravity controlled instruments, a small adjustable weight is attached to the spindle of the moving system such that the deflecting torque produced by the instrument has to act against the action of gravity.
- Thus a controlling torque is obtained.
- This weight is called the control weight.
- Another adjustable weight is also attached in the moving system for zero adjustment and balancing purpose. This weight is called balance weight.

$$T_c = \omega sin\theta \times l$$

$$= \omega l sin\theta$$

$$T_c = K_g \ sin\theta$$

Where, K_g is a constant.

T_c is the controlling torque

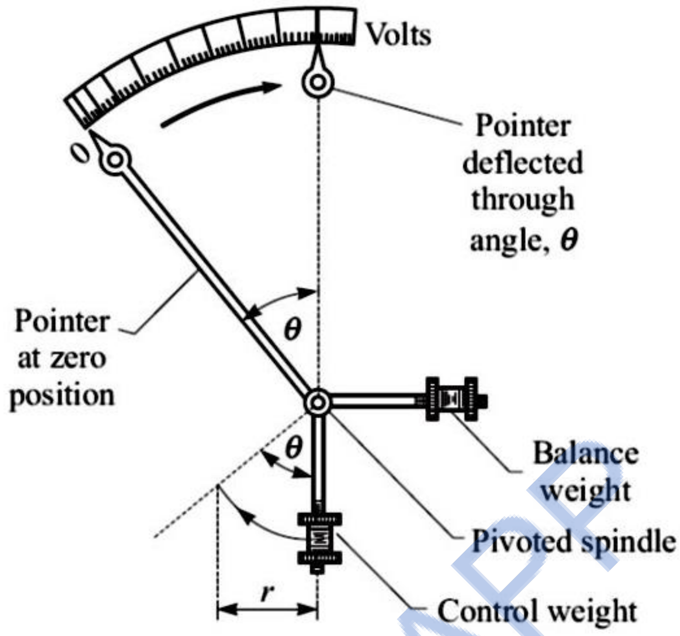


Figure 4.5: Gravity control

DAMPING TORQUE:

- Due to inertia, pointer moves from point 'a' to point 'b'.
- This action produces oscillations and pointer will take some amount of time for settling.
- To damp or to make these oscillations disappear some force or torque is required, this torque is called damping torque.
- This damping torque is produced by any one of the four damping system.

Air friction damping:

✓ Aluminum piston attached to the spindle moves over the air chamber produces damping by air friction.

Fluid friction damping:

✓ In this type oil is used instead of air because viscosity of oil is greater.

✓ A disc attached to the moving system is dipped into the oil pot.

✓ The disc moves in the oil and produces friction drag.

✓ This produces damping.

Eddy current damping:

✓ A conductor is attached to the moving system and made to move in the magnetic field produced by a permanent magnet.

✓ The conductor is aluminium circular disc.

- ✓ When the moving system oscillates, the disc moves and cuts the magnetic flux.
- ✓ An emf is induced in the disc, since the disc has several closed path, a current flows. This current is called eddy current.
- ✓ This eddy current interacts with the magnetic field, produces a torque which opposes the spindle motion.
- ✓ This type of damping is called eddy current damping.

Electromagnetic damping:

- ✓ The deflecting system makes the coil to move in a magnetic field, produces a torque which produces the current in the coil.
- ✓ By lenz law, this current produces a torque which opposes the movement of the coil, and damps the oscillations of the moving system.
- ✓ This is called electromagnetic damping.

6. Explain the working of permanent magnet moving coil.

- The principle operation of PMMC is based upon the principle of "current carrying conductor is placed in a magnetic field it is acted upon by the force which tends to move it."

Construction:

- A coil of thin wire is mounted on an aluminium spindle positioned between the poles of a U shaped permanent magnet which is made up of magnetic alloys like alnico.

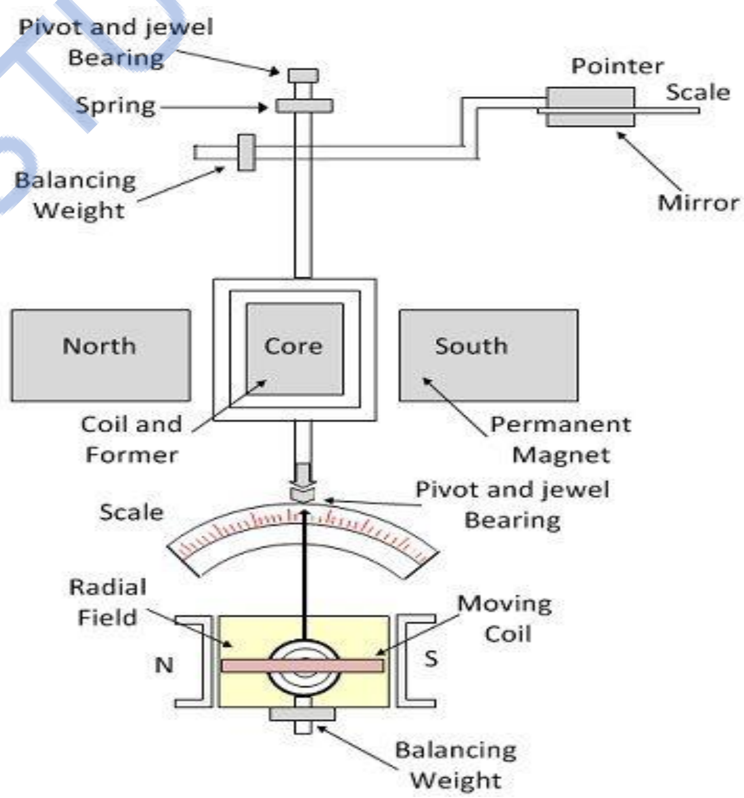


Figure 4.6: PMMC

- The coil is pivoted on the jewel bearings and thus the coil is free to rotate.

Operation:

- When a current flows through the coil, it generates a magnetic field which is proportional to the current in case of an ammeter.
- The deflecting torque is produced by the electromagnetic action of the current in the coil and the magnetic field.
- The controlling torque is provided by two phosphor bronze hair springs.
- Damping is caused by the current set up in the aluminium coil which prevents the oscillation of the coil.

Torque equation

$$deflecting\ torque, T_d = NBAI$$

Where, T_d= deflecting torque in N-m

N= number of turns of coil.

A= effective area of the coil in m^2

I = current passing through the moving coil in A.

B= flux density in air gap in Wb/m^2.

Let G=NBA= constant

Now T_d= GI

- Controlling torque is provided by the spring and is proportional to the angular deflection of the pointer.

$$T_c \propto \theta$$

$$\therefore T_c = K_s\theta$$

Where,

T_c= controlling torque in N-m

K_S= spring constant in Nm/rad or Nm/deg.

θ = angular deflection in rad or degree.

- For the final steady deflection i.e at equilibrium:

$T_c = T_d$

$K_s\ \theta = GI$

$$\theta = \left(\frac{G}{K_s}\right)I$$

- $I \propto \theta$ (deflection of the pointer is directly proportional to the current)

Errors in PMMC instruments:

- Weakening of permanent magnet due to ageing and temperature effects.

- Weakening of the springs due to ageing and temperature effects.
- Change of resistance of moving coil with temperature.

Advantages:

- Power consumption is less.
- High accuracy.
- Scale is uniformly divided.

Disadvantages:

- Only used for DC measurements.
- Torque reverses if current reverses.
- Cost is high.

7. With neat sketch, explain the construction and operation of repulsion type moving iron instrument. Give advantages and limitations of such instruments.(April/May 2016)

- Moving iron instruments are used for both AC and DC measurements.
- It has two types: attraction type and repulsion type.
- It consists of a stationary coil which is excited by the current or voltage under measurement.
- It also consists of a plate of soft iron in case of attraction type.
- In case of repulsion type two plates are present.
- The plate or the vane forms the moving element of the instrument and moves in a magnetic field produced by the stationary coil.

Principle:

- Supply is given to the stationary coil it becomes electromagnet.
- Vane moves to increase the flux of the electromagnet because the vane tries to follow a path of minimum reluctance.

$$\therefore inductance \propto \frac{1}{reluctance}$$

- Thus a force is developed for getting high inductance.
- This force gives the deflecting torque.

i. Attraction type MI instruments:

- The flat stationary coil forms the narrow slot like opening.
- Moving element is a flat disc or plate.
- When the current flows through the coil, magnetic field is produced.
- Moving iron moves from weaker field to stronger field side.

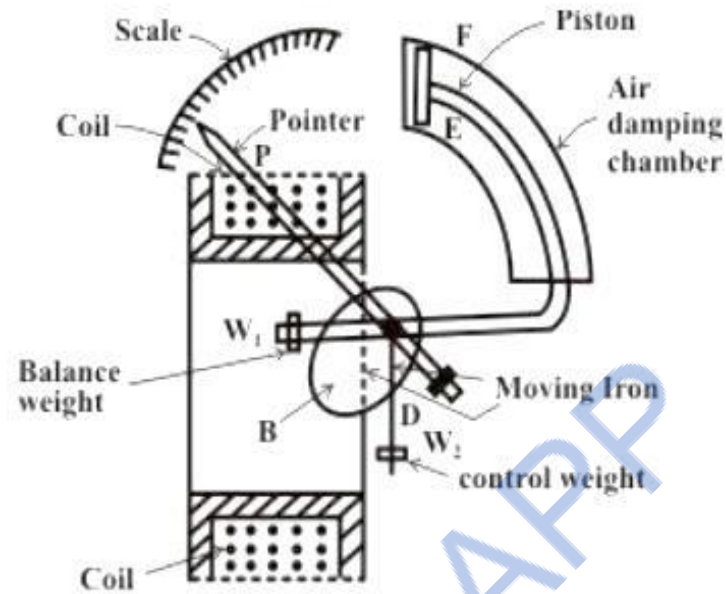


Figure 4.7: Attraction type MI instrument

- For control torque this instrument uses spring.
- Damping is provided by air friction damping.

ii. **Repulsion type MI instrument:**

- Two vanes are present inside the stationary coil, one vane is fixed and another vane is movable.

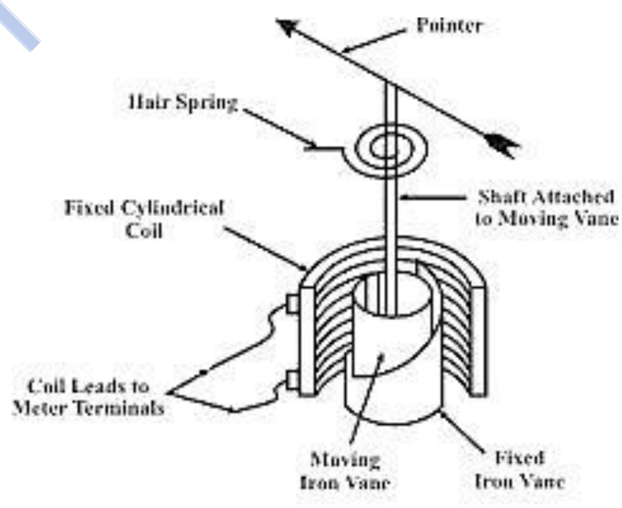


Figure 4.8: Repulsion type MI instrument

- Both vanes are similarly magnetized when the current flows through the stationary coil therefore repulsion occurs.
- This type is divided into two types:

- ✓ Radial vane type- vanes are radial strips of iron
- ✓ Co-axial vane type- vanes are sections of co-axial cylinders.

Torque equation:

- Normally current flows through the coil.
- Now a small increment in current is supplied to the coil, it results in a small increment in deflection.

$$mechanical\ work\ done = T_d.d\theta .... (1)$$

$$e = \frac{d}{dt}(LI)$$

$$e = I\frac{dL}{dt} + L\frac{dI}{dt} ..... (2)$$

- Electrical energy supplied is given by, multiply I.dt on both the sides of the equation (2),

$$eIdt = I^2\frac{dL}{dt}dt + LI\frac{dI}{dt}.dt$$

$$eIdt = I^2dL + LIdI \qquad .....(3)$$

- Stored energy changes from

$$\frac{1}{2}I^2L\ to\ \frac{1}{2}(I + dI)^2(L + dL)$$

- Therefore change in stored energy is

$$\frac{1}{2}(I^2 + 2IdI + dI^2)(L + dL) - \frac{1}{2}I^2L$$

- Neglecting second and higher order terms,

$$ILdI + \frac{1}{2}I^2dL \qquad ....(4)$$

- by the principle of conservation of energy,

  Electrical energy supplied= increase in stored energy +mechanical work done
- from equation (3), (4) and (1),

$$dL + ILdI = ILdI + \frac{1}{2}I^2dL + T_d.d\theta$$

$$T_d.d\theta = I^2dL - \frac{1}{2}I^2dL$$

$$T_d . d\theta = \frac{1}{2} I^2 dL$$

$$T_d = \frac{1}{2} I^2 \frac{dL}{d\theta} \quad .....(5)$$

- control torque is provided by the spring

$$\therefore T_c = K\theta \quad ......(6)$$

- For final steady deflection, $T_c = T_d$
- From equation (5) and (6),

$$K\theta = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

$$\theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta}$$

8. With a neat diagram explain the construction and working principle of 1f wattmeter. What is the importance of deflection torque in these instruments? (April/May 2010)

(or)

With a neat diagram, explain the construction and working principle of electrodynamometer type wattmeter. Also derive its torque equation. (Nov/Dec 2010) (April/May 2019) (Dec 2020)

- Single phase power can be easily measured using a 1 f wattmeter. Various types of 1 phase wattmeter are:
  - Electrodynamometer wattmeter
  - Ferro dynamic
  - Thermocouple
  - Low power factor.

Constructional details:

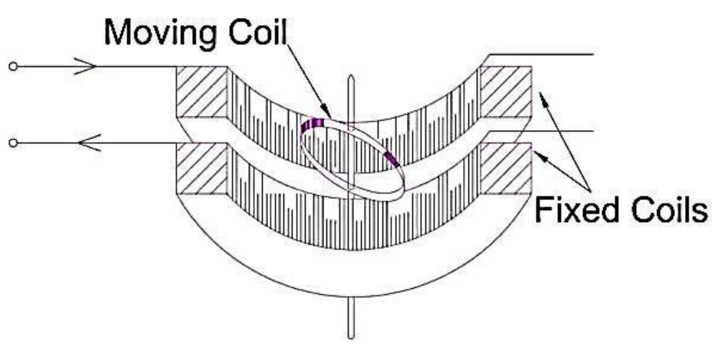


Fig 4.9 Electrodynamometer wattmeter

Fixed coil:

- Fixed coils are wound with heavy wire with less number of turns in order to have low resistance and hence low voltage drop across the meter.
- It is also called as current coil which is connected in series with the load and properly laminated in order to avoid eddy current loss in conductor when heavy current flows.

Moving coil:

- It is generally attached to the spindle which is connected to the pointer. The moving coil is also called as pressure coil.
- It is made up of thin wire and has more number of turns in order to have high resistance.

Control torque:

- It is provided by springs.

Damping:

- Air friction damping is used.

Pointer and scale:

- Mirror type scale and knife edge pointer to avoid parallax error while reading.

Torque equation:

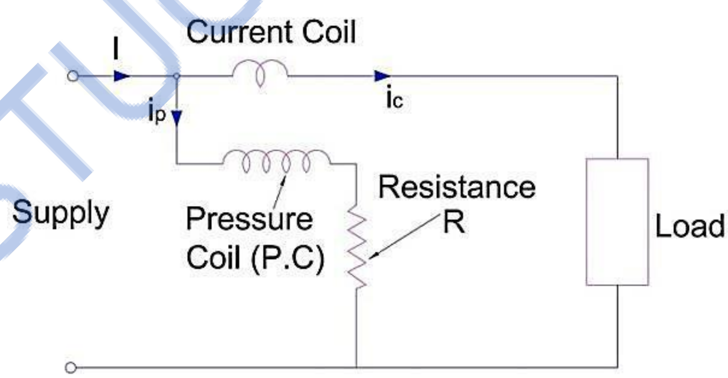


Fig 4.10 electric circuit of electrodynamometer wattmeter

$T_i = i_1 i_2 \frac{dM}{d\theta} N - m$ ....(1)

T_i= instantaneous torque.

$i_1$and i_2 = instantaneous value of currents in 2 coils in A.

ASSUMPTION:

As PC has very high resistance, it is assumed to be purely resistive by neglecting the inductance.

$i_P = \frac{V}{R_p} = \frac{\sqrt{2}V}{R_p}\sin\omega t$ ………..…………..(2)

Where

i_p= instantaneous current in PC in A.

V=instantaneous voltage of PC in V.

R= total resistance in Ω.

As the current through the current coil lags voltage PC by an angle of φ,

$i_c = \sqrt{2}I sin(\omega t - \varphi)$ …………………(3)

Where, i_c= instantaneous current in CC in A.

Φ= lagging angle between i_c and v.

Let $T_i = i_p i_c \frac{dM}{d\theta}$ ………………..(4)

Substitute (2) and (3) in equation (4)

$T_i = \sqrt{2}I_p \sin\omega t * \sqrt{2}I\sin(\omega t - \varphi)\frac{dM}{d\theta}$ (5)

$= I_p I[\cos\varphi - \cos(2\omega t - \varphi)]\frac{dM}{d\theta}d(\omega t)$ (6)

Average deflecting torque,

$$T_d = \frac{1}{T}\int_0^T T_i d(\omega t)$$

$$= \frac{1}{T}\int_0^T I_p I[\cos\varphi - \cos(2\omega t - \varphi)]\frac{dM}{d\theta}d(\omega t)$$

$$= I_p\ Icos\ \frac{dM}{d\theta}$$

$$T_d = \frac{VI}{R_p}\cos\varphi\frac{dM}{d\theta}$$

$$T_c = K_s\theta$$

At balance position ($T_d = T_c$)

$$K_s\theta = \frac{VI}{R_p}\cos\varphi\frac{dM}{d\theta}$$

$$\boldsymbol{\theta = \frac{VI}{K_s R_p}\cos\varphi\frac{dM}{d\theta}}$$

$$\boldsymbol{\theta \propto VI\cos\varphi}$$

9. Write notes on three phase power measurement.

The three phase power measurement can be done by the following methods:

- By using three-phase wattmeter
- By using 3- single phase wattmeter (i.e.,) 3 wattmeter method.
- By using 2- single phase wattmeter (i.e.,) 2 wattmeter method.
- By using single phase wattmeter (i.e.,) 1 wattmeter method.

