Electrical Circuits and Machines

Unit - I

The three fundamental laws that governs the electric circuit are Ohm's law, Kirchoff's voltage law and Kirchoff's current law.

Ohm's law:

Ohm's law states that the potential difference (or voltage) across any two ends of a conductor is directly proportional to the current flowing between the two ends provided the temperature of the conductor remains constant.

The constant of proportionality is the resistance R of the conductor.

$$\therefore V \propto I \quad \text{or} \quad V = IR$$

Linear element: linear element is a element whose value does not depends on the current flowing or voltage across it.

Ex: Resistance, inductance

Non linear element: Non linear element is a element whose value depend upon the current flowing or voltage across it

Ex: Diode

Bi-lateral element: Bi-lateral element is one whose properties are same in either direction of current flow or voltage across it. Ex: Resistor, inductor, capacitor.

Uni - lateral element: Uni - lateral element is one whi characteristics depends on voltage apply or current flowing through it.

Ex: Diode.

Kirchoff's laws → KCL
→ KVL

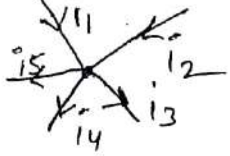
(1) Kirchoff's current law (KCL): It is always defined at a node.

node :- → Simple node
→ principle node

The simple node is an interconnection of only two branches, where as the principal node is an interconnection of atleast 3 branches.

Defination: In a lumped electric circuit, for any of its node and at any time 't', the algebric sum of branch current leaving the node is zero.

By KCL:



Σ leaving current $= 0$

$\Rightarrow -i_1 - i_2 + i_3 + i_4 + i_5 = 0$

$\Rightarrow i_1 + i_2 = i_3 + i_4 + i_5$

ie sum of the entering current is equal to sum of the leaving currents

Since $i = \frac{dq}{dt}$

$$\Rightarrow \frac{dq_1}{dt} + \frac{dq_2}{dt} = \frac{dq_3}{dt} + \frac{dq_4}{dt} + \frac{dq_5}{dt}$$

$$\Rightarrow q_1 + q_2 = q_3 + q_4 + q_5$$

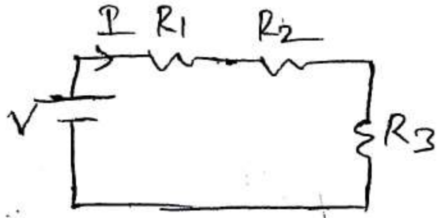
ie sum of entering charges is equal to sum of the leaving charges.

→ KCL expresses conservation of charge.

→ KCL + Ohm's law = Nodal Analysis

2) KVL (Kirchoff's voltage law): It is defined in a loop or mesh ie in a closed path.

Defination: In a lumped electric circuit, for any of its loop and at any time 't' the algebric sum of branch voltages around the loop is zero.



By KVL ⇒

Σ branch voltage $= 0$

$$\Rightarrow V - IR_1 - IR_2 - IR_3 = 0$$

$$= V = IR_1 + IR_2 + IR_3$$

→ The KVL expresses the conservation of energy

→ KVL + Ohm's law = Mesh Analysis.

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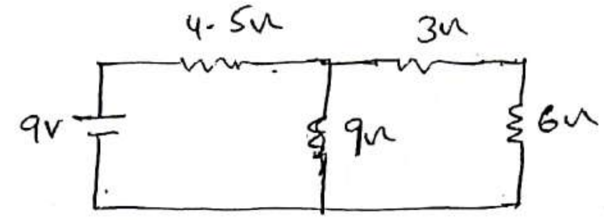
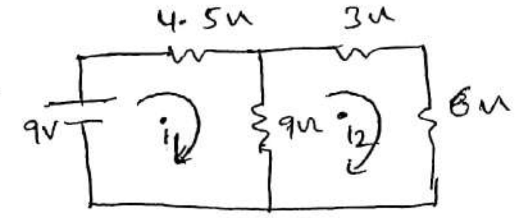
Some example problems on Mesh Analysis

1) Solve the current in various branches of the circuit by mesh Analysis



Sol)



Applying the KVL for loop 1

$$9 - 4.5\,i_1 - 9(i_1 - i_2) = 0$$

(∵ the current flowing in 9Ω resistor is i_1 is one direction i_2 is in opp direction)

$$9 - 4.5\,i_1 - 9i_1 + 9i_2 = 0$$

$$-13.5\,i_1 + 9i_2 = -9$$

$$13.5\,i_1 - 9i_2 = 9 \quad \text{— (1)}$$

Applying the KVL for loop 2

$$-3i_2 - 6i_2 - 9(i_2 - i_1) = 0$$

$$-9i_2 - 9i_2 + 9i_1 = 0$$

$$9i_1 - 18i_2 = 0 \quad \text{— (2)}$$

Solve (1) & (2)

$$13.5\,i_1 - 9i_2 = 9 \times 2$$

$$9i_1 - 18i_2 = 0$$

$$27i_1 - 18i_2 = 18$$

$$\underline{-9i_1 + 18i_2 = -0}$$

$$18i_1 = 18$$

$$i_1 = 1\,A$$

sub i_1 in eq (2)