Three wattmeter method:

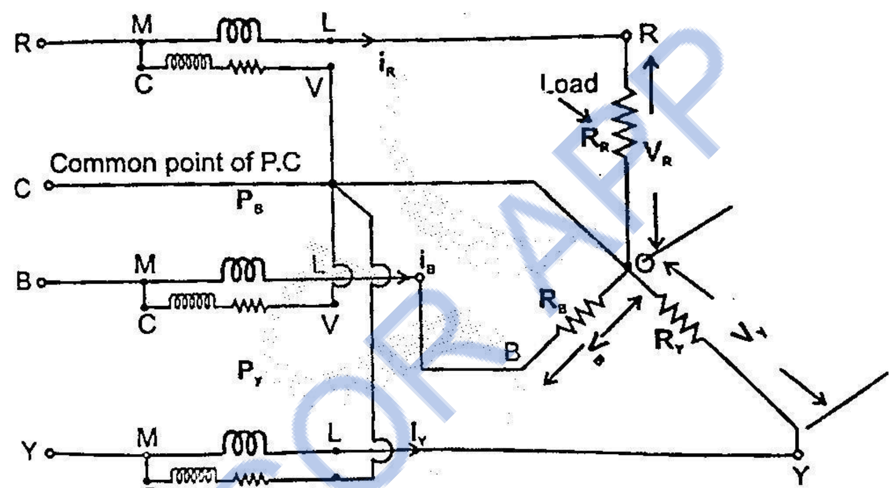


Fig. 4.11 Three wattmeter method

- This method consists of 3 wattmeter and hence the name 3 wattmeter and a combination of PC and CC is called as element.
- In this 3 phase 4 wire system, the common point C of pressure coil and neutral point O of the load coincides and hence voltages across PC of wattmeter is equal to per voltage across the load.

Voltage across PC of wattmeter 1= V_R

Voltage across PC of wattmeter 2= V_Y

Voltage across PC of wattmeter 3= V_B

Where

V_R= voltage across R-phase of load. (V)

V_Y= voltage across Y-phase of load. (V)

V_B= voltage across B-phase of load. (V)

i_R= current flowing through R-phase of load. (A)

i_Y= current flowing through Y-phase of load. (A)

i_B= current flowing through B-phase of load. (A)

- instantaneous power consumed by load= $V_R i_R + V_Y i_Y + V_B i_B$
- Current flowing through CC of each wattmeter= current flowing through each phase of load.
- Instantaneous readings of wattmeter will be equal to instantaneous power consumed by the load.

$$P = P_R + P_Y + P_B = v_R i_R + v_Y i_Y + v_B i_B$$

P_R= instantaneous reading of the wattmeter connected in R-phase.

P_Y= instantaneous reading of the wattmeter connected in R-phase.

P_B= instantaneous reading of the wattmeter connected in R-phase.

Two wattmeter method: (may2021) (13m)

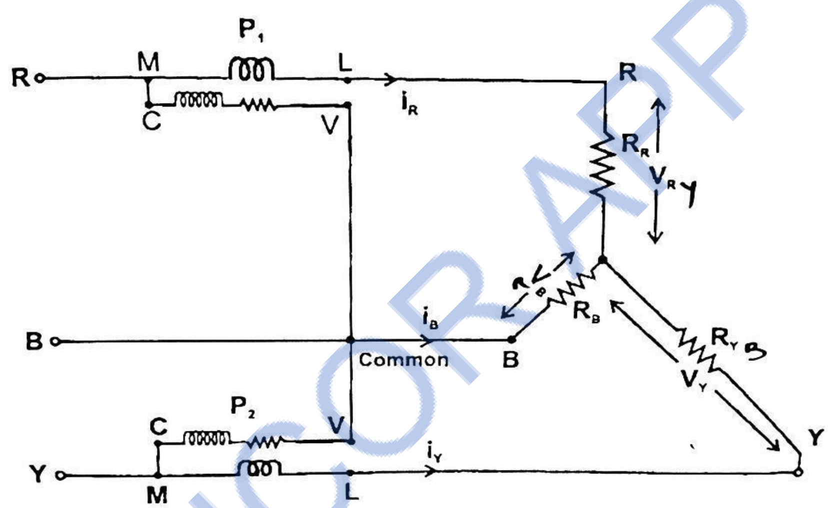


Fig. 4.12 Two wattmeter method

- It is applicable to 3φ, 3W system.
- Generally a 3φ, 3W system require 3 wattmeter but if we coincide the common point of PC of 2 wattmeter with the third phase, then we will require only n-1=2.
- 2 cases in 2 wattmeter method:
  - Star connected load
  - Delta connected load

Case (i) star connection/wye connection or y-connection:

Let v_R= voltage across R-phase of load. (V)

v_Y= voltage across Y-phase of load. (V)

v_B= voltage across B-phase of load. (V)

i_R= current flowing through R-phase of load. (A)

i_Y= current flowing through Y-phase of load. (A)

i_B= current flowing through B-phase of load. (A) instanataneous reading of wattmeter 1= $P_1 = i_R(v_R - v_B)$

instanataneous reading of wattmeter 2= $P_2 = i_y(v_Y - v_B)$

$$= P_1 + P_2$$

$$= i_R(v_R - v_B) + i_y(v_Y - v_B)$$

$$= i_R v_R - i_R v_B + i_y v_Y - i_y v_B$$

$$-v_R i_R - i_y v_Y - v_B(i_R + i_y)$$

As the load is star connected, using KCL,

$i_R + i_Y + i_B = 0$

$i_R + i_Y = -i_B$

Substitute (6) in equation (5)

$$P_1 + P_2 = v_R i_R + v_Y i_Y - v_B(-i_B)$$

$$P_1 + P_2 = v_R i_R + v_Y i_Y + v_B i_B$$

- Therefore sum of the instantaneous reading of 2 watt meters= total power consumed by load.

Case (ii) delta connection:

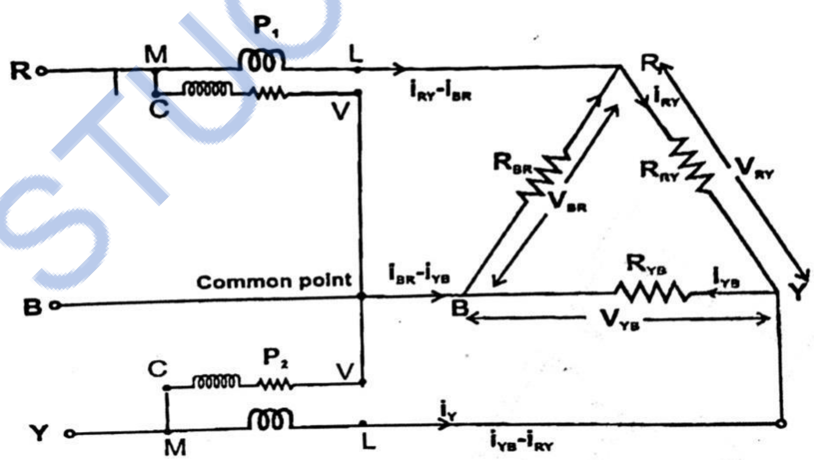


Fig. 4.13 Two wattmeter method for delta connected load

Instantaneous reading of wattmeter 1 $P_1 = -v_{BR}(i_{RY} - i_{BR})$

Instantaneous reading of wattmeter 2 $P_2 = v_{YB}(i_{YB} - i_{RY})$

$$P_1 + P_2 = -v_{BR}(i_{RY} - i_{BR}) + v_{YB}(i_{YB} - i_{RY})$$

$$P_1 + P_2 = -v_{BR} i_{RY} + v_{BR} i_{BR} + v_{YB} i_{YB} - v_{YB} i_{RY}$$

$$P_1 + P_2 = v_{BR} i_{BR} + v_{YB} i_{YB} - i_{RY}(v_{YB} + v_{BR})$$

Applying KVL,

$$v_{YB} + v_{BR} = -v_{RY}$$

Substitute (11) in (10)

$$P_1 + P_2 = v_{BR}i_{BR} + v_{YB}i_{YB} - i_{RY}(-v_{RY})$$

$$P_1 + P_2 = v_{BR}i_{BR} + v_{YB}i_{YB} + v_{RY}i_{RY}$$

i.e., the sum of the instantaneous reading of the two wattmeter is equal to the total power consumed by the load.

Derivation of two wattmeter method for a balanaced star conneceted load:

- Let V_R, V_Y, V_B be the rms value of the phase voltages of R-phase, Y-phase and B-phase respectively and I_R, I_Y, I_B be the rms value of phase currents in R-phase, Y-phase and B-phase respectively.

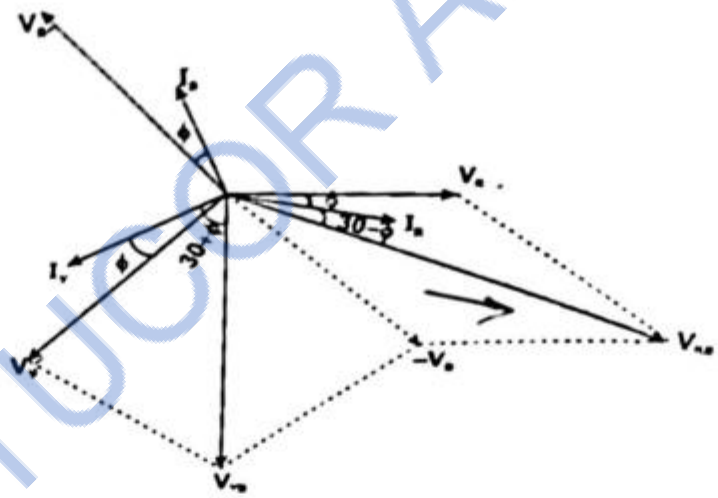


Fig.4.14 Phasor diagram of balanced star connected load

- As the load is balanced,

  Phase voltages, V_R, V_Y, V_B = V

  Line voltages V_{RY}, V_{YB}, V_{RB}= $\sqrt{3}V$

  Phase currents I_R, I_Y, I_B = I
- As the load is star connected, phase currents= line currents= I

  Let cosφ = power factor of the load.
- The phase current lags the phase voltage by an angle φ.

  Current through the wattmeter 1= I_R

  Voltage across the wattmeter 1= V_{RB}

- From the figure, the phase angle between I_R and V_{RB} is (30°-φ)

  Hence, reading of wattmeter 1 $P_1 = I_R V_{RB} \cos(30° - \varphi)$

$$\boldsymbol{P_1 = \sqrt{3}VI\cos(30° - \varphi)}$$

- Similarly current through the wattmeter 2 = I_Y.

  Voltage acroos the wattmeter 2 = V_{YB}

- From the figure, the phase angle between I_Y and V_{YB} is (30°+φ)

  Hence, reading of wattmeter 1 $P_2 = I_Y V_{YB} \cos(30° + \varphi)$

$$\boldsymbol{P_2 = \sqrt{3}VI\cos(30° + \varphi)}$$

- sum of the readings of the two wattmeters = $\boldsymbol{P_1 + P_2}$

$$P_1 + P_2 = \sqrt{3}VI\cos(30° - \varphi) + \sqrt{3}VI\cos(30° + \varphi)$$

$$= \sqrt{3}VI\,[\cos(30° - \varphi) + \cos(30° + \varphi)]$$

$$= \sqrt{3}VI[\cos 30° \cos\varphi + \sin 30° \sin\varphi + \cos 30° \cos\varphi - \sin 30° \sin\varphi]$$

$$= \sqrt{3}VI[2 * \cos 30° \cos\varphi]$$

$$= \sqrt{3}VI\left[2 * \frac{\sqrt{3}}{2}\cos\varphi\right]$$

$$\boldsymbol{P_1 + P_2 = 3VI\cos\varphi} = \text{total power consumed by the load}$$

Calculation of power factor:

$$P_1 - P_2 = \sqrt{3}VI\cos(30° - \varphi) - \sqrt{3}VI\cos(30° + \varphi)$$

$$= \sqrt{3}VI\,[\cos(30° - \varphi) - \cos(30° + \varphi)]$$

$$= \sqrt{3}VI[\cos 30° \cos\varphi + \sin 30° \sin\varphi - \cos 30° \cos\varphi - \sin 30° \sin\varphi$$

$$= \sqrt{3}VI[2 * \sin 30° \sin\varphi]$$

$$= \sqrt{3}VI\left[2 * \frac{1}{2}\sin\varphi\right]$$

$$\boldsymbol{P_1 - P_2 = \sqrt{3}VI\sin\varphi}$$

$$\frac{P_1 - P_2}{P_1 + P_2} = \frac{\sqrt{3}VI\sin\varphi}{3VI\cos\varphi} = \frac{\tan\varphi}{\sqrt{3}}$$

$$\tan\varphi = \sqrt{3}\left(\frac{P_1 - P_2}{P_1 + P_2}\right)$$

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

- power factor of the load, $\cos\varphi = 1$ *and* $\varphi = 0$

  From equation (16), $P_1 = \sqrt{3}VIcos(30° - 0) = \frac{3}{2}VI$

  Equation (17) becomes, $P_2 = \sqrt{3}VIcos(30° + 0) = \frac{3}{2}VI$

$$P_1 + P_2 = 3VI$$

10. Explain the construction and working principle of single phase induction type energy meter. Write short notes on any 2 adjustments required in energy meter. (Nov/Dec 2009, May/June 2014,2017) (Nov/Dec 2018)

- Energy meter is an instrument used to measure the total power consumed over a specific interval oftime. Unit of energy is Kwh.
- Energy= power * time
- Energy meter is an integrating type of instrument which measures the energy consumed when power is delivered at an average rate of 1000 watts for one hour.

Basic principle:

- It is an integrating type instrument which works on the principle of induction. i.e., in this type of instrument, alternating fluxes are produced because of 1φ AC supply.
- These alternating fluxes induce the generation of eddy current in the moving system which interacts with each other to produce a driving torque which causes the aluminium disc to rotate and thus records the energy.

Constructional details:

- The four main parts of induction type of energy meter are:
  - ➢ Driving system
  - ➢ Moving system
  - ➢ Braking system
  - ➢ Registering system

Driving system:

- The driving system of the energy meter consists of two electromagnets whose core is made up ofsilicon steel laminations.
- The coil of one of the electromagnets which is excited by the load current is called as current coiland the corresponding electromagnet is called as series magnet.

- The coil of the second electromagnet which is connected across the supply is called pressure coiland the corresponding electromagnet is called shunt magnet.

Moving system:

- The moving system consists of aluminium disc mounted on a light alloy shaft.
- The disc is positioned in the air gap between the series and shunt magnets.
- The moving system is connected to a hardened steel pivot which is screwed to the foot of the shaft.
- In this type of energy meter as there is no controlling torque, continuous rotation of the disc isproduced due to driving torque only.

Braking system:

- The braking system consists of permanent magnet positioned near the edge of the aluminium disc.
- The aluminium disc moves in the field of this magnet and thus provides a braking torque.

Registering system:

- The function of a registering or counting mechanism is to record continuously a number which isproportional to the revolutions made by the moving system.

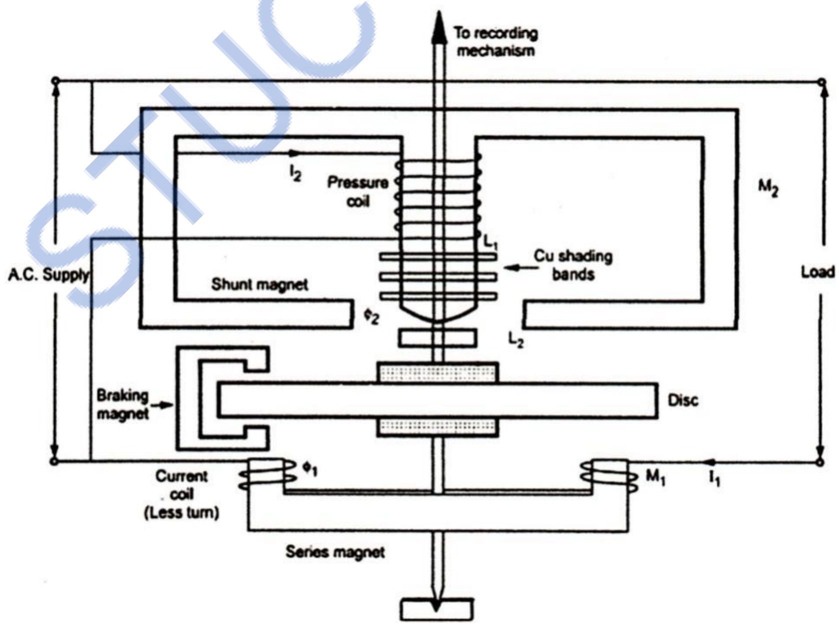


Fig. 4.15 Induction type single phase energy meter

Principle of operation:

- When the pressure coil wound on the shunt magnet is connected across the supply voltage, it carriesa current IP proportional to the supply voltage, thus producing an alternating flux φP.

- As this flux φP is alternating in nature, it indicates an emf E_{ep} in the disc which in turn produceseddy current I_{ep}.
- When the current coil wound on the series magnet carries the load current I, it produces analternating flux φe.
- This flux φ_C induces an emf E_{ec} in the disc which in turn produces eddy current I_{ec}.
- Now the eddy current I_{ep} interacts with φ_C and produces a torque T_1.
- Similarly the eddy current I_{ec} interact with φP and produces another torque T_2.

As these torques arein the opposite direction, the net torque is the difference of the above two torques.

Let

V= supply voltage

I_p= current through the pressure coil which is proportional to supply voltage. I= load current.

Φ= phase angle of load.