$$9 \times 1 - 18 i_2 = 0$$

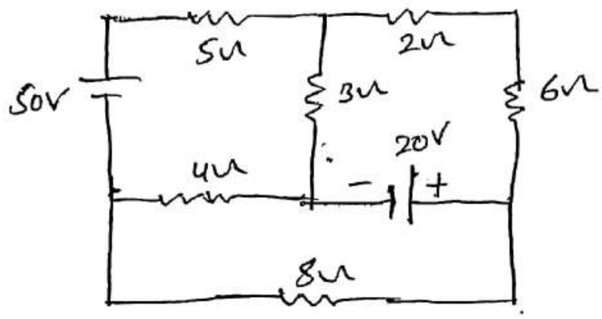
$$-18 i_2 = -9$$

$$i_2 = 0.5\,A$$

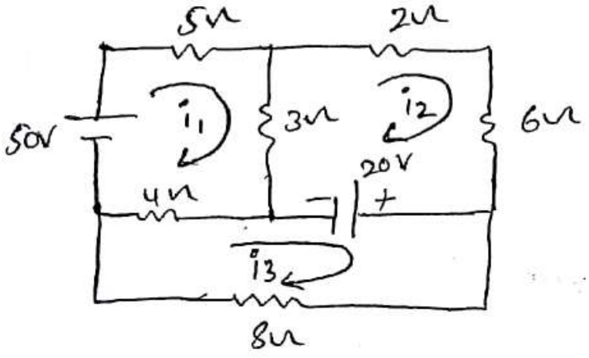
$$i_1 = 1\,A$$

$$i_2 = 0.5\,A.$$

(2) solve the current in various branches in the circuit by mesh analysis.



sol)



Applying KVL for loop 1

$$50 - 5 i_1 - 3(i_1 - i_2) - 4(i_1 - i_3) = 0$$

$$50 - 5 i_1 - 3 i_1 + 3 i_2 - 4 i_1 + 4 i_3 = 0$$

$$50 - 12 i_1 + 3 i_2 + 4 i_3 = 0$$

$$12 i_1 - 3 i_2 - 4 i_3 = 50 \quad \text{—(1)}$$

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Applying KVL for loop 2

$$-2i_2 - 6i_2 - 20 - 3(i_2 - i_1) = 0$$

$$-8i_2 - 20 - 3i_2 + 3i_1 = 0$$

$$3i_1 - 11i_2 = 20 \quad \text{— (2)}$$

Applying KVL for loop 3

$$-8i_3 - 4(i_3 - i_1) + 20 = 0$$

$$-8i_3 - 4i_3 + 4i_1 + 20 = 0$$

$$4i_1 - 12i_3 + 20 = 0$$

$$-4i_1 + 12i_3 = 20 \quad \text{— (3)}$$

The equation (1), (2) & (3) are the mesh equation of the circuit are

$$12i_1 - 3i_2 - 4i_3 = 50$$

$$3i_1 - 11i_2 = 20$$

$$-4i_1 + 12i_3 = 20$$

The mesh equation can be arranged in the matrix form as shown below and then solved by Cramer's rule.

$$\begin{bmatrix} 12 & -3 & -4 \\ 3 & -11 & 0 \\ -4 & 0 & 12 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 50 \\ 20 \\ 20 \end{bmatrix}$$

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determinants Δ, Δ_1, Δ_2 & Δ_3

$$\Delta = \begin{vmatrix} 12 & -3 & -4 \\ 3 & -11 & 0 \\ -4 & 0 & 12 \end{vmatrix} = 12(-11\times12 - 0\times0) - 3[3\times12 - 0\times(-4)]$$

$$-4(3\times0 - (-11\times-4))$$

$$= 1300$$

$$\Delta_1 = \begin{vmatrix} 50 & -3 & -4 \\ 20 & -11 & 0 \\ 20 & 0 & 12 \end{vmatrix} \qquad \Delta_2 = \begin{vmatrix} 12 & 50 & -4 \\ 3 & 20 & 0 \\ -4 & 20 & 12 \end{vmatrix}$$

$$\Delta_3 = \begin{vmatrix} 12 & -3 & 50 \\ 3 & -11 & 20 \\ -4 & 0 & 20 \end{vmatrix}$$

Solve $\Delta_1, \Delta_2, \Delta_3$ as ~~same~~ solved as Δ

we get $\Delta_1 = 6760$ $\quad \Delta_2 = -520$ $\quad \Delta_3 = 4420$

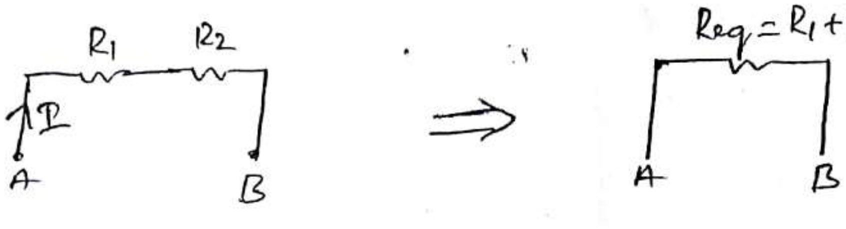
$$i_1 = \frac{\Delta_1}{\Delta_1} = \frac{6760}{1300}$$

$$= 5.2\,A$$

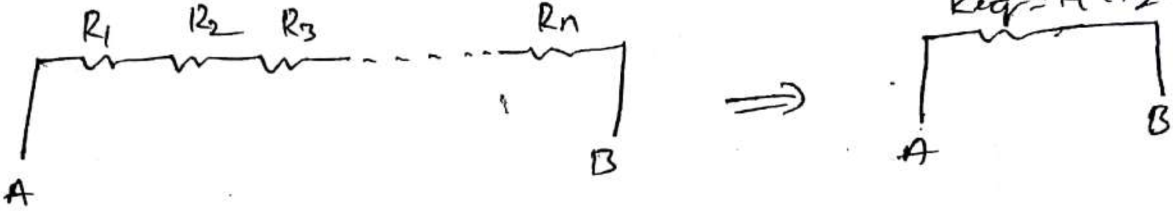
$$i_2 = \frac{\Delta_2}{\Delta} = \frac{-520}{1300} = -0.4\,A$$

$$i_3 = \frac{\Delta_3}{\Delta} = 3.4\,A.$$

Resistance in series : In series circuit the current is [illegible] in all Resistors.

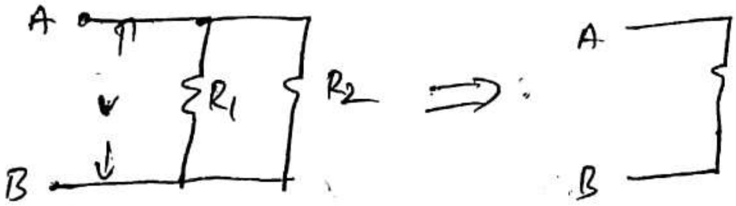


$$R_{eq} = R_1 + R_2$$

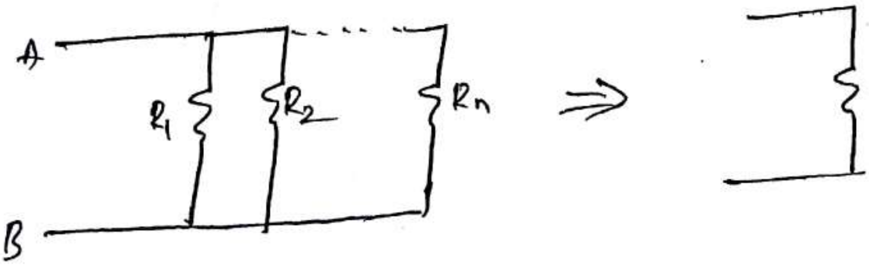


$$R_{eq} = R_1 + R_2 + R_3 - \cdots R_n$$

Resistance in Parallel : In parallel circuit voltage across Resistor is same



$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 R_2}{R_1 + R_2}$$



$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}}$$

$$= \cancel{\frac{R_1 R_2 \cdots R_n}{R_1 + R_2 + \cdots + R_n}}$$

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}}.$$

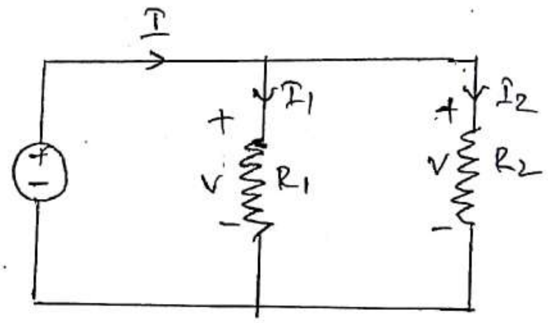
Current and voltage division rules

Current division in parallel connected resistances.

Consider two resistances R_1 & R_2 in parallel by the source and I_1 & I_2 and connected to a dc source of v volts as shown in fig.

Let I be the current supplied by the source and I_1 & I_2 be the current through R_1 & R_2 respectively. Since the resistance are parallel to the source, the voltage across them will be V volts

By ohms law we can write,



$$I_1 = \frac{V}{R_1} \quad \text{—— (1)}$$

$$I_2 = \frac{V}{R_2} \quad \text{—— (2)}$$

By Kirchoff's current law

$$I = I_1 + I_2 \quad \text{—— (3)}$$

on substituting for I_1 & I_2 from eq (1) & (2) in eq (3) we get

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

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = V\left(\frac{R_2 + R_1}{R_1 R_2}\right)$$

$$V = I \times \frac{R_1 R_2}{R_1 + R_2} \quad \text{—— (4)}$$

Sub eq (4) in eq (1)

$$I_1 = I \times \frac{R_1 R_2}{R_1 + R_2} \times \frac{1}{R_1} = I \times \frac{R_2}{R_1 + R_2} \quad \text{—— (5)}$$

on Sub eq (4) in eq (2)

$$I_2 = I \times \frac{R_1 \cancel{R_2}}{R_1+R_2} \times \frac{1}{\cancel{R_2}}$$