Φ_p= flux produced by the current through P.CΦ_c= flux produced by the current through C.C

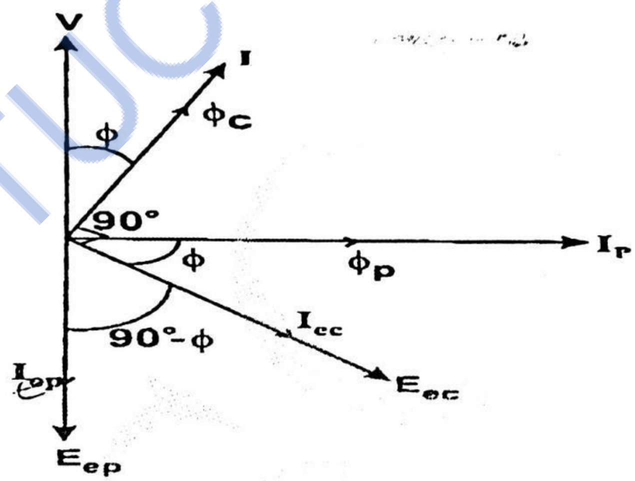


Fig. 4.16 Phasor diagram of the induction type 1φ energy meter

E_{ep}= eddy emf induced by flux Φ_p

E_{ec}= eddy emf induced by flux Φ_c.

I_{ep}= eddy emf induced by flux Φ_p

I_{ec}= eddy emf induced by flux Φ_c

Net driving torque, T_d a $T_2 - T_1$ ....(1)

- As the pressure coil is highly inductive in nature, I_P lags V by 90°, neglecting the resistance inpressure coil.

- Since Φ is the phase angle of load, load current I lags the supply voltage by the angle Φ.
- However ΦP will be in phase with IP, as Φp is the flux produced due to current IP.
- Similarly ΦC will be in phase with I, as ΦC is the flux produced due to load current I. Let,

T1= ΦCIepcos(angle between ΦC and Iep)

T1= ΦCIepcos(90°+90°-φ) .... (2)

T1= ΦCIepcos(180°-φ)

T2= ΦPIeccos(angle between ΦPand Iec)

T2= ΦPIeccosφ .... (3)

Net driving torque, T_d a $T_2 - T_1$

Hence $\varphi_P I_{ec} - \cos\varphi - \varphi_c I_{ep}\cos(180° - \varphi)$.. (4)

T_d a $\varphi_P I_{ec}\cos\varphi + \varphi_c I_{ep}\cos\varphi$..(5)

We know that ,φ_P a I_P a V

$$I_{ep} \propto E_{ep} \propto V$$

$$I_{ec} \propto E_{ec} \propto I \text{ and } \varphi_c \propto I$$

Hence in the equation (5)

$\varphi_P$can be replaced by V

I_{ec}can be replaced by I

$\varphi_c$can be replaced by I

I_{ep}can be replaced by V

Now the equation (5) becomes

$$T_d = K_1 VI\cos\varphi + K_2 VI\cos\varphi$$

$$T_d = (K_1 + K_2)VI\cos\varphi \qquad ....(6)$$

$$T_d \propto VI\cos\varphi \qquad ....(7)$$

Now the braking torque is proportional to the speed of revolution of the disc.

Hence

$$T_b \propto N$$

Where, T_b is the braking torque.

For constant speed of operation $T_b = T_d$

$$\therefore N \propto VI\cos\varphi$$

Multiplying the above equation by both the sided, we get

$$Nt \propto VIt\cos\varphi$$

Creeping in energy meter:

- At zero load conditions without any current through the current coil the disc rotates due to the supply voltage existing in its pressure coil. This is called creeping.

Advantages:

- Accurate readings can be taken.
- Less maintenance.
- Cheap in cost.
- Frictional errors are less.

Disadvantages:

- used only for AC circuits.
- Creeping can cause errors.

11. Write short notes on two and three element energy meter.

Two element energy meter:

- The two element energy meter is used for 3 phase 3 wire system, which consists of 2 discs, one for each element.
- It is essential that the driving torque of the two elements should be equal when equal amount of power passes through each element.
- Hence in addition to normal compensating devices attached to each element, adjustable magnetic shunt is provided to both the elements in order to balance the 2 driving torques of the two elements.

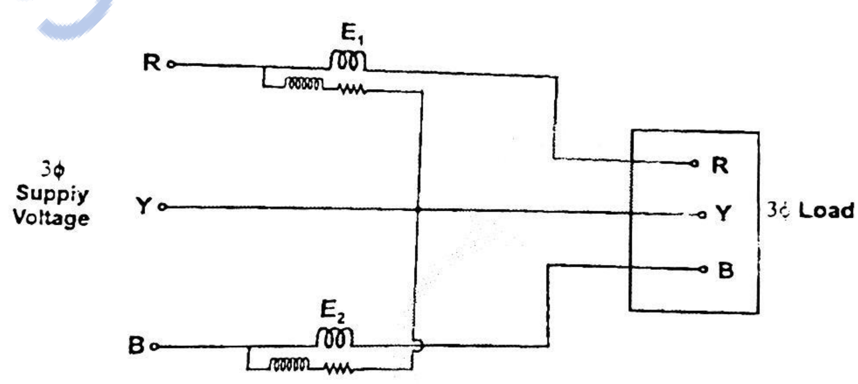


Fig. 4.17 Circuit diagram of 2 element energy meter

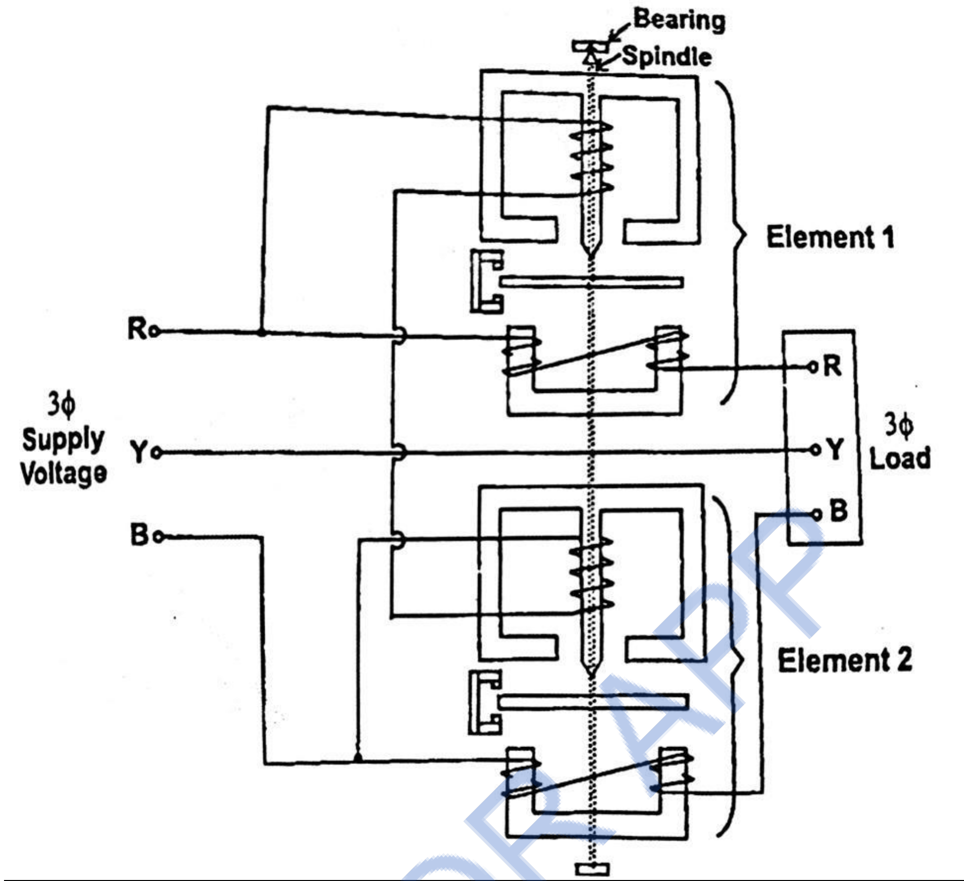


Fig. 4.18 Two element energy meter

Three element energy meter:

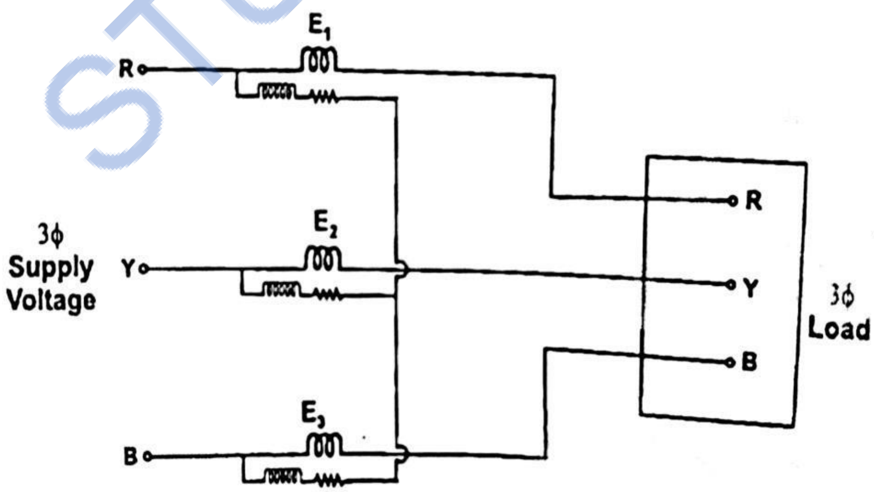


Fig. 4.19 circuit diagram of three element energy meter

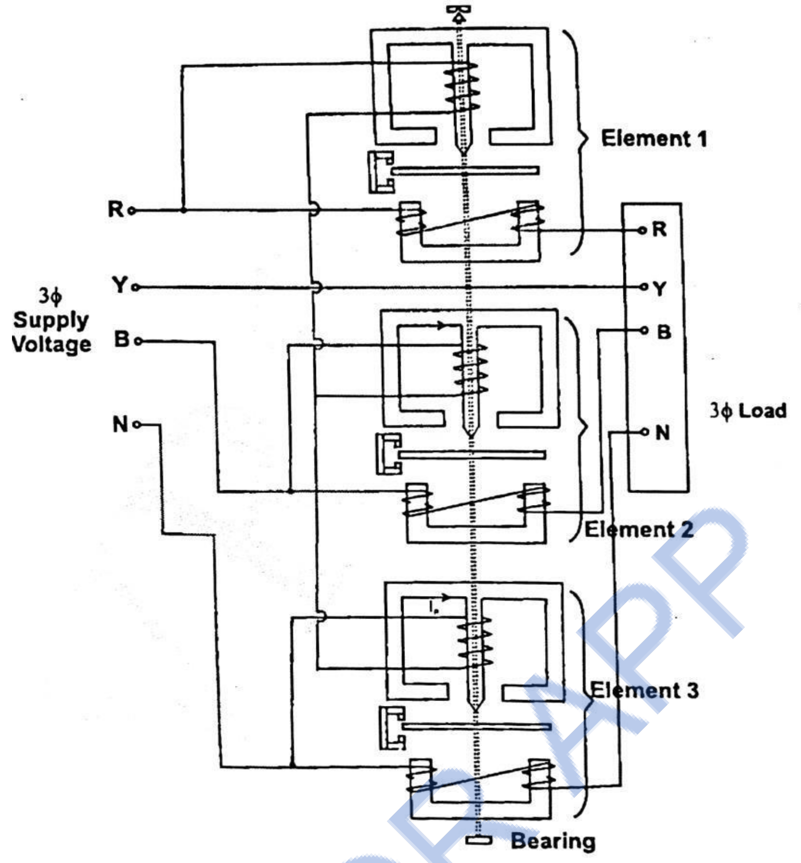


Fig. 4.20 Three element energy meter

- It consists of 3 elements necessary to measure energy consumed by the load connected to 3 phase 4wire system.

12. Explain with neat sketch the classification of instrument transformer. Write a note on the errors affecting the characteristics of an instrument.

- In power systems, currents and voltages handled are very large therefore direct measurements are not possible.
- The large currents and voltages are stepped down with the help of transformers so that they could be measured with instruments of moderate size.
- Thus the transformers used in combination with measuring instruments for measurement purposes are called as instrument transformers.
- Transformers used for measuring current is called as current transformer (C.T)
- The transformer used for measuring voltage is called potential transformer (P.T).

Current transformers:

- Current transformer is a device used to decrease the current level by stepping up or down the voltage and keeping the energy constant.
- Hence current transformers are basically step-up transformers.
- The primary winding of the transformer is connected in series with the line

carrying the current to be measured and therefore the primary current is dependent on the load connected to the system whose current is to be measured.

- The secondary winding of the C.T is connected to a low range ammeter.
- In case of C.T the secondary current is less than the primary current.

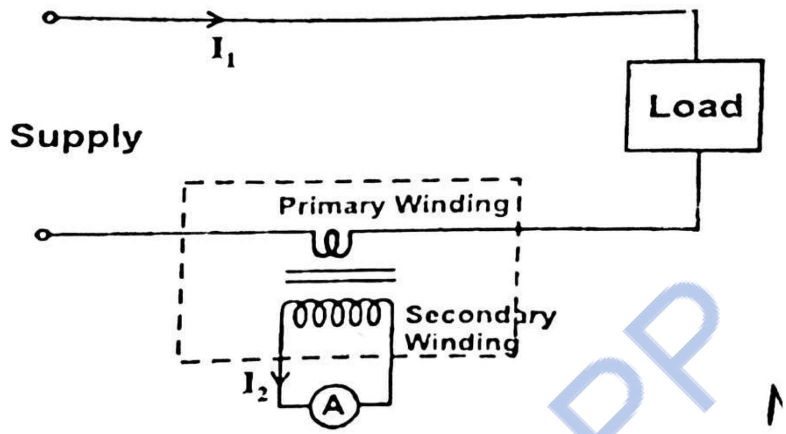


Fig. 4.21 Current Transformer

- Incase of C.T, turns ratio, $n = \frac{N_2}{N_1}$

  Where N_1= number of turns in primary winding.

  N_2= number of turns in secondary winding.

- We know that, for an C.T, $\frac{N_2}{N_1} = \frac{I_1}{I_2} = \frac{V_2}{V_1}$

  Where I_1= primary current in A.

  I_2= secondary current in A.

  V_1= primary voltage in V.

  V_2= secondary voltage in A.

- From the above equations it is clear that, if the range of C.T is 500:5

$$n = \frac{500}{5} = 100$$

$$\frac{V_2}{V_1} = 100$$

$$V_2 = 100V_1$$

- From the above equation it is clear that in order to decrease the secondary current by 100 times, the secondary voltage should be increased by 100 times.
- If the turn's ratio of C.T is known and the meter reading is known, the actual high line current valuecan be determined.

Potential transformers:

- The primary winding is connected across the high voltage line whose voltage is to be measured andthe secondary is connected to the low range voltmeter coil.
- One end of the secondary winding is always grounded for safety purpose.

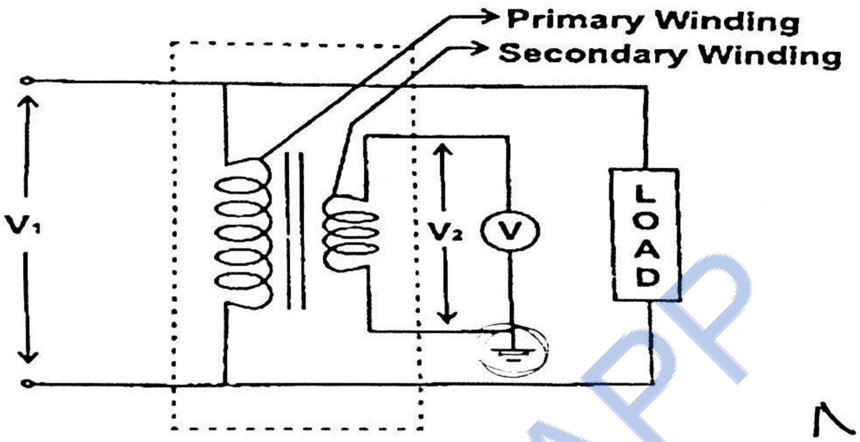


Fig. 4.22 Potential Transformer

The main difference between C.T and P.T are:

- C.T acts as a step-up transformer whereas P.T acts as a step-down transformer.
- Secondary voltage of P.T is lesser than the primary voltage whereas secondary voltage of C.T ishigher than the primary voltage.
- Secondary current of the P.T is more than the primary current whereas secondary current of the C.Tis less than the primary current.
- In case of P.T, primary winding has more number of turns compared to the secondary whereas incase of C.T, primary winding has less number of turns compared to secondary.
- In case of P.T, the primary winding is connected across the load, whereas in case of C.T, the primarywinding is connected in series with the load.
- Turns ratio of P.T $\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$

  Turns ratio of C.T $\frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2}$

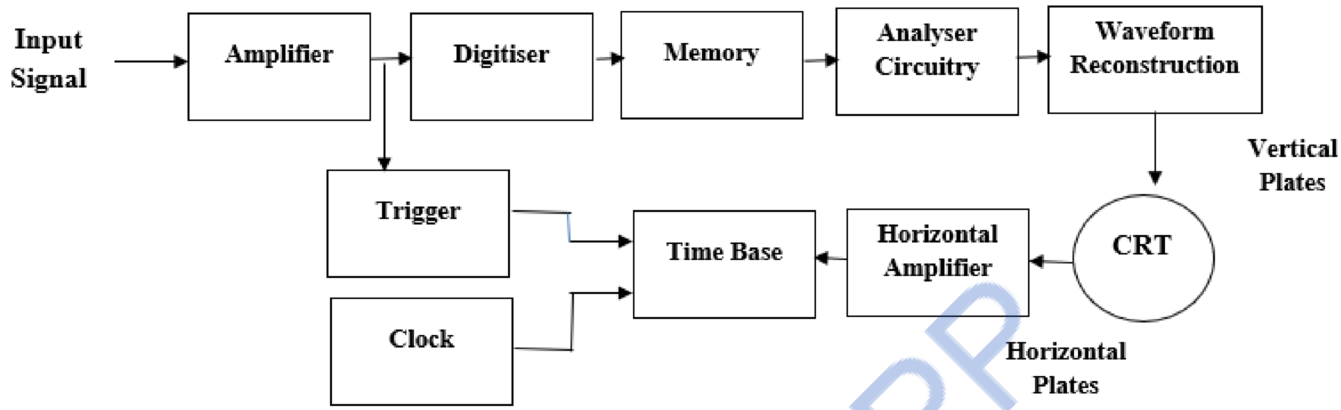
13. Digital Storage Oscilloscope (DSO)

- Digital storage oscilloscope definition is an electronic device that stores and analyses the signal in the digital format is known as Digital Storage Oscilloscope (DSO).
- When the input signal is given to the DSO, then it is processed, stored in the

memory, and displayed on the screen.