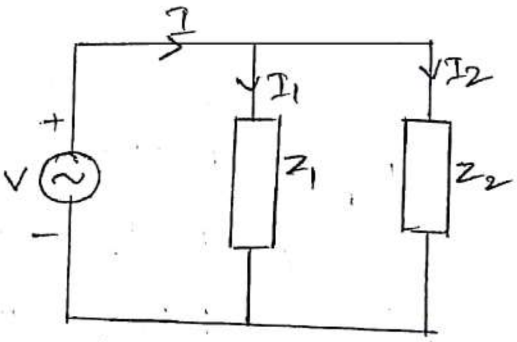
$$= I \times \frac{R_1}{R_1+R_2} \quad \text{--- (6)}$$

The eq (5) & (6) can be used to solve the current in parallel connected resistance in term of total current drawn by the parallel combination and the value of individual resistance.

The concept of current division can be extended to two impedance in parallel and excited by Sinusoidal source (AC source). The current I_1 & I_2 are

$$I_1 = I \times \frac{Z_2}{Z_1+Z_2}$$

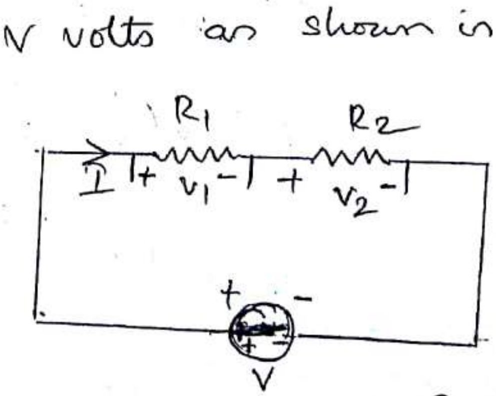
$$I_2 = \frac{I \times Z_1}{Z_1+Z_2}$$



<u>voltage division in Series connected Resistances:</u>

Consider two resistance R_1 & R_2 in Series and connected to a dc source of V volts as shown in fig.

Let I be the current supplied by the source, the current voltage across R_1 & R_2 are V_1 & V_2



Since the resistance is in series the current through them will be same.

V dc voltag source

By ohms law we can write

$$V_1 = IR_1 \quad \text{—— (1)}$$

$$V_2 = IR_2 \quad \text{—— (2)}$$

By KVL we get

$$V = V_1 + V_2$$

$$V = IR_1 + IR_2$$

$$= I(R_1 + R_2)$$

$$I = \frac{V}{R_1 + R_2} \quad \text{—— (3)}$$

Sub eq (3) in eq (1)

$$V_1 = \frac{V}{R_1+R_2} \times R_1 \quad = \quad V_1 = V \times \frac{R_1}{R_1+R_2} \quad \text{—— (4)}$$

Sub eq (3) in eq (2)

$$V_2 = \frac{V}{R_1+R_2} \times R_2$$

$$V_2 = V \times \frac{R_2}{R_1+R_2} \quad \text{—— (5)}$$

The equation 4 & 5 can be used to solve the voltage in series connected resistance in term of total voltage across the series combination and the values of individual resistance.

The concept of voltage division can be extended to two impedance in series and excited by a sinusoidal source (AC source) as shown in fig. The voltages V_1 & V_2 are given by.

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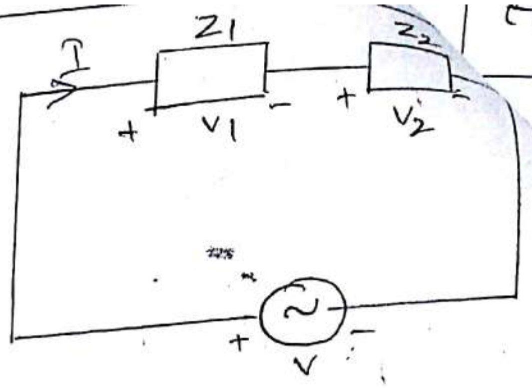
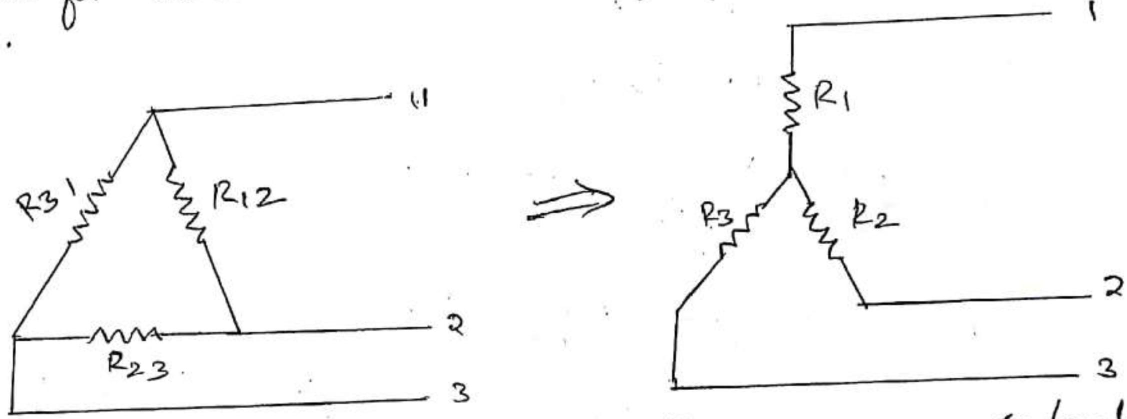
$$V_1 = \frac{V \times Z_1}{Z_1 + Z_2}$$

$$V_2 = \frac{V \times Z_2}{Z_1 + Z_2}$$



Formulas for delta to star transformation.