- It stores the signal in the form of digital data as either 1 Or 0.

Block Diagram of Digital Storage Oscilloscope



- As seen in the above figure, at first digital storage oscilloscope digitizes the analog input signal, then the analog input signal is amplified by amplifier if it has any weak signal.
- After amplification, the signal is digitized by the digitizer and that digitized signal stores in memory.
- The analyzer circuit process the digital signal after that the waveform is reconstructed (again the digital signal is converted into an analog form) and then that signal is applied to vertical plates of the cathode ray tube (CRT).
- The cathode ray tube has two inputs they are vertical input and horizontal input.
- The vertical input signal is the 'Y' axis and the horizontal input signal is the 'X' axis.
- The time base circuit is triggered by the trigger and clock input signal, so it is going to generate the time base signal which is a ramp signal.
- Then the ramp signal is amplified by the horizontal amplifier, and this horizontal amplifier will provide input to the horizontal plate.
- On the CRT screen, we will get the waveform of the input signal versus time.

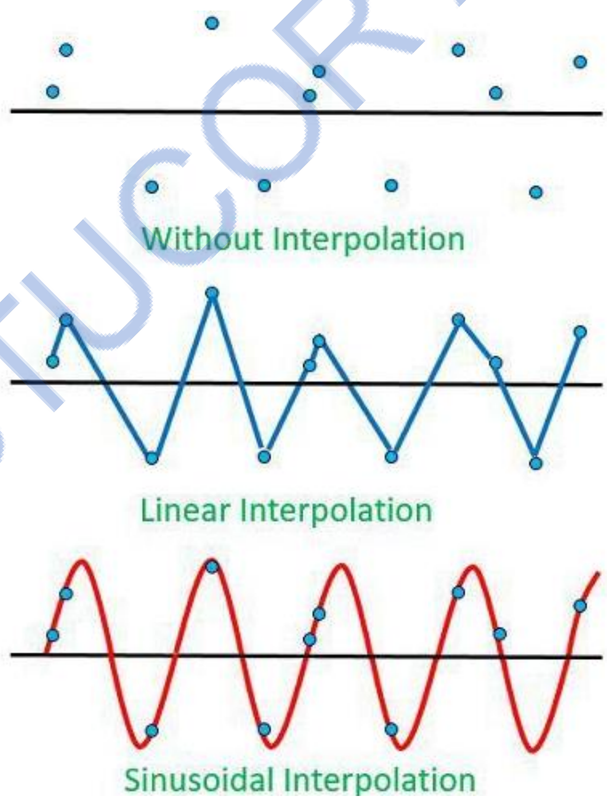
Working Principle

- The working principle of a Digital Storage Oscilloscope (DSO) is based on digitizing and storing the input signals with the help of CRT (Cathode Ray Tube) and digital memory.
- The process of digitization is the sampling of input signals at different periodic signals.
- Here, the signal's maximum frequency measured by the DSO depends on 2 factors,

which are sampling rate and the converter nature.

- And also the function of the digital storage oscilloscope depends on the sampling and the converter.
- Waveform Reconstruction
- Although the input is sampled according to sampling theory, aliasing effect can still occur.
- This is so because the output is present as series of dots, that corresponds to the sampled value.
- Digital storage oscilloscope uses interpolation technique, for visualization of final waves.
- Interpolation is a technique that creates new data points with the help of a discrete set of known data points. It is basically of two types-
  - Linear interpolation
  - Sinusoidal interpolation

Let's have a look at the figure illustrating interpolation methods-



- In linear interpolation, the dots are connected together by a straight line. It can be used in pulsed or square wave generation but not in case of sinusoidal waves.
- In sinusoidal interpolation, the dots are connected so as to form sinusoidal waveform. But it is not suitable for square or pulse waves.

TWO MARKS

1. **What is meant by measurement?**

A measurement of any quantity either physical or electrical gives meaningful act when it is compared with predefined standard quantity.

2. **What is the broad classification of measuring instruments? (MAY 2018)**
   - Active/passive instruments
   - Null/deflection type instruments
   - Monitoring/control instruments
   - Analog/digital instruments
   - Absolute/secondary instruments

3. **What is meant by instrument?**

   An instrument is a device for measuring the value or magnitude of a quantity or variable.

4. **What are the applications of measurement system?**
   - Monitoring of operations.
   - Control of processes and operations.
   - Experimental engineering analysis.

5. **Define static characteristics of an instrument.**
   - When the instrument is used to measure a quantity which do not vary with time is called static characteristics.

6. **Define dynamic characteristics of an instrument.**
   - When the instrument is used to measure a quantity which vary with time is called dynamic characteristics.

7. **Define true value.**
   - True value is defined as the average of an infinite number of measured values when the average deviation due to the various contributing factors tends to zero.

8. **Define static error.**
   - It is defined as the difference between the measured value and true value of the quantity.

9. **What are the factors influenced in accuracy?**
   - Static error
   - Dynamic error
   - Reproducibility

- Dead zone

10. Write the main static characteristics.

- Accuracy
- Reproducibility
- Sensitivity
- Drift
- Static error
- Dead zone
- Resolution

11. Define reproducibility.

- It is defined as the degree of closeness with which a given value may be repeatedly measured.
- It is specified in terms of scale readings over a given period of time.

12. Define threshold.

- It is defined as the minimum value of the input at which the output starts changing/ increasing from zero.

13. State the function of measurement system.

- The measurement system consists of a transducing element which converts the quantity to be measured in an analogous form the analogous signal is then processed by some intermediate means and it is fed to the end device which presents the result of the instrument.

14. What factors cause drift?

- Mechanical vibrations.
- High mechanical stress
- Wear and tear
- Stray electric and magnetic fields

15. Differentiate between accuracy and precision.

ACCURACY	PRECISION
It is the degree of closeness of a measurement compared to true value.	A measure of the consistency or repeatability of measurements
It gives the maximum error which is maximum departure of the final result from its true value.	It gives its capability to reproduce a certain reading with a given accuracy.

16. Classify the drift.

- Zero drift
- Span drift
- Zonal drift

17. Define zero drift.

- The whole instrument calibration may gradually shifts due to slippage or due to undue warming up of electronic tube circuits; this drift is called zero drift.

18. Define span drift.

- There is a proportional change in the indication all along the upward scale; this drift is called as span drift.

19. Define zonal drift.

- The drift occurs over a span of an instrument, it is called as zonal drift.

20. Define measuring lag and fidelity of dynamic characteristics of an instrument.

- **Measuring lag** is defined as the retardation or delay in response of an instrument to changes in measured quantity.
- **Fidelity** is defined as the ability of an instrument to produce a wave shape of input with respect to time.

21. Differentiate resolution from threshold.

RESOLUTION	THRESHOLD
It is the smallest change in measured value to which the instrument will respond.	It is defined as the minimum value Of the input at which the output starts changing/ increasing from zero.

22. Define the term sensitivity of an instrument.

- Sensitivity is defined as the ratio of the magnitude of the output signal to the magnitude of input signal to be measured.

23. What is meant by absolute error of measurement?

- **Absolute error** is difference between the true value and measured value of a quantity.

$$e = R_0 - R_T$$

e-Absolute error

R_T-true reading

R_0-observed reading

24. What are different types of errors in measurement system. (MAY 2018).

- Gross Errors
- Systematic Errors
  - (i) Instrumental Errors
  - (ii) Environmental Errors
  - (iii) Observational Errors
- Random errors

25. What are the reasons for gross errors?

- Incorrect adjustment
- Misreading of instrument scale
- Incorrect recording of experimental data
- Parallax error

26. What are the reasons for instrumental errors?

- Inherent short comings in an instrument
- Misuse of instrument
- Loading effect

27. How can we reduce the environmental errors?

- Air-conditioning
- Shielding
- Proper earthing
- Spring mounting

28. What are the causes for random errors?

- Hysteresis in elastic members
- Backlash in the movement
- Mechanical vibrations

29. What are the sources of errors?

- Energy exchanged by interaction
- Noise
- Design limitations
- Deterioration of measuring system.

30. Define backlash.

- It is defined as the maximum distance through which a part of the mechanical system can be moved in one direction without applying appreciable force or motion to the next part in a mechanical system.

31. Define linearity.

- The ability to produce the input characteristics symmetrically is known as Linearity.

32. What are the sources of errors that may occur in permanent magnet moving coil instrument?

- Weakening of permanent magnets due to ageing and temperature effects.
- Weakening of springs due to same reasons
- Change of resistance of the moving coil with temperature

33. What are the advantages and disadvantages of PMMC instrument?

Advantages:

- The scale is uniform
- Low power consumption
- High torque / Weight ratio
- Using suitable value of shunts and multipliers respectively, we can use a single instrument for many different ranges of current and voltages.

Disadvantages:

- These instruments are useful only for DC not for AC
- The cost is higher than that of PMMI instrument

34. What is the basic operating principle of a PMMC instrument?

- A moving coil that carries the current is placed between two poles of a permanent magnet.
- When current passes through the coil, it produces a strong magnetic field. The permanent magnet also produces magnetic field. The deflecting torque is produced due to the interaction between two fluxed.
- Since the permanent magnet is fixed, the moving coil tends to move and the pointer which is one of the parts of moving coil arrangement also moves.

35. Explain the operating principle of moving iron (MI) instrument.

- In this type of instrument the coil in which the current passes through is fixed. The moving iron is a flat disc, which is mounted between the fixed coils.
- When current passes through the coil, the moving iron is moved either by force of attraction or repulsion.

36. Why cannot a moving coil instrument be used in AC circuits?

- The deflecting torque of the instrument reverses if the current reverse.

- If the instrument is connected to AC, the pointer cannot follow the rapid reversals and the deflection corresponds to mean torque, which is zero.
- So these instruments cannot be used for AC.

37. Which type of instruments is called universal instrument?

The moving iron instruments are known as universal instruments, because these instruments can be used for both AC and DC.

38. What are the errors occurring in MI (MOVING IRON) instruments?

- Hysteresis error
- Temperature error
- Stray magnetic field error
- Frequency error due to reactance of instrument coil and eddy currents.

39. What are the advantages and disadvantages of MI Instruments?

Advantages:

- Universal use – Suitable for the measurement of both AC and DC
- Less friction loss hence high torque / weight ratio
- Cheapness – A single type moving element could cover entire range of current
- Robustness – Simple and rugged construction because there is no current Carrying moving parts.
- Accuracy – Capable of giving good accuracy like $\pm$ 2%

Disadvantages:

- Scale – The scale of MI instrument is not uniform and is cramped at the lower end and therefore accurate readings are not possible at this end.
- Errors – these instrument are subjected to serious errors due to hysteresis, frequency changes and stray magnetic field
- Difference u AC and DC calibrations – there is a difference between DC and AC calibrations on account of effect of inductance and eddy currents when the meter is used on AC. Hence they must be calibrated for frequency at which they are used.

40. What are the main types of instrument used as ammeters and voltmeters?

- Permanent magnet moving coil
- Moving Iron
- Electrodynamometer
- Hot wire
- Thermocouple
- Induction

- Electrostatic
- Rectifier

41. Write and explain the torque equation of moving coil.

$$Deflecting\ Torque, T_d = \frac{NB}{dI} = GI$$

Where

$$G = \frac{NB}{d} = constant$$

$$Controlling\ Torque, T_c = K\theta$$

Where

$K - spring constant$

For final steady state condition

$T_c = T_d$

$GI = K\theta$

Final Deflection, $\theta = \left(\frac{G}{K}\right) I$

Current, $I = \left(\frac{K}{G}\right) \theta$

42. What are the operating forces needed for indicating instruments?

i)<u>Deflecting force:</u>

The force required for moving the pointer from its zero position

ii)<u>Controlling force:</u>

The force required to bring the pointer to final steady state position without over shoot and to bring back the pointer to zero when deflecting force is absent.

iii)<u>Damping force:</u>

The force required to bring the pointer to final steady state position quickly without oscillations.

43. What are the control systems used for producing control force?

- Gravity control
- Spring Control

44. What are the advantages of spring control over gravity control?

Advantages:

- Gravity control can be used only in vertically mounted instruments
- The scale used in gravity control type instruments is cramped at the lower end. Hence not uniform.

45. What are the damping systems used in instrument?

- Air friction damping

- Eddy current damping
- Fluid friction damping

46. What are the applications of PMMC?

- These instruments can be used as voltmeter and ammeter with multi-ranges
- Self-shielding magnets make the core magnet mechanism particularly useful in aircrafts and other aerospace applications where more number of instruments are mounted in one case to form a unified display. There by considerable amount of weight is reduced.

47. Mention the two types of MI instruments.

- Attraction type
- Repulsion type

48. What are the applications of MI instruments?

- Used as multi-range ammeters and voltmeters
- Used as inexpensive indicators such as charging and discharging current indicators in automobiles
- Extensively used in industries for measurement of AC voltage and current where errors of the order of 5% to 10% are acceptable.

49. Mention the importance of moving coil instruments.

- Low power consumption
- Their scales are uniform
- High torque / weight ratio
- No hysteresis loss

50. Mention the importance of moving iron instruments.

- It is suitable for the measurement of both AC and DC
- Less friction loss
- High accuracy
- Simple and rugged construction.

51. What are the types of indicating instruments?

- Moving coil instruments
- Moving iron instruments

52. What are the different torque acts upon the moving system of the instruments for good operation?

- Deflecting torque
- Controlling torque

- Damping torque

53. List the measuring instruments you known.

- Permanent Magnet Moving Coil (PMMC) instrument
- Permanent Magnet Moving Iron (PMMI) instrument
- Dynamometer type wattmeter
- Energy meter

54. Why we need damping device in indicating instruments?

- Damping device is mainly used to prevent oscillation of the moving system and enable the latter to reach its final position quickly.

55. Compare moving coil and moving iron instruments based on any two salient features.

Sl.No.	Moving Coil Instrument	Moving Iron instrument
1.	Scale is uniform	Scale is not uniform
2.	High Cost	Less Cost
3.	It is used only measurement of DC	Measurement of AC and DC

56. Mention any two types of wattmeter.

- Dynamometer type wattmeter
- Induction type wattmeter
- Electrostatic type wattmeter

57. What are the coils in the wattmeter?

- Current coil
- Pressure coil

58. What are the errors which occur in an electro dynamometer type wattmeter?

- Error due to pressure coil inductance
- Error due to pressure coil capacitance
- Error caused by connections
- Eddy current errors
- Stray magnetic field errors
- Errors caused by vibrations
- Temperature errors

59. Name the instrument used for measuring the electrical power consumed during a specific period.

- Energy meter – used to measure energy consumption

60. What are the advantages of induction type energy meter?

- Simple operation
- High torque / weight ratio
- Cost is cheap
- Unaffected by temperature variations

61. What is the use of copper shading band in energy meter?

- Copper shading band also known as the power factor compensator is provided in the central limb of the shunt magnet.
- It is mainly used to achieve exactly 90^o phase displacement between the flux produced in shunt magnet and the voltage across the shunt magnet.

62. List the major components of single phase induction type energy meter.

- Shunt Magnet
- Series Magnet
- Braking Magnet
- Pressure Coil
- Current Coil
- Disc

63. What is instrument transformer? Give its types.

Transformers used in conjunction with the measuring instruments for measurement purposes arecalled instrument transformer. It is also used for production of power circuits.

- Potential transformer
- Current transformer

64. State the advantages of instrument transformers.

- Used for extension of range
- Power loss is minimum
- High voltage and currents can be measured.

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UNIT-V

BASICS OF POWER SYSTEMS

Power system structure -Generation , Transmission and distribution , Various voltage levels, Earthing – methods of earthing, protective devices- switch fuse unit- Miniature circuit breaker molded case circuit breaker- earth leakage circuit breaker, safety precautions and First Aid.

1. STRUCTURE OF POWER SYSTEM:

Explain with a simple diagram the basic structure of electric power system to deliver electricity to the consumer place [MAY 2018]. (OR) Explain in detail about the transmission and distribution of electrical energy.

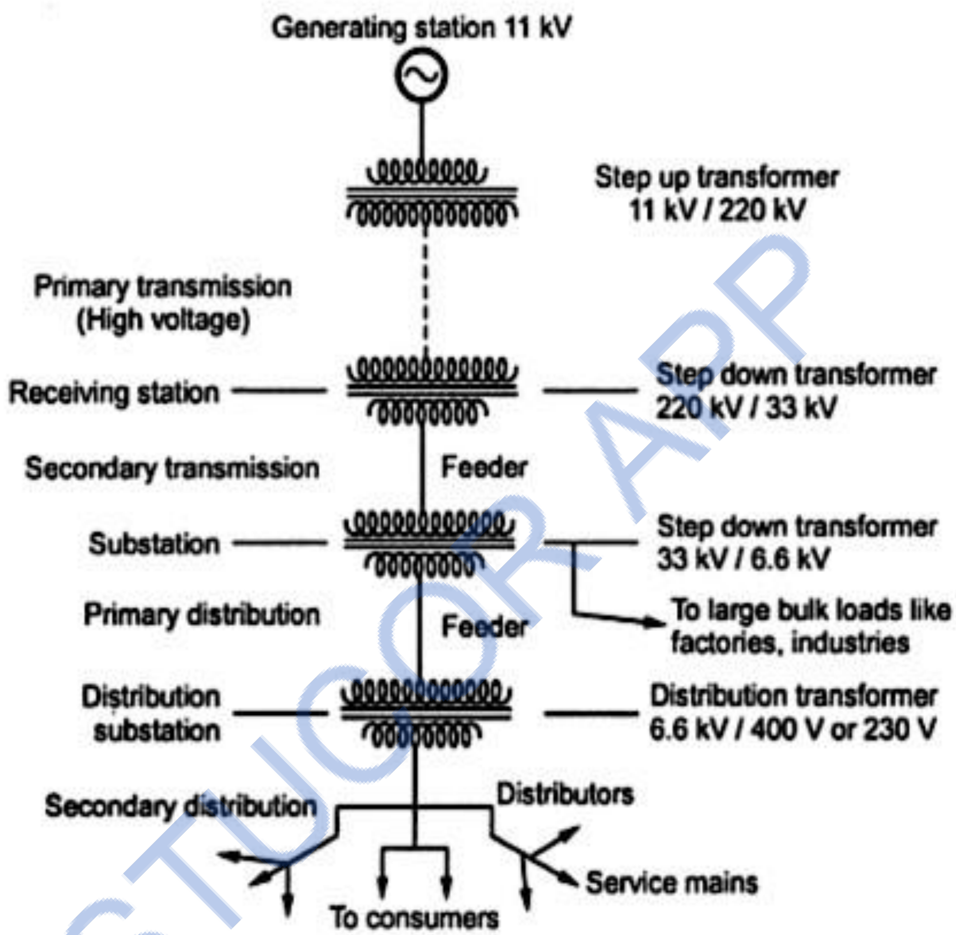

Figure 5.1: Structure of an AC power system

- The structure of power system can be divided into three parts,
  - ✓ Generating station
  - ✓ Transmission system
  - ✓ Distribution system
- The transmission system is sub-divided into two—primary transmission and secondary transmission.
- The distribution system is sub-divided into two— primary distribution and secondary distribution.
- Fig. 1.1 shows the layout of a typical AC power supply scheme by a single line diagram.

Generating station:

- In the generating station, electric power is produced by 3-phase alternators.
- The usual generation voltage is 11 kV.
- The generation voltage is stepped-up to 220 KV at the generating station with help of 3-phase transformers.

Advantages of high voltage transmission:

- ✓ The saving of conductor material
- ✓ High transmission efficiency

Disadvantages of high voltage transmission:

- ✓ It introduces insulation problems
- ✓ The cost of switchgear and transformer equipment is increased

- The primary transmission is carried at 66 KV, 132 KV, 220 KV, 400 KV or 765 KV.
- The highest transmission voltage adopted for power transmission in India is 765 KV.

Primary transmission:

- The electric power at 220KV is transmitted by 3-phase, 3-wire overhead system. This forms the primary transmission.

Secondary transmission:

- The primary transmission line terminates at the receiving station (RS).
- At the receiving station, the voltage is reduced to 33 KV by step-down transformers.
- From this station, electric power is transmitted at 33 KV by 3-phase, 3-wire overhead system to various sub-stations (SS). This forms the secondary transmission.

Primary distribution:

- The secondary transmission line terminates at the sub-station (SS), where voltage is reduced from 33 kV to 6.6 KV by step-down transformer.
- The 6.6KV lines run along the important road sides of the city. This forms the primary distribution.
- Big consumers (>50 kW) are supplied power at 6.6KV with their own sub-stations.

Secondary distribution:

- The electric power from primary distribution line (6.6KV) is delivered to distribution sub-stations (DS).
- These distribution sub-stations are located near the consumer localities.
- Here, step down the voltage to 400 V, 3-phase, 4-wire for secondary distribution.
- The voltage between any two phases is 400 V and between any phase and neutral is 230 V.

- The single-phase residential lighting load is connected between any one phase and neutral.
- 3-phase, 400V motor load is connected across 3-phase lines directly.
- The secondary distribution system consists of **feeders, distributors and service mains.**

2. DISTRIBUTION SYSTEM:

The part of power system which distributes electric power for local use is known as distribution system.

- In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumer's meters.
- It generally consists of feeders, distributors and the service mains.
- Fig. 1.2 shows the elements of low voltage distribution system.

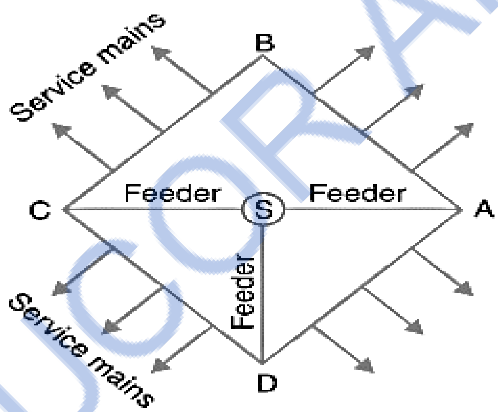

Figure 5.2: Distribution Systems

Feeders:

- A feeder is a conductor which connects the sub-station (or localized generating station) to the area where power is to be distributed.
- Generally, no tapings are taken from the feeder so that current in it remains the same throughout.
- The main consideration in the design of a feeder is the current carrying capacity.

Distributor:

- A distributor is a conductor from which tapping's are taken for supply to the consumers. In Fig. 1.2, AB, BC, CD and DA are the distributors.
- The current through a distributor is not constant because tappings are taken at various places along its length.

- While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ± 6% of rated value at the consumer's terminals.

Service mains:

- The service mains are generally a small cable which connects the distributor to the consumers' terminals.

3. CLASSIFICATION OF DISTRIBUTION SYSTEMS:

A distribution system may be classified according to;

i. According to supply:

✓ According to supply, distribution system may be classified as:

(a) DC Distribution system

(b) AC Distribution system

ii. According to construction:

Compare the Overhead and Underground Distribution System. (Apr/May 2017)

✓ According to type of construction distribution system may be classified as:

(a) Overhead system

(b) Underground system

(a) Overhead system:

- The overhead system is employed for distribution.
- It is 5 to 10 times cheaper than the underground system.
- The spacing is provided between the conductors, at the supports & intermediate points.
- This spacing provides insulation which avoids an electric discharge between the conductors.

(b) Underground system:

- The underground system is used at places where overhead construction is impracticable.
- In crowded areas, underground system using cables is preferred.
- The line surges are suppressed by using the cables.
- It can save transformers and generators from the damage due to line surges.

S.NO	OVERHEAD SYSTEM	UNDERGROUND SYSTEM
1	It is employed for distribution as it is 5 to 10 times cheaper than the underground system.	It is used at places where overhead construction is not practicable.

2	The overhead lines can be easily repaired from the faults occurring due to lightening, short circuits, breakage of line etc.,	The underground lines is difficult to repair from the faults occurring due to short circuits, breakage of line etc.,
3	The maximum stress exists between the conductor and earth (supporting structure).	The maximum stress exists on the insulation between the conductors.
4	The voltage level used in overhead system can be as high as 400KV.	The voltage level used in underground system is below 66KV (due to insulation difficulties).
5	The volume of copper required is 1/4 the volume of copper required for 2-wire DC system.	The volume of copper required is same as that required for two wire DC system.
6	It is difficult to find the exact point of fault if the transmission lines are very long.	It is easy to find the exact point of fault as compared with overhead system.
7	The transmission by overhead system is cheaper.	The transmission by underground system is costlier.
8	The maintenance cost of the underground system is more.	The maintenance cost of the underground system is less.

iii. According to connection:

(a) Radial distribution system

(b) Ring main distribution system

(c) Inter-connected distribution system

Radial distribution system:

- When the distributor is connected to substation on one end only with the help of feeder, then the system is called radial distribution system.
- The feeders, distributors and service mains are radiating away from the substation hence name given as radial system.
- There are combinations of one distributor and one feeder, connecting that distributor to the substation.

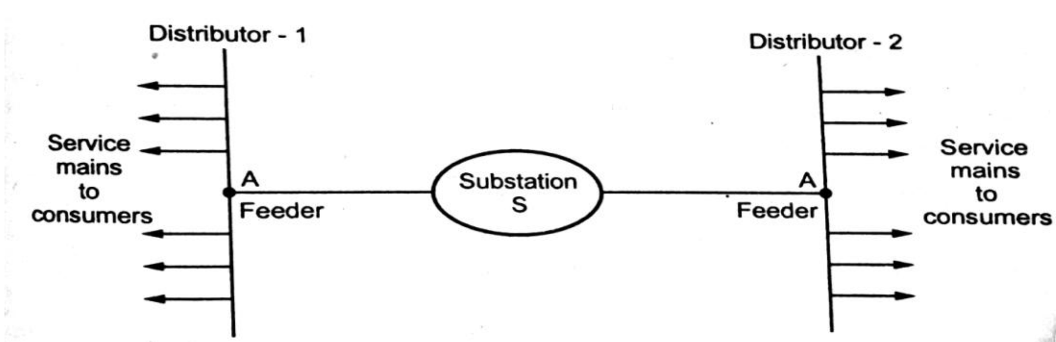

Figure 5.3: Radial distribution system

Advantages:

- ✓ Simplest.
- ✓ The initial cost is low.
- ✓ Useful when the generation is at low voltage.
- ✓ Preferred when the station is located at centre of the load.

Disadvantages:

- ✓ The end of distributor near to the substation gets heavy loaded.
- ✓ When load on the distributor changes, the consumer faces serious voltage fluctuations.
- ✓ As consumers are dependent on single feeder and distributor, a fault on any of these two causes interruption in supply.

Drawbacks:

- ✓ A distributor nearest to the substation is heavily loaded.
- ✓ Due to load variation, voltage fluctuations are more at the far ends.
- ✓ If any fault occurs, there is no continuity of supply.

Ring Main Distribution system:

- A ring main distribution system is arranged to form a closed loop.
- It may have one or more feeding points.
- The feeder covers the whole area of supply in the ring fashion and finally returning to the substation.

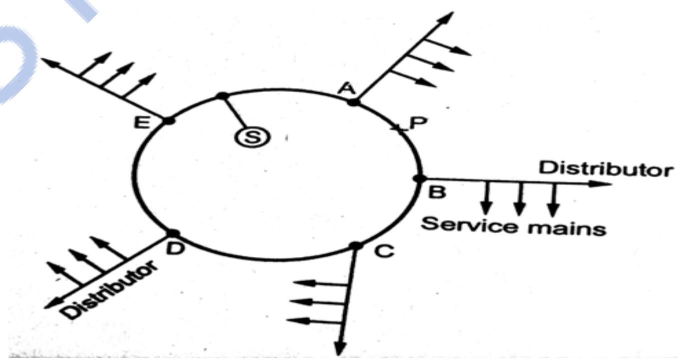

Figure 5.4: Ring Main distribution system

- The feeder in the ring fashion is divided into number of sections as AB, BC, CD, DE and EA.
- The various distributors are connected at A, B, C, D and E.
- Each distributor is supplied by the two feeders.

Advantages:

- ✓ Due to load variations, the voltage fluctuation is less at the far end.
- ✓ Better reliability.
- ✓ It gives continuity of supply, when fault occurs at any one distributor.

Interconnected system:

- When the feeder ring is energized by two or more than two generating stations or substations is called as interconnected system.

Advantages of Interconnected System:

- ✓ Better reliability.
- ✓ During peak load, reserve power capacity reduces and efficiency increases.
- ✓ It gives continuity of supply.

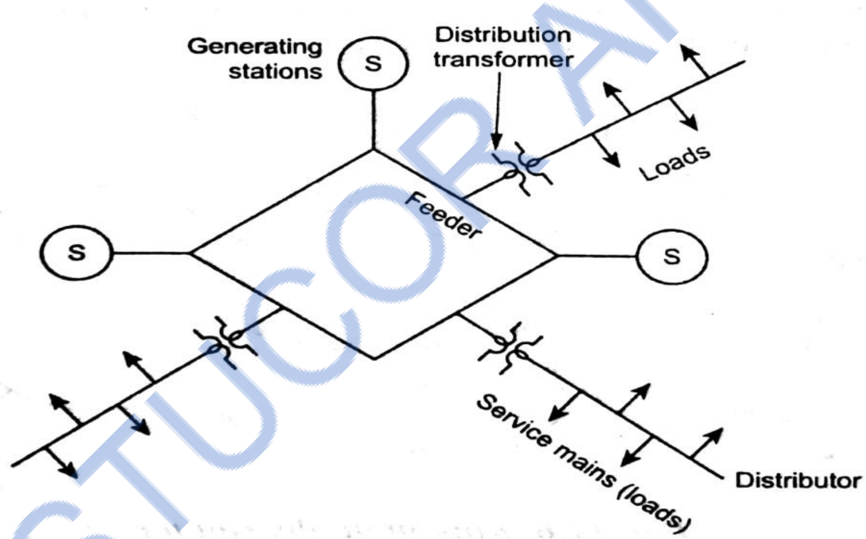

Figure 5.5: Interconnected system

4. AC DISTRIBUTION SYSTEM:

- Electrical energy is generated, transmitted & distributed in the form of AC.
- Because, alternating voltage can be changed in magnitude by means of a transformer.
- Transformer has made it possible to transmit AC power at high voltage.
- High transmission and distribution voltages have reduced the current in the conductors & the line losses.
- The AC distribution system is classified into:

  i. primary distribution system and

  ii. Secondary distribution system.

i. Primary distribution system:

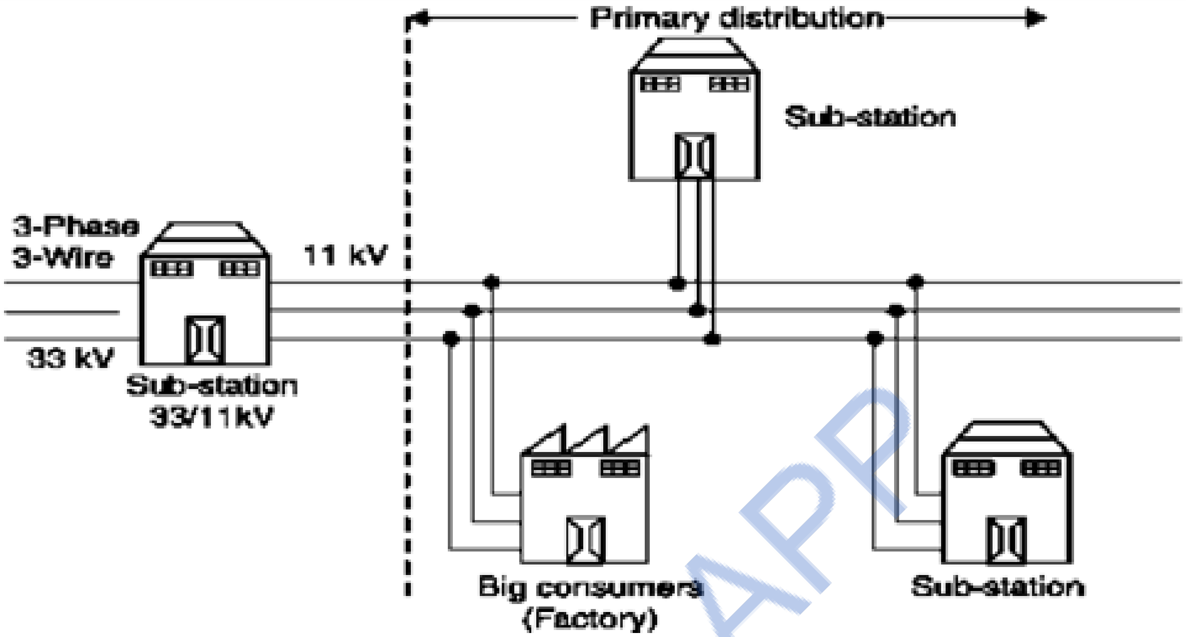

Figure 5.6: Primary distribution system

- It is that part of AC distribution system which operates at voltages higher than general utilization.
- It handles large blocks of electrical energy than the average low voltage consumer uses.
- The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed.
- The most commonly used primary distribution voltages are 11 kV, 6·6 kV and 3·3 kV.
- Due to economic considerations, primary distribution is carried out by 3- phase, 3-wire system.
- Electric power from the generating station is transmitted at high voltage to the substation located in or near the city.

ii. Secondary distribution system:

- It is that part of AC distribution system.
- The secondary distribution employs 400/230V, 3phase, 4wire system.
- Fig 5.6 shows a typical secondary distribution system.
- The primary distribution circuit delivers power to various substations, called distribution sub-stations.

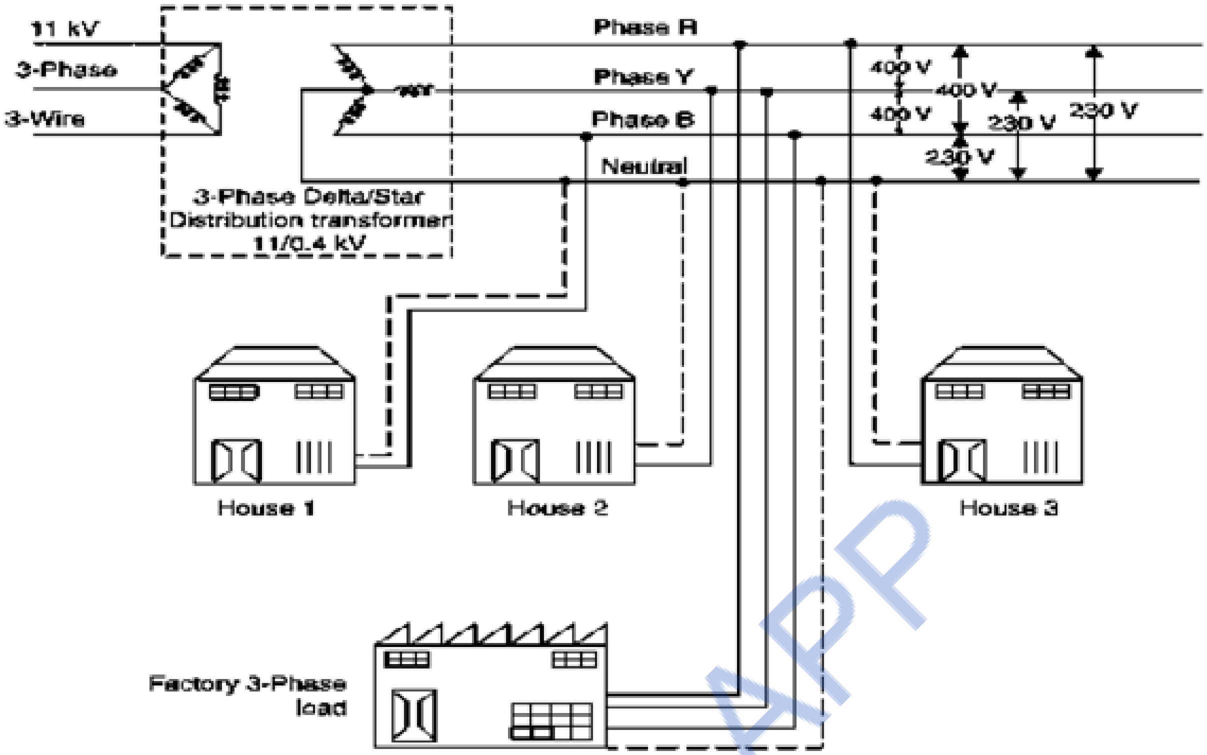

Figure 5.7: Secondary distribution system

- The substations are situated near the consumer's localities.
- It contains step-down transformers.
- At each distribution substation, the voltage is stepped down to 400V.
- The power is delivered by 3-phase, 4-wire AC system.
- The voltage between any two phases is 400V and between any phase and neutralize 230V.
- The single phase domestic loads are connected between anyone phase and the neutral.
- The 3phase 400V motor loads are connected across 3- phase lines directly.