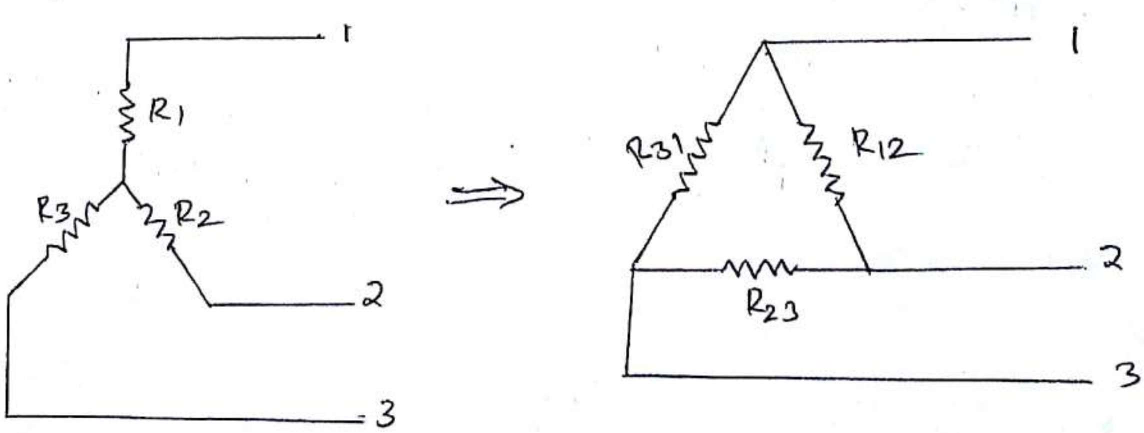
if R_{12}, R_{23}, R_{31} values are given then we can calculate R_1, R_2, R_3 with help of these formula.

$$R_1 = \frac{R_{12} R_{31}}{R_{12} + R_{23} + R_{31}}$$

$$R_2 = \frac{R_{12} R_{23}}{R_{12} + R_{23} + R_{31}}$$

$$R_3 = \frac{R_{23} R_{31}}{R_{12} + R_{23} + R_{31}}$$

Formula for star to delta transformation



If star connected R_1, R_2, R_3 values are given then we can calculate the R_{12}, R_{23} & R_{31} of delta connected circuit

$$R_{12} = R_1 + R_2 + \frac{R_1 R_2}{R_3}$$

$$R_{23} = R_2 + R_3 + \frac{R_2 R_3}{R_1}$$

$$R_{31} = R_3 + R_1 + \frac{R_3 R_1}{R_2}$$

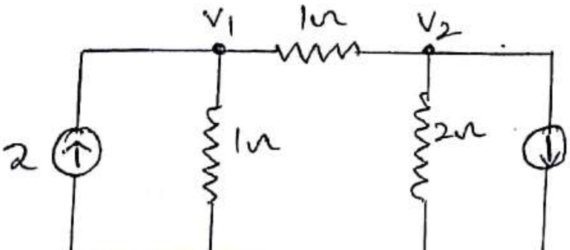
<u>Various steps to obtain the solution of node voltage and branch voltage in a circuit.</u>

Step 1: For a given circuit determine the number of Nodes 'N' and choose one of the node as reference.

Step 2: In a given circuit denote the node 1, 2, 3 . . . n and node voltage as $V_1, V_2, V_3 \ldots V_n$ where $n = N-1$

Step 3: From the node basis matrix equation by inspection and solve the node voltage

Example:



In this circuit we can find two nodes

For node (1)

$$-2 + \frac{V_1}{1} + \frac{V_1 - V_2}{1} = 0 \quad —(1)$$

For node 2

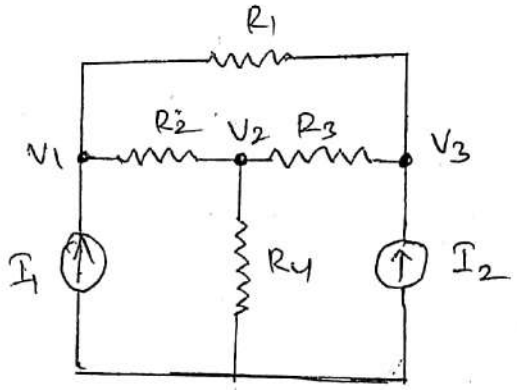
$$\frac{V_2 - V_1}{1} + \frac{V_2}{2} + 2 = 0 \quad -(2)$$

Here (+2) because current leaving the node.

If we solve eq (1) & (2) we can get V_1 & V_2.

Suppose if we want to calculate current in 2Ω resistor by using $\frac{V_2}{2}$ will give the current flows in 2Ω resistor. Similarly for other branch resistors also.

Example 2:



For this circuit there are 3 nodes are present

equation for node 1

$$-I_1 + \frac{V_1 - V_2}{R_2} + \frac{V_1 - V_3}{R_3} = 0$$

node 2

$$\frac{V_2 - V_1}{R_2} + \frac{V_2}{R_4} + \frac{V_2 - V_3}{R_3} = 0$$

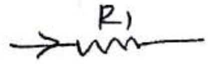
node 3

$$\frac{V_3 - V_1}{R_1} + \frac{V_3 - V_2}{R_3} - I_2 = 0$$

After solving 3 equation we get $V_1, V_2, \& V_3$

Current flow in R_1 is

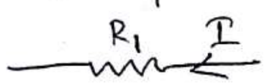
$$I_{R_1} = \frac{V_1 - V_3}{R_1}$$



also

$$I_{R_1} = \frac{V_3 - V_1}{R_1}$$

but the direction of current is change



||ly for R_2, R_3 & R_4

Thevinin's Theorem:

Any linear bilateral two terminal network can be replaced with single voltage source in Series with resistance. Then voltage is known as V_{th} thevinins voltag and resistance is R_{th} thevinin's.

Procedure:

1) Remove the resistance when ever response is going to be find

2) Calculate V_{th} across the open circuited terminal

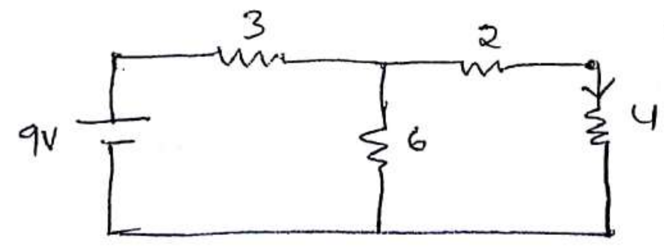
3) Calculate R_{th} resistance between the open circuited terminal by short circuiting the voltage source and open circuiting the current source.

4) Replace the network with the thevinin's equivalent circuit (i.e V_{th} is Series with R_{th} b/w the terminal)

5) Replace the removed resistance or load resistance where ever the response is going to find.

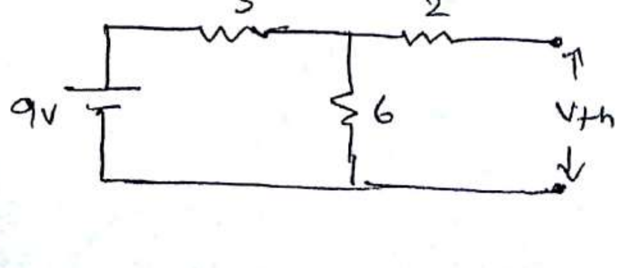
6) Calculate the required resistance (voltage, current, power)

Example:

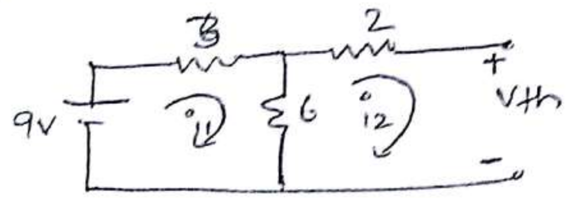


Calculate the current flowing through un resistor.

Sol)