5. D.C. DISTRIBUTION SYSTEM:

- The electric power is generated, transmitted and distributed as AC.
- For certain applications, DC supply is necessary.
- DC supply is required for the operation of variable speed machinery (DC motors).
- For this purpose, AC power is converted into DC power at the substation by rectifiers.
- The DC system is classified into
  i. 2-wire DC system
  ii. 3-wire DC system

(i) 2-wire DC system:

- This system consists of two wires.
- One is the **outgoing or positive wire** and the other is the **return or negative wire.**
- The loads such as lamps, motors etc. are connected in parallel between the two wires.
- This system is never used for transmission purposes due to low efficiency.
- It may be employed for distribution of DC power.

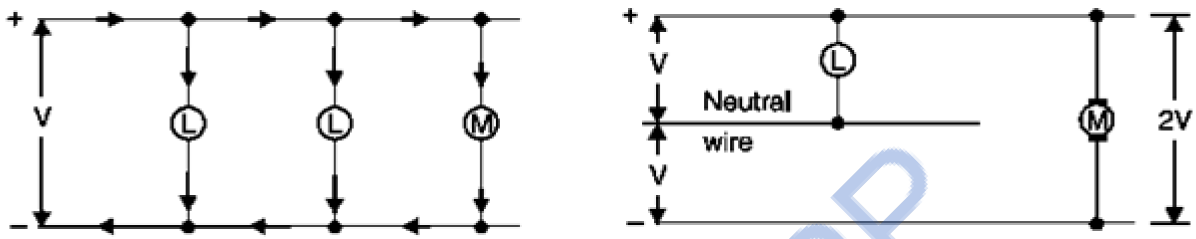

Figure 5.8: DC distribution system

(ii) 3-wire DC system:

- It consists of two outers and a middle or neutral wire which is earthed at the substation.
- The voltage between the outers is twice the voltage between outer and neutral wire.

Advantage:

It have two voltages at the consumer terminals viz., V between any outer and the neutral and 2V between the outers.

- ✓ Loads requiring high voltage are connected across the outers.
- ✓ Loads requiring less voltage are connected between outer and the neutral.

6. EARTHING:

- The process of connecting the metallic frame (i.e., non- current carrying part) of electrical equipment or some electrical part of the system (e.g., neutral point in a star-connected system) to the earth is called grounding or Earthing.
- The potential of the earth is to be considered zero for all practical purposes.
- Earthing is to connect any electrical equipment to earth with a very low resistance wire, making it to attain earth's potential.
- This ensures safe discharge of electrical energy due to failure of the insulation line coming in contact with the casing, etc.
- Earthing brings the potential of the body of the equipment to zero i.e., to the earth's potential, thus protecting the operating personnel against electrical shock.

The earth resistance is affected by the following factors:

(a) Material properties of the earth, wire and the electrode.

(b) Temperature and moisture content of the soil.

(c) Depth of the pit.

(d) Quantity of the charcoal used.

Necessity of Earthing:

The requirement for provision of earthing can be listed as follows:

- To protect the operating personnel from the danger of shock.
- To maintain the line voltage constant, under unbalanced load condition.
- To avoid risk of fire due to earth leakage current through unwanted path.
- Protection of the equipments.
- Protection of large buildings and all machines fed from overhead lines against lighting.

Methods of Earthing:

The various methods of earthing in common use are,

(a) Plate earthing

(b) Pipe earthing

(c) Rod earthing

(d) Strip or wire earthing

(a) Plate earthing:

- In this method either a copper plate of 60cm × 60cm ×3.18cm

  (Or)

  GI plate of 60cm × 60cm × 6.35cm is used for earthing.
- The plate is buried into the ground not less than 3m from the ground level.
- The earth plate is embedded in alternate layers of coal and salt for a thickness of 15cm as shown in figure (5.9).
- In addition, water is poured for keeping the earth's electrode resistance value below a maximum of 5Ω. The earth wire is securely bolted to the earth plate.
- A cement masonry chamber is built with a cast iron cover for easy regular maintenance.

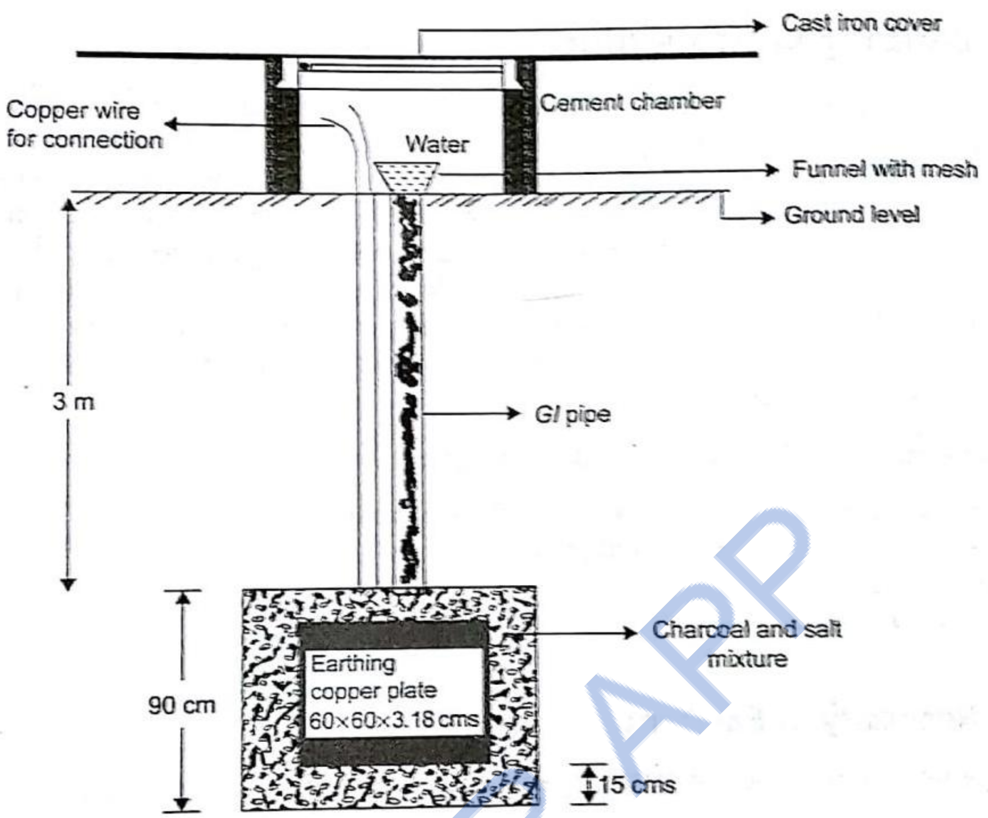

Figure 5.9: Plate Earthing

(ii) Pipe earthing:

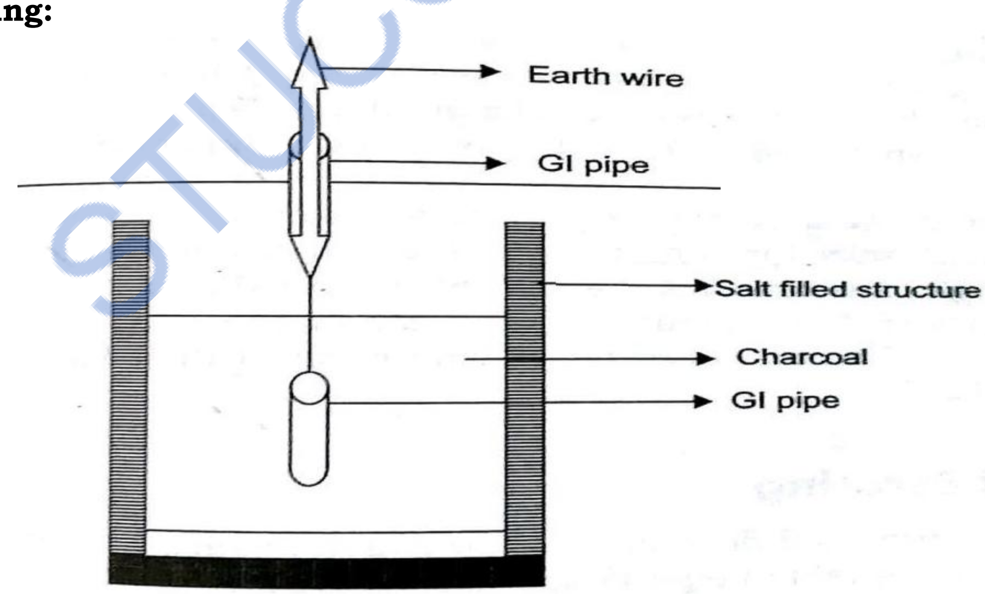

Figure 5.10: Pipe Earthing

- Earth electrode made of a GI (galvanized iron) pipe of 38mm in diameter and length of 2m (depending on the current) with 12mm holes on the surface is placed upright at a depth of 4.75cm in a permanently wet ground.

- To keep the value of the earth resistance at the desired level, the area (15 cm) surrounding the GI pipe is filled with a mixture of salt and coal.
- The efficiency of the earthing system is improved by pouring water through the funnel periodically.
- The GI earth wires of sufficient cross-sectional area are run through a 12.7mm diameter pipe (at 60cm below) from the 19mm diameter pipe and secured tightly at the top as shown in figure (5.10).

(iii) Rod earthing:

- It is the same method as pipe earthing.
- A copper rod of 12.5cm (1/2 inch) diameter or 16mm (0.6in) diameter of galvanized steel or hollow section 25mm (1 inch) of GI pipe of length above 2.5m (8.2 ft) are buried upright in the earth manually or with the help of a pneumatic hammer.
- The length of embedded electrodes in the soil reduces earth resistance to a desired value.

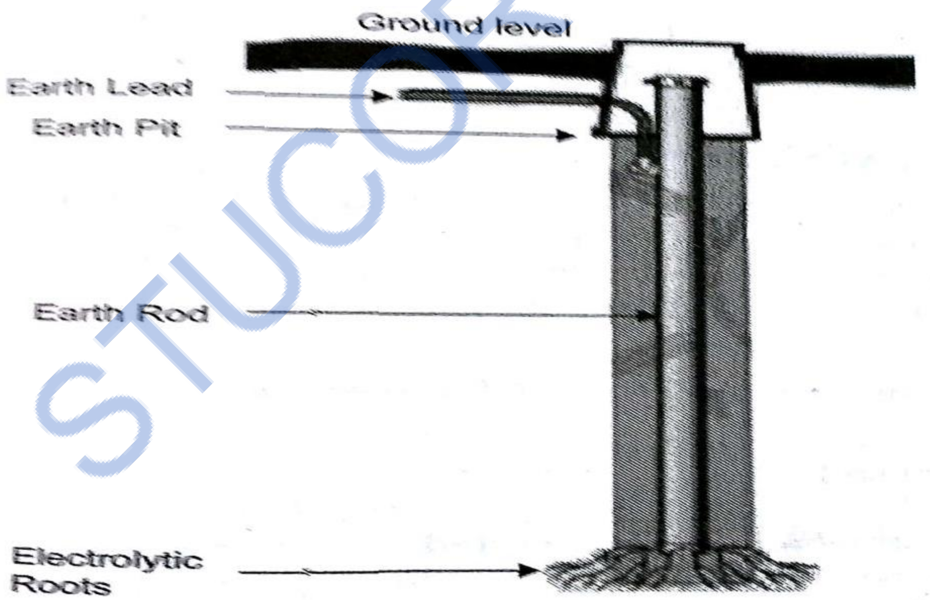

Figure 5.11: Rod Earthing

(iv) Strip or wire earthing:

- In this method of earthing strip electrodes of cross- section not less than 25mm × 1.6mm (1 in × 0.06in) is buried in horizontal trenches of a minimum depth of 0.5m.
- If copper with a cross-section of 25mm × 4mm (1inch × 0.15inch) is used and a dimension of 3.0 mm2 if it's a galvanized iron or steel.
- If at all round conductors are used, their cross-section area should not be too small, say less than 6.0 mm2 if it's a galvanized iron or steel.

- The length of the conductor buried in the ground would give a sufficient earth resistance and this length should not be less than 15m.
- The electrodes shall be as widely distributed as possible in a single straight or circular trenches radiating from a point.
- This type of earthing is used where the earth bed has a rocky soil and excavation work is difficult.

Selection of Earthing:

- The type of earthing to be provided depends on many factors such as type of soil, type of installation, etc.
- The following table helps in selecting a type of earthing for a particular application.

S.No	Type of Earthing	Application
01	Plate earthing	Large installations such as transmission towers, all sub-stations generating stations
02	Pipe earthing	• For domestic installations such as heaters, coolers, refrigerators, geysers, electric iron, etc. • For 11kV/400V distribution transformers • For induction motors rating upto 100HP • For conduit pipe in a wall, all wall brackets
03	Rod earthing	In areas where the soil is loose or sandy
04	Strip of wire earthing	In rocky ares

Earth Resistance:

- The earth resistance should be kept as low as possible so that the neutral of any electrical system, which is earthed, is maintained almost at the earth potential.
- The earth resistance for copper wire is 1Ω and that of GI wire less than 3Ω.
- The typical value of the earth resistance at large power stations is 0.5Ω , major substations is 1Ω, small sub stations is 2 Ω and in all other cases 5Ω.
- The resistance of the earth depends on the following factors:
    - Condition of soil.
    - Moisture content of soil.
    - Temperature of soil.

- Depth of electrode at which it is embedded.
- Size, material and spacing of earth electrode.
- Quality and quantity of coal and salt in the earth pit.

Difference between Earth Wire and Neutral Wire:

Neutral Wire:

- In a 3-phase 4-wire system, the fourth wire is a neutral wire.
- It acts a return path for 3-phase currents when the load is not balanced.
- In domestic single phase AC circuit, the neutral wire acts as return path for the line current.

Earth Wire:

- Earth wire is actually connected to the general mass of the earth and metallic body of the equipment.
- It is provided to transfer any leakage current from the metallic body to the earth.

7. SWITCH FUSE UNIT:

- The electrical equipments are designed to carry a particular rated value of current under normal conditions.
- Under abnormal conditions such as short circuits, overload, or any fault; the current rises above this value, damaging the equipment and sometimes resulting in fire hazard.
- Fuses come into operation under fault conditions.
- A fuse is short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuits.
- Under normal operating conditions it designed to carry the full load current.
- If the current increases beyond this designed value due to any of the reasons mentioned above, the fuse melts, isolating the power supply from the load.

a) Desirable characteristics of a Fuse Element:

- The material used foe fuse wires must have the following characteristics:
  - Low melting point e.g., tin, lead.
  - High conductivity e.g., copper.
  - Free from deterioration due oxidation e.g., silver.
  - Low cost e.g., tin, copper.

b) Materials:

- Materials used are tin lead or silver having low melting points. Use of copper or iron is dangerous, though tinned copper may be used.

c) Types of Fuses:

Fuses are classified into following types,

1. Re-wireable or kit-Kat fuse
2. High rupturing capacity (H.R.C) cartridge fuse

1. Re-wireable or Kit-Kat Fuse:

- Re-wireable fuse is used where low values of fault current are to be interrupted.
- These fuses are simple in construction, cheap and available up to a current rating of 200A.
- They are erratic in operation and their performance deteriorates with time.
- An image of re-wireable fuse is as shown in figure (5.12)

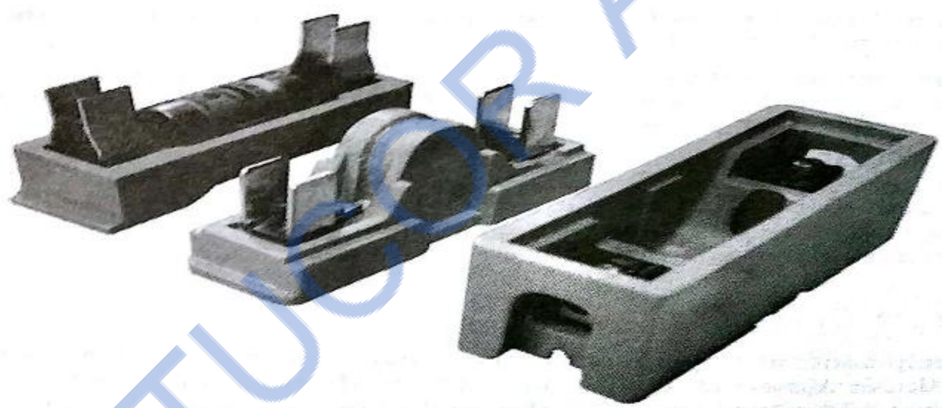

Figure 5.12: Re-wireable or Kit-Kat Fuse

2. High Rupturing Capacity (HRC) Cartridge Fuse:

- Figure (5.13) shown an image of HRC cartridge fuse and figure (5.14) shown the essential parts of a typical HRC cartridge fuse.
- It consists of a heat resisting ceramic body having metal end-caps to which a silver current-carrying element is welded.
- The space within the body surrounding the elements is completely packed with a filling powder.
- The filling material may be chalk, plaster of Paris, quartz or marble dust and acts as an arc quenching and cooling medium.
- Therefore, it carries the normal current without overheating.
- Under normal loading conditions, the fuse element is at a temperature below its melting point.