By Mesh Analysis



loop 1

$$9 - 3i_1 - 6(i_1 - i_2) = 0$$

where $i_2 = 0$ b'coz the terminal is open, so no 'i_2' current

Sub $i_2 = 0$

$$9 - 3i_1 - 6(i_1 - 0) = 0$$

$$9 - 9i_1 = 0$$

$$i_1 = 1A$$

loop 2

$$-2i_2 - V_{th} - 6(i_2 - i_1) = 0$$

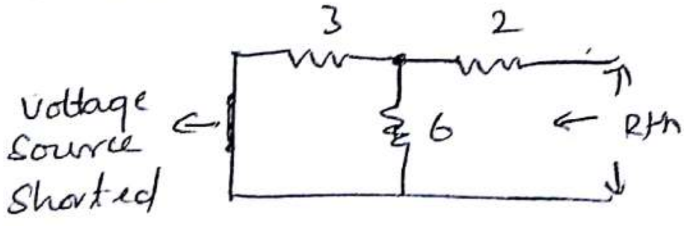
Sub $i_2 = 0$

$$-0 - V_{th} - 6(-i_1) = 0$$

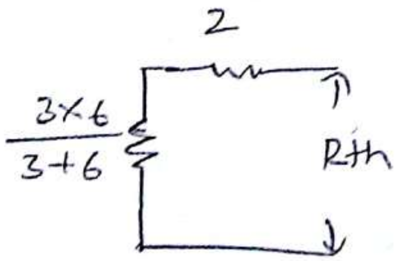
$V_{th} = 6i_1$ where $i_1 = 1A$

$$V_{th} = 6 \times 1 = 6V$$

Calculate R_{th}

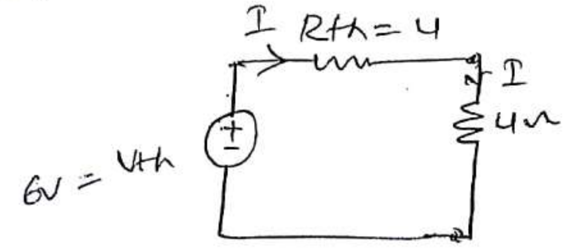


Here 3 & 6 are in parallel and is series with 2Ω



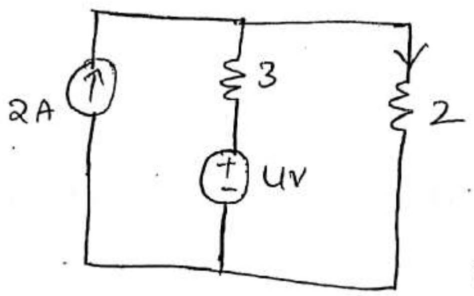
$R_{th} = 2 + 2 = 4\Omega$.

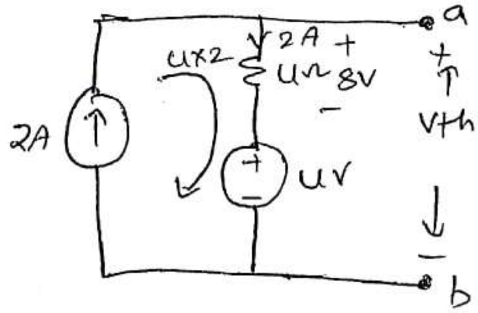
Replace the network with thevenin's voltage & resistance and connect removed resistance



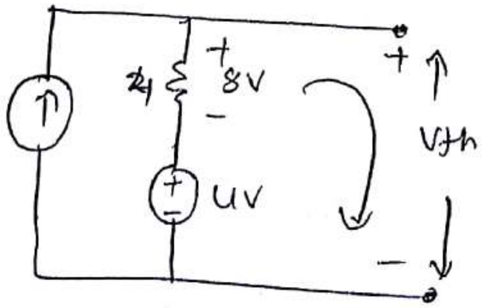
$$I = \frac{V_{th}}{R_{th}+4} = \frac{6}{4+4} = \frac{6}{8} = \frac{3}{4} = 0.75\,A$$

Example 2





Here terminal A & B are open so 2A will flow in closed path.

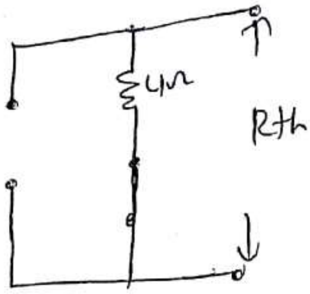


$$4 + 8 - V_{th} = 0$$

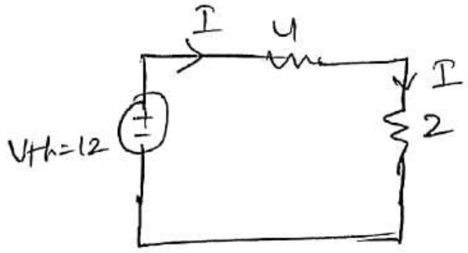
$$V_{th} = 12V$$

Calculate Rth.

Current source open
voltage source Short



$R_{th} = 4\Omega$



$$I = \frac{V_{th}}{R_{th}+2} = \frac{12}{4+2} = 2A.$$

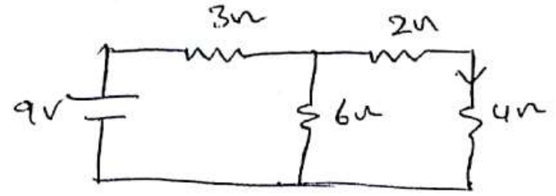
Norton's Theorem:

Any linear bilateral two terminal network can be replaced with single current source in parallel with resistance. Then current is known as I_N (norton's current) and resistance is R_N Norton.

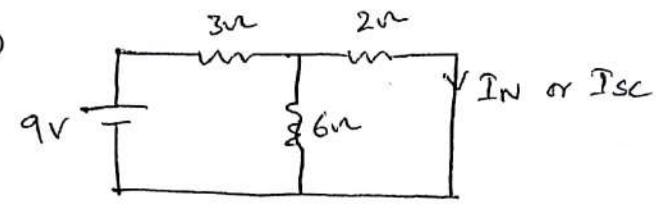
Procedure:

1) Remove the resistance and short the terminal where ever response is going to find.
2) Calculate I_N flowing in short circuit terminal.
3) Calculate R_N between the open terminal by S.C the voltage source and O.C the current source.
4) Replace the network with the Norton's equivalent circuit (ie I_N in parallel with R_N b/w the terminal)
5) Replace the removed resistance or load resistance wherever the response is going to be find.
6) Calculate the required resistance (current, power)