- When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak.
- The heat produced in the process vaporizes the melted silver element.
- The chemical reaction between the silver vapours and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

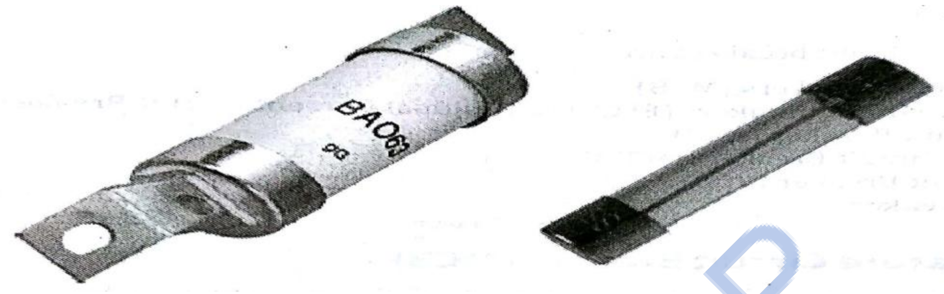

Figure 5.13: HRC Cartridge Fuse

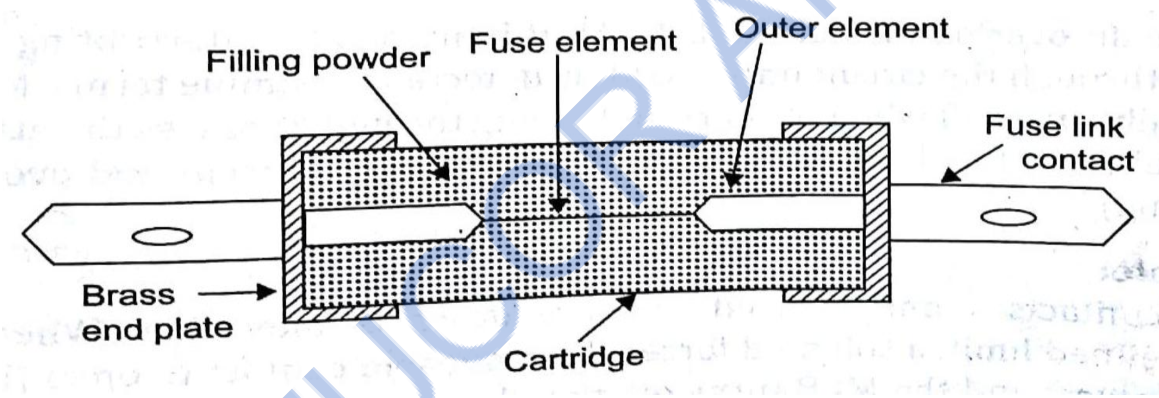

Figure 5.14: Cross section of HRC Cartridge Fuse

8. CIRCUIT BREAKER:

- Electrical circuit breaker is a switching device which can be operated manually and automatically for the controlling and protection of electrical power system, respectively.
- During shirt circuits fault or any other type of electrical fault, these equipments, as well as the power network, suffer a high stress of fault current, which in turn damage the equipment and networks permanently.
- For saving these equipment and the power networks, the fault current should be cleared from the system as quickly as possible.
- Again after the cleared, the system must come to its normal working condition as soon as possible for supplying reliable quality power to the receiving ends.
- The circuit breaker is the special device all the required switching operations during current carrying condition.

- A circuit breaker essentially consists of fixed and moving contacts, called electrodes.
- Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty.
- The contacts can be opened manually or by remote control whenever desired.
- When a fault occurs in any part of the system, the trip coils of the breaker get energized and the moving contacts are pulled apart by some mechanism, thus opening the circuits.

The main types of circuit breakers are,

- Miniature circuit breakers (MCB)
- Molded Case Circuits Breakers (MCCB)
- Earth leakage circuit breakers (ELCB) or Residual Current Breaker (RCCB)
- Air blast Circuits Breaker (ACB)
- Vacuum Circuits Breaker (VCB)
- SF6 Circuits Breaker.

9. MINIATURE CIRCUIT BREAKERS (MCB)

- Minimum circuit breakers are electromechanical devices which protect an electrical circuit from over currents.
- Over currents in an electrical circuit may results from short circuits overload, or faulty design.
- MCB is better alternative than fuse, since it does not require replacement once an overload is detected.
- MCB functions by interrupting the continuity of electrical flow through the circuits once a fault is detected.
- In simple terms, MCB is a switch which automatically turns off when the current flowing through it passes the maximum allowable limit.
- Generally MCB is designed to protect against over current and over temperature faults (over heating).

Working Principle:

- There are two contacts - one is fixed and the other is moveable.
- When the current exceeds the predefined limit, a solenoid forces the moveable contact to open (i.e., disconnect from the fixed contact) and the MCB turns off, thereby stopping the current from flowing in the circuits.

Operation:

- An image of MCB is shown in figure (5.15) and internal parts of an MCB are shown in figure (5.16).
- It mainly consists of one bi- metallic strip, one trip coil and one hand operated on-off lever.
- Electric current carrying path of a MCB is as follows - first left hand side power terminal-then bimetallic strip - then current coil - then moving contact - then fixed contact and lastly right hand side power terminal, and all are arranged in series.

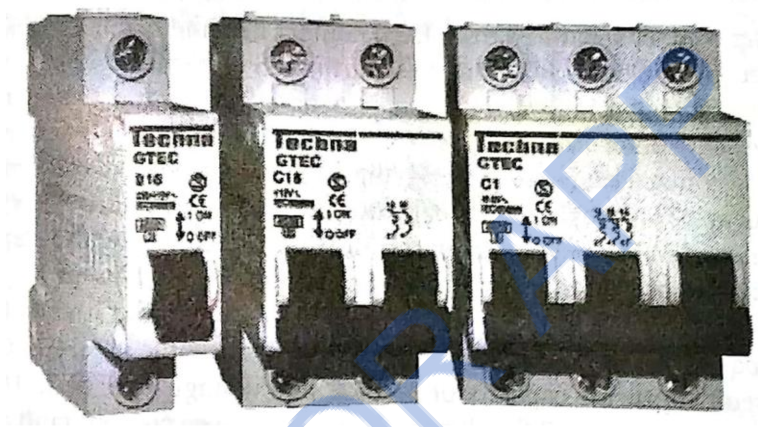

Figure 5.15: Miniature circuit breakers

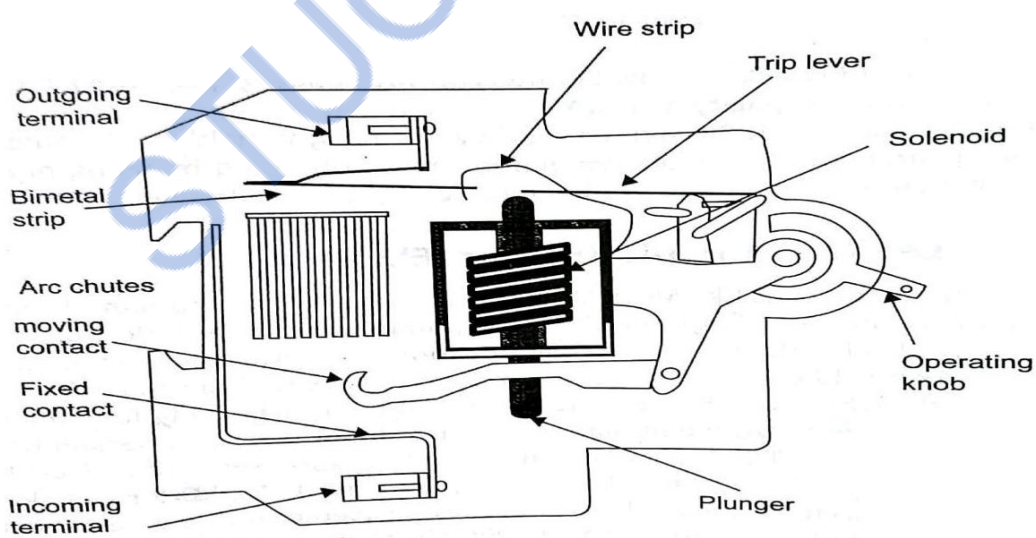

Figure 5.16: Cross section of MCB

- If circuit is overload for a long time, the bi -metallic strip becomes over heated and deformed. This deformation of bi-metallic strip causes displacement of latch point.
- The moving contact of the MCB is so arranged by means of spring, with this latch point, that a little displacement of latch causes releases of spring and makes the moving contact to move for opening the MCB.

- The current coil or trip coil placed in such a manner that during SC faults, the MMF of that coil causes its plunger to hit the same latch point and force the latch to be displaced. Hence, the MCB will open in the same manner.
- Again when operating lever of the MCB is operated by hand, that means when we make the MCB at off position manually, the same latch point is displaced as a result moving contact separated from fixed contact in same manner.
- So, whatever may be the operating mechanism, i.e., may be due to deformation of bi-metallic strip or may be due to increased MMF of trip coil or may be due to manual operation - actually the same latch point is displaced and the deformed spring is released, which is ultimately responsible for movement of the moving contact.
- When the moving contacts are separated from fixed contact, there may be a high chance of arc.
- This are then goes up thorough the arc runner and enters into arc splitters and is finally quenched.
- When we switch on the MCB, we actually reset the displaced operating latch to its previous on position and make the MCB ready for another switch off or trip operation.
- These are available in single pole, double pole, triple pole, and four pole versions with neutral poles, if required.
- The normal current ratings are available from 0.5-63 A with a sym-metrical short circuits rupturing capacity of 3-10kA, at a voltage level of 230/440v.
- MCBs are generally designed to trip within 2.5 millisecond when an over current fault arises.
- In case of temperature rise or over heating it may take 2 seconds to 2 min for the MCB to trip.

Advantages:

- MCBs are replacing the re-wireable switch i.e., fuse units for low power domestic and industrial applications.
- The disadvantages of fuses, like low SC interrupting capacity (say 3kA), Etc, are overcome with high SC breaking capacity of 10kA.
- MCB is combination of all three functions in a wiring system like switching, overload and short circuits protection. Overload protection can be obtained by using bi-metallic strips where as shorts circuit protection can be obtained by using solenoid.

10. EARTH LEAKAGE CIRCUITS BREAKER (ELCB):

- None of the protection devices like MCB, MCCB, etc; it can protect the human life against electric shocks or avoid fire due to leakage current.
- An Earth Leakage Circuits Breakers (ELCB) is a device used to directly detect currents leaking to earth from an installation and cut the power.
- There are two types of ELCBs:
  - (i) Voltage Earth Leakage Circuits Breaker (voltage -ELCB)
  - (ii) Current Earth Leakage Circuits Breaker (Current -ELCB)

(i) Voltage Earth Leakage Circuits Breaker (voltage -ELCB):

- Voltage –ELCB is a voltage operated circuits breakers. The device will function when the current passes through the ELCB.
- Voltage-ELCB contains relay coil and one end of the coil is connected to metallic load body and the other end is connected to ground wire as shown in figure (5.17).
- If the voltage of the equipment body rises (by touching phase to metal part or insulation failure of equipment), which could cause the difference between earth and load body voltage, and the danger of electric shock will occur.

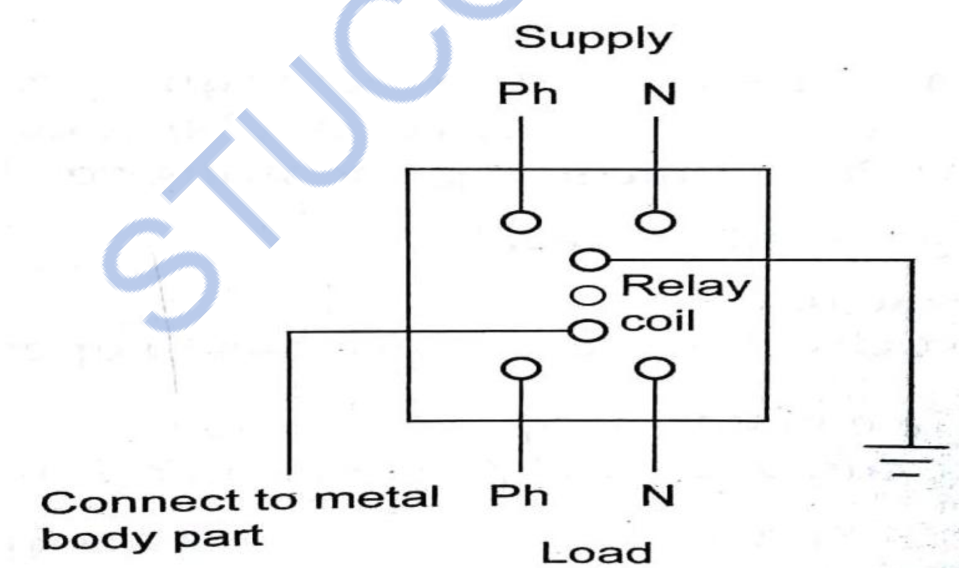

Figure 5.17: Voltage Earth Leakage Circuits Breaker

- This voltage difference will produce an electric current from the load metallic body and phase through the loop to the Earth.
- When voltage on the equipment metallic body rises to danger level i.e., which exceed to 50V, the flowing current through relay loop could move the relay contact by disconnecting the supply current and avoid from any danger electric shock.

- The ELCB detects fault currents from line to the earth (ground) wire within the installation it protects.
- If sufficient voltage appears across the ELCB's sensing coil, it will switch off the power, and remain off until manually reset.
- A voltage – sensing ELCB does not sense fault current from line to any other earthed body.

(ii) Current Earth Leakage Circuits Breaker (Current -ELCB):

- Current –ELCB is a current operated circuit breaker which is a commonly used ELCB.
- Current-ELCB consists of a 3- winding transformer, which has two primary windings and 1 secondary winding as shown in figure (5.18).
- Neutral and line wires act as the two primary windings. A wire wound coil is the secondary winding.
- The current thorough the secondary winding is zero at the balanced condition.
- In the balanced condition, the flux due to current through the phase wire will be neutralized by the current through the neutral wire, since the current which flows from the phase will be returned back to the neutral.
- When a fault occurs, a small current will flow to the ground also. This makes an unbalanced between line and neutral currents and creates an unbalanced magnetic field.
- This induces a current through the secondary winding, which is connected to the sensing circuits.
- This will sense the leakage and send a signal to the tripping system and trips the contact.

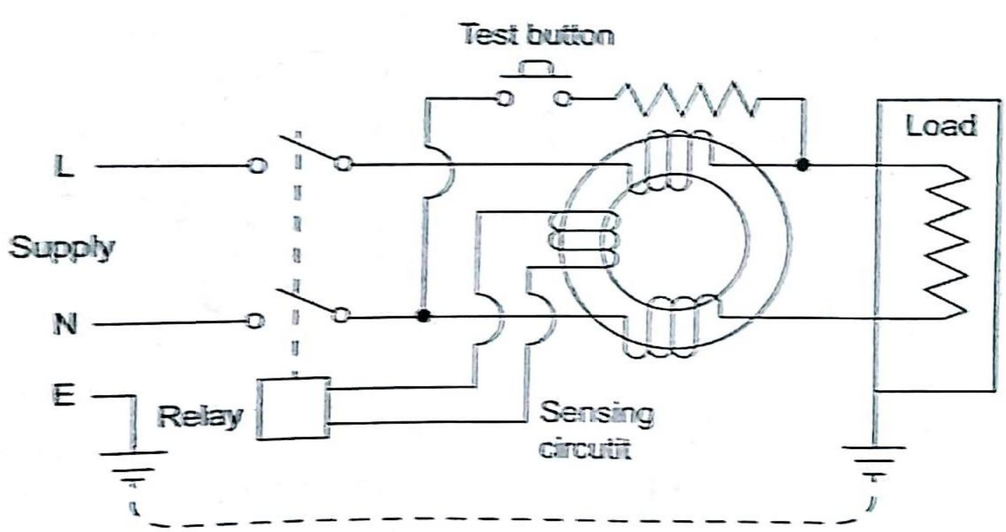

Figure 5.18: Current Earth Leakage Circuits Breaker

11. MOLDED CASE CIRCUITS BREAKER (MCCB):

- Molded case circuits breakers are electromechanical devices which protect a circuits from over current and short circuits.
- They provide over current and short circuits protection for circuits ranging from 63A up to 3000 A.
- Their primary functions are to provide a means to manually open a circuit and automatically open a circuit under overload or short circuits conditions respectively.
- The over current, in an electrical circuit, may result from short circuits, overload of faulty design.
- MCCB is an alternative to a fuse, since it does not require replacement once an overload is detected.
- Unlike a fuse, an MCCB can be easily reset after a fault and offer improved operational safety and convenience without incurring operating cost.
- Molded case circuits breakers generally have a,
- Thermal element for over current and
- Magnetic element for short circuits release which has to operate faster.
- The MCCBs are comprised of five major components such as molded case or frame operating mechanism, arc extinguishers, contacts and trip components as shown in figure (5.19)

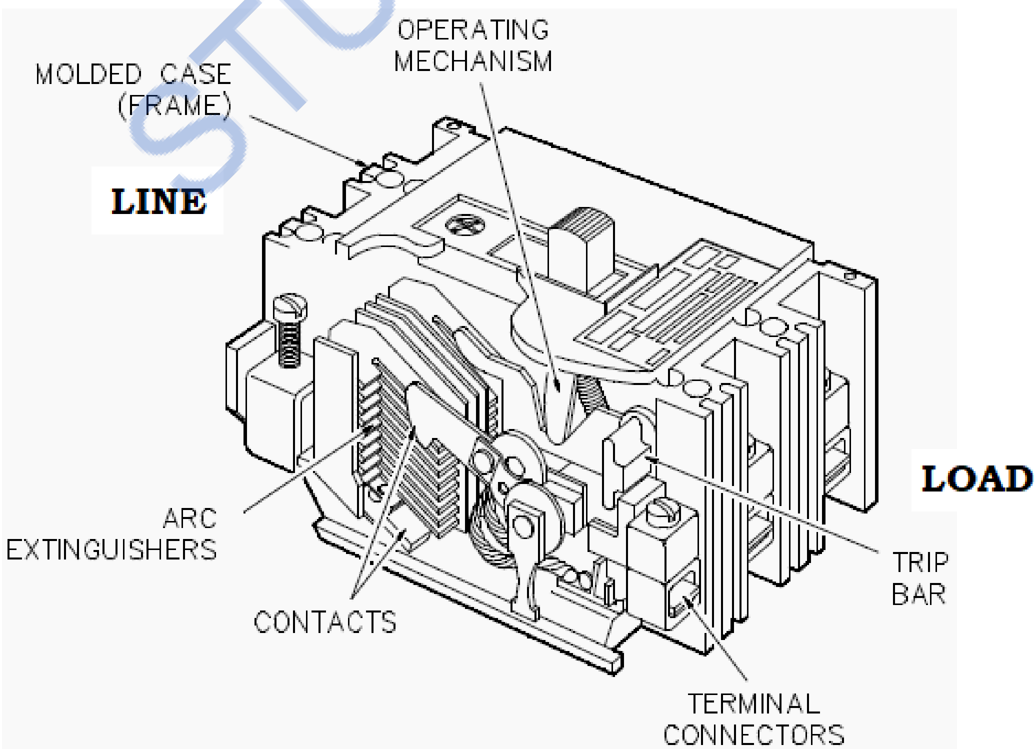

Figure 5.18: Current Earth Leakage Circuits Breaker

- MCCB are manufactured such that the end user will not have access to internal workings of the over-current protection device.
- Generally constructed of two pieces of heavy-duty electrically insulated plastic, these halves are riveted together to form the whole.
- Inside the plastic shell is series of thermal elements and a spring-loaded trigger.
- When the thermal element gets too warm, from an over current situation, the spring trips, which in turn will shut off the electrical circuits.

Operating mechanism:

- At its core, the protection mechanism employed by MCCBs is based on the same physical principles used by all type of thermal – magnetic circuit breakers.
- Overload protection is accomplished by means of a thermal mechanism.
- MCCBs have a bimetallic contact that expands and contacts in response to changes on temperature.
- Under normal operating conditions, the contact allows electric current through the MCCB.
- However as soon as the current exceeds the adjusted trip value, the contact will start to heat and expend until the circuits is interrupted.
- The thermal protection against overload is designed with a time delay to allow short duration over current, which is a normal part of operation for many devices.
- Fault protection is accomplished with electromagnetic induction, and the response is instant.
- Fault currents should be interrupted immediately, no matter if their duration is short or long.
- Whenever a fault occurs, the extremely high current induces a magnetic field in a solenoid coil located inside the breaker – this magnetic induction trips a contact and current it interrupted.
- As a complement to the magnetic protection mechanism, MCCBs have internal arc dissipation measure to facilitate interruption.
- As with all types of circuit breakers, the MCCB includes a disconnection switch which is used to trip the breaker manually.
- It is used whenever the electric supply must be disconnected to carry out field work such as maintenance or equipment upgrades.

Applications:

- Molded case circuits breakers can have very high current ratings, which allows them to be used in heavy duty applications. Such as,
  - Main electric feeder protection
  - Capacitor bank protection
  - Generator protection
  - Welding applications
  - Low current application that require adjustable trip setting
  - Motor protection

12. SAFETY PRECAUTIONS AND FIRST AID

Safety precautions in Handling Electrical Appliance:

It is essentially important to take precautions when we are working with electricity and using electrical appliances. Here, some of the basic precautions are mentioned for safe usage of electrical appliance:

1. Follow the manufacturer's instructions:

- Always read the manufacturer's instructions carefully before using a new appliance.

2. Replace or repair damaged power cords:

- Exposed wiring is a danger that cannot be ignored. If you see the protective coating on a wire is stripped away, be sure to replace it or cover it with electrical tape as soon as possible.

3. Keep electrical equipment or outlets away from water:

- Avoid water at all times when working with electricity. Never touch or repairing any electrical equipments or circuits with wet hands.
- It increases the conductivity of electrical current. Keep all electrical appliances away from water such as sinks, bathtubs, pools or overhead vents that may drip.

4. Use insulated tools while working:

- Always use appropriate insulated rubber gloves, goggles, protective clothes and shoes with insulated soles while working on any branch circuits or any other electrical circuits.
- Use only tools and equipment with non-conducting handles when working on electrical devices.
- Never use metallic pencils or rulers or wear rings or metal watchbands when working with electrical equipment as they cause a strong electric shock.

5. Don't overload your outlets:

- Every outlet in your home is designed to deliver a certain amount of electricity; by plugging too many devices into it at once, you could cause a small explosion or a fire.
- If you have a lot of things to plug in, use a power strip that can safely accommodate your needs.

6. Shut-off the power supply:

- Always make sure that the power source should be shut-off before performing any work related to electricity.
- For example; inspecting, installing, maintaining or repairing.

7. Avoid extension cords as much as possible:

- Running extension cords through the house can trip up residence; this can cause injury and damage to the wire or outlet if it causes the cord to be ripped out of the wall.
- If you find yourself using extension cords very often, consider having an electrician install new outlets throughout your home.

8. Avoid the usage of flammable liquids:

- Never use highly flammable liquids near electrical equipment.
- Never touch another person's equipment or electrical control devices unless instructed to do so.

9. Use electric tester:

- Never try repairing energized equipment. Always check that it is de-energized first by using a tester.
- When an electric tester touches a live or hot wire, the bulb inside the tester lights up showing that an electrical current is flowing through the respective wire.
- Check all the wires, the outer metallic covering of the service panel any other hanging wires with an electrical tester before proceeding with your work.

10. Display danger board:

- Danger board should be displayed at the work place.
- We should not allow any unauthorized person to enter in the working place and we should not put any new equipment into the service without necessary testing by the concern authority.

11. Usage of circuits breaker or fuse:

- Always use a circuit breaker or fuse with the appropriate current rating.
- Circuit breakers and fuses are protection devices that automatically disconnect the live wire a condition of short circuits or over current occurs.
- The selection of the appropriate fuse or circuit breaker is essential.
- Normally for protection against short circuits a fuse rated of 150% of the normal circuit current is selected.

<u>First Aid for Electric Shock Victims:</u>

1. Don't touch them!
2. Unplug the appliance or turn off the power at the control panel.
3. If you can't turn off the power, use a piece of wood, like a broom handle, dry rope or dry clothing, to separate the victim from the power source.
4. Do not try to move a victim touching a high voltage wire. Call for emergency help.
5. Keeps the victim lying down. Unconscious victims should be placed on their side to allow drainage of fluids. Do not move the victim if there is a suspicion of neck or spine injuries unless absolutely necessary.
6. If the victim is not breathing, apply mouth-to-mouth resuscitation. If the victim has no pulse, begin cardiopulmonary resuscitation (CPR). Then cover the victim with a blanket to maintain body heat, keep the victim's head low and get medical attention.

TWO MARKS

1. What are the advantages of three phase system?

- In the three phase circuit, the total power is more nearly uniform unlike in a single phase circuit.
- Three phase machines have better power factor and efficiency.
- The capacity of three phase machine is higher.

2. What are the principle divisions of an electric power system?

- The structure of power system can be divided into three parts,
  - Generating station
  - Transmission system
  - Distribution system

3. What is meant by distribution system?

- That part of power system which distributes electric power for local use is known as distribution system.

4. What are the parts of distribution system?

- Feeders
- Distributors
- Service mains

5. What are the different types of distributions?

AC Distribution:

i. Primary distribution
ii. Secondary distribution

DC Distribution:

i. 2-wire dc system
ii. 3-wire dc system

6. What are the advantages of ring main distributor?

- There are less voltage fluctuations at consumer's terminals.
- The system is very reliable as each distributor is feed via two feeders.

7. What is an interconnected system?

- When a feeding ring is energized by two or more than two generating stations or substations is called as interconnected system.

8. Define the terms feeders and service mains.

- Feeders: It is a circuit carrying power from a main substation to a secondary substation such that the current loading is the same throughout its length.
- Service mains: They are small conductors, which delivers power to the consumer premises up to the metering point.

9. What is earthing?

- It is the process of instant discharge of electrical energy into the earth through a low resistance wire.

10. Name the types of earthing.

- Pipe earthing
- Plate earthing
- Rod earthing
- Strip earthing

11. How is earthing done?

- It is carried out by connecting the neutral or non-current carrying part of the equipment to the ground.

12. What are the advantages of earthing?

- Ensures the safety of electrical appliances and devices from the excessive amount of electric current.
- Helps in the flow of electric current directly inside the ground.
- Keeps the electric appliance safe from the damage.
- It protects building breakdown from the lightning.

13. What are three main reasons for earthing?

- It keeps people safe by preventing electric shocks.
- It prevents damage to electrical appliances and devices by preventing excessive current from running through the circuit.
- It prevents the risk of fire that could otherwise be caused by current leakage.

14. What is the purpose of Using Salt and Coal in the Earthing?

- The salt soaks the alkali of the ground and the Coal makes the soil to hold the moisture.
- So, using these Salt and Coal helps to increase the overall conductivity of the earthing system.
- When the conductivity increases, the leakage current easily flows to the ground.
- It increases the efficiency of the overall earthing system.

15. What is pipe earthing?

- A galvanized steel perforated pipe is buried vertically, connecting all the electrical conductors to the ground where the depth of the pipe depends on the soil conditions.
- Pipe earthing is an economical type of earthing compared to other earthing methods.

16. What is the procedure for pipe earthing?

- 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.

17. What is Rod Earthing?

- This type of earthing system is similar to a pipe earthing system.
- A copper rod with galvanized steel pipe is placed upright in the ground physically or using a hammer.
- The embedded electrode lengths in the earth decrease the resistance of the earth to a preferred value.

18. What is Plate Earthing?

- The earthing system, where a copper or galvanized iron plate is used to connect all the earthing conductors to the earth is called Plate Earthing.
- Generally, the plate is placed vertically at a depth not less than three meters or 10 feet from the ground level.
- And all the conductors are connected to the plate.

19. What are the advantages of Plate Earthing?

- It can carry a very high current than rod earthing.
- It provides a very good conductivity between earthing conductors and the ground.
- Plate earthing helps to connect more number of ground wires or earth wires from different loads.

20. What are the applications of Plate Earthing?

- Plate Earthing is used in power stations, transmission lines, large electrical panels, high voltage transformers, where the amount of fault current is very high.

21. Mention the procedure for Plate Earthing.

- The size or dimension of the plate used in plate earthing is 60cm (H) x 60cm (W) x 3.18mm (D) for copper plate and 60cm (H) x 60cm (W) x 6.35mm (D) for the galvanized iron plate.
- Place the earthing plate vertically at a depth of below 3 meter from the ground level.
- Use a 12.5 mm diameter pipe to lay the earthing conductors through it.
- Use a 190mm diameter pipe to connect the funnel and earthing plate.
- Put the Coal, Sand, and salt around the earthing plate. After that fill the top with black soil.
- At last put the water to the earthing to increase the conductivity.

22. Mention the disadvantages of Plate Earthing.

- The main disadvantage of plate earthing is the high installation cost.
- It is very costly to install a plate earthing system than plate earthing.

23. What is strip Earthing?

- In this type of earthing, a copper strip or GI Strip of minimum cross-section 25 mm × 1.6 mm is buried horizontally inside the Soil or ground.
- For this purpose around conductor can also be used and at that case the minimum cross-sectional area for copper conductor would be 3 mm^2 and for galvanized iron conductor it would be 6 mm^2.

24. What is difference between earthing and grounding?

- "Earthing" means that the circuit is physically connected to the ground which is Zero Volt Potential to the Ground (Earth).
- Whereas in "Grounding" the circuit is not physically connected to ground, but its potential is zero with respect to other points.

25. What is earth Resistance?

The resistance offered by the earth electrode to the flow of current into the ground is known as the earth resistance or resistance to earth.

26. What are the factors affecting the Earth resistivity?

- Soil Resistivity. It is the resistance of soil to the passage of electric current.
- Soil Condition
- Moisture
- Dissolved salts
- Climate Condition
- Physical Composition

- Location of Earth Pit
- Effect of grain size and its distribution

27. What is switch fuse unit?

- Switch fuse unit is compact combination, generally metal enclosed of a switch and a fuse. It is very widely used for low and medium voltages.

28. What is purpose of switch fuse unit?

- The Rewirable Switch Fuse Units are used for distributing power and protecting electrical devices and cables from damage due to fluctuations.

29. What are the advantages of Kit Kat Fuse?

- It is simple and quick to install, and it takes very little time to replace.
- It is incredibly cost-effective and is the most cost-effective type of fuse.
- The Electrical Kit Kat Fuse requires little to no maintenance.
- With typical handle and lugs options, the range is available from 16A to 500A.

30. What is HRC Fuse?

- HRC fuse (high rupturing capacity fuse) is one kind of fuse, where the fuse wire carries a short circuit current in a set period. If the fault occurs in the circuit then it blows off.

31. Mention the advantages and disadvantages of HRC Fuse.

Advantages of HRC Fuse:

- It clears high as well as low fault currents.
- Do not deteriorate with age.
- Having high-speed operation.
- Provides reliable discrimination.
- Require no maintenance.
- Cheaper than other circuit interrupting devices with same rating.
- Permit consistent performance
- Fusing operation is fast without Noise and Smoke

Disadvantages of HRC Fuse:

- After each operation, they have to be replaced.
- Heat being produced by the arc may affect the associated switches.

32. What are the Applications of HRC Fuse?

The applications of these fuses include the following.

- HRC fuses are used to protect the circuit from short circuits in HV switchgear.
- Used for backup safety.

- Used to protect electrical devices like motors, transformers, automobiles, etc
- These types of fuses are used in stators of motor.

33. What is circuit breaker?

- A circuit breaker is an automatically-operated electrical switch designed to protect an electrical circuit from damage caused by overload of electricity or short circuit.
- A circuit breakers function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow.

34. What is difference between fuse and circuit breaker?

- The main difference between fuse and circuit breakers is that fuses cannot be reused while circuit breakers can be reused over and over again.
- Circuit breakers are used to protect homes and devices against overloading and short-circuiting while fuses protect devices and homes against overloading only.

35. What type of circuit breaker is used in houses?

Miniature circuit breakers (MCBs), Residual current circuit breaker (RCCB) and Mounded Case Circuit Breaker (MCCB) are the most widely used electrical circuit breakers for domestic electrical connections.

36. What are the types of circuit breaker?

For low voltage rating circuits,

- Miniature circuit breakers (MCB)
- Molded Case Circuits Breakers (MCCB)
- Earth leakage circuit breakers (ELCB) or Residual Current Breaker (RCCB)

For high voltage rating circuits,

- Air blast Circuits Breaker (ACB)
- Vacuum Circuits Breaker (VCB)
- SF6 Circuits Breaker.

37. What is Miniature Circuit Breakers (MCB)?

- The MCB is an electromechanical device that switches off the circuit automatically if an abnormality is detected. The MCB easily senses the over current caused by the short circuit.

38. What is MCCB?

- MCCB is an abbreviation for Molded Case Circuit Breaker.
- The MCCB is a protective device protecting the circuit from overloading.
- Additionally, it has a switch that is operated manually for tripping the circuit.

- The device features two arrangements, one for the over current and one for the over-temperature.

39. Mention the similarity between MCB and MCCB.

- They both provide an element of protection
- The MCB and MCCB sense and protect the power circuit from the short circuit or over current situation.
- They are mostly used in low tension or low voltage circuit.

40. Give the advantages of MCCB.

- MCCB has an adjustable trip setting.
- It can interrupt very large currents.
- It has a movable trip unit.
- It has a very small tripping time thus fast switching during fault current.
- It also offers remote ON/OFF feature.
- It has a compact design & takes less space.

41. Mention the differences between the MCB and MCCB.

- The MCB's tripping circuit is fixed and is movable in the MCCB.
- MCBs have less than 100 amps, while MCCBs have as high as 2,500 amps.
- In MCB, the remote on/off is impossible, while in MCCB, it is possible by the use of shunt wire.
- The MCB is largely used in low circuit current, while MCCB is used for the heavy current circuit.
- The MCB is used for low energy requirements (domestic purposes), whereas the MCCB is used in high energy requirement regions (large industries).

42. What is ELCB?

- An Earth-leakage circuit breaker (ELCB) is a safety device used in electrical installations with high earth impedance to prevent shock. It detects small stray voltages on the metal enclosures of electrical equipment and interrupts the circuit if the voltage level exceeds danger threshold.

43. What is the Purpose of ELCB?

- The main purpose of ELCB is to detect Earth leakages and prevent injury to human beings from electrical shocks and prevent electrical fires that are caused by short Circuit.

44. What are the types of ELCB?

- Voltage Earth Leakage Circuit Breaker (Voltage ELCB).
- Current Earth Leakage Circuit Breaker (Current ELCB).

45. What is Voltage Earth Leakage Circuit Breaker?

- Voltage ELCB is a voltage-operated Circuit breaker. The device will function when the current passes across the ELCB.
- Voltage ELCB contains a relay coil which is connected to the metal body at one and connected to the ground on the other end.

46. What is Current Earth Leakage Circuit Breaker?

- The current ELCB is a circuit breaker that is commonly used. It is also called RCCB (Residual Current Circuit Breaker).

47. What are the advantages and disadvantages of ELCB?

Advantages:

- ELCB instantly breaks the circuit to avoid electrical shock.
- It prevents damage caused due to broken wires or damaged insulation.

Disadvantages:

- ELCB cannot protect against overloading & short circuit current.
- It cannot protect against live-neutral shock.
- It may trip unnecessarily due to small current leakages in old appliances.