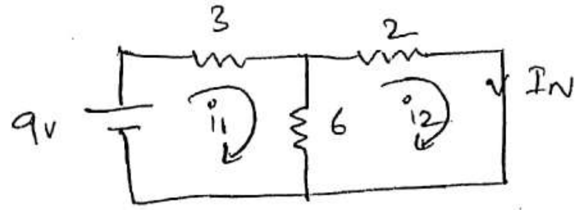
Example:



Sol)



By mesh Analysis



loop 1

$$9 - 3i_1 - 6(i_1 - i_2) = 0$$

$$9 - 9i_1 + 6i_2 = 0$$

$$3 - 3i_1 + 2i_2 = 0 \quad — ①$$

$$3 - 3i_1 + 2I_N = 0 \quad — ①$$

loop 2

$$-2(i_2) - 6(i_2 - i_1) = 0 \quad \text{where } i_2 = I_N$$

$$-2I_N - 6I_N + 6i_1 = 0$$

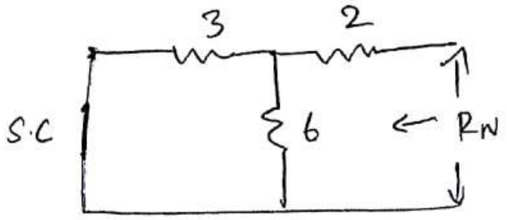
$$-8I_N + 6i_1 = 0 \quad — ②$$

Solve eq ① & ② we get

$i_1 = 2A$

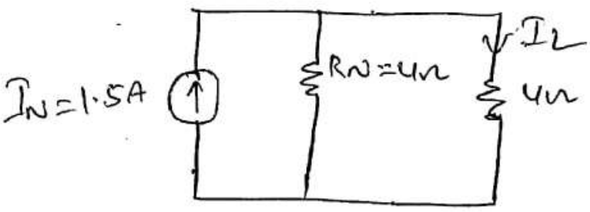
$I_N = 1.5A$

Calculate R_N



$R_N = 4\Omega$ (as previous we did with ~~norton's~~ Thevenin's Theorem here instead of R_{th} we are representing as R_N (Norton's resistance).

Now replace the network with I_N & R_N and connect the removed resistance.



$$I_L = \frac{I_N \times R_N}{R_N + 4}$$

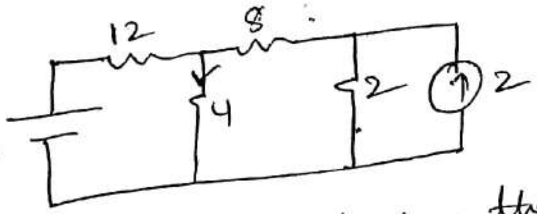
$$= \frac{1.5 \times 4}{4+4} = 0.75A.$$

Superposition theorem :

In a linear network, with several independ. sources the response in a particular branch when all the source are acting simultaneously is equal to the linear sum of individual response calculated by taking one independent source at a time.

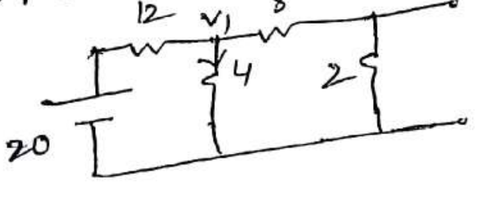
Note: All the voltage sources are eliminated from the network by shorting the source and all the current source are eliminated by opening the source.

Example



Find the current flowing through 4Ω resistor using super position theorem.

Sol: step 1 : Put one source as active & remaining source as inactive



$$\frac{v_1-20}{12}+\frac{v_1}{4}+\frac{v}{8+2}=0$$

$40v_1$

Alternating currents (A.C.)

→ The voltage acting in the circuit changes polarity at regular intervals of time and resulting current changes direction accordingly, this type of system is called "Alternating current" (A.C. current).

→ The A.C system offers so many advantages like electrical energy is universally generated, transmitted and used in the form of alternating current.

→ Three principal advantages are claimed for a.c. system over the d.c. system.

(i) First, alternating voltages can be stepped down & stepped up efficiently by means of a transformer.

(ii) A.C. motors (Induction motors) are cheaper and simpler in construction than d.c. motors.

(iii) Thirdly, the switch gear [e.g. switches, circuit breakers etc.] for a.c. system is simpler than the d.c. system.

Sinusoidal Alternating voltage and current

→ Commercial alternators produce sinusoidal alternating voltage i.e. alternating voltage is a sine wave.

→ A sinusoidal alternating voltage can be produced by rotating a coil with a constant angular velocity (say ω rad/sec) in a uniform magnetic field.

→ The sinusoidal alternating voltage can be expressed by the equation.

$$e = E_m \sin\omega t$$

where e = Instantaneous value of alternating voltage

E_m = Maximum value of alternating voltage

→ Sinusoidal voltages always produce sinusoidal currents.

∴ the sinusoidal current can be expressed in the same way as voltage

i.e., $i = I_m \sin \omega t$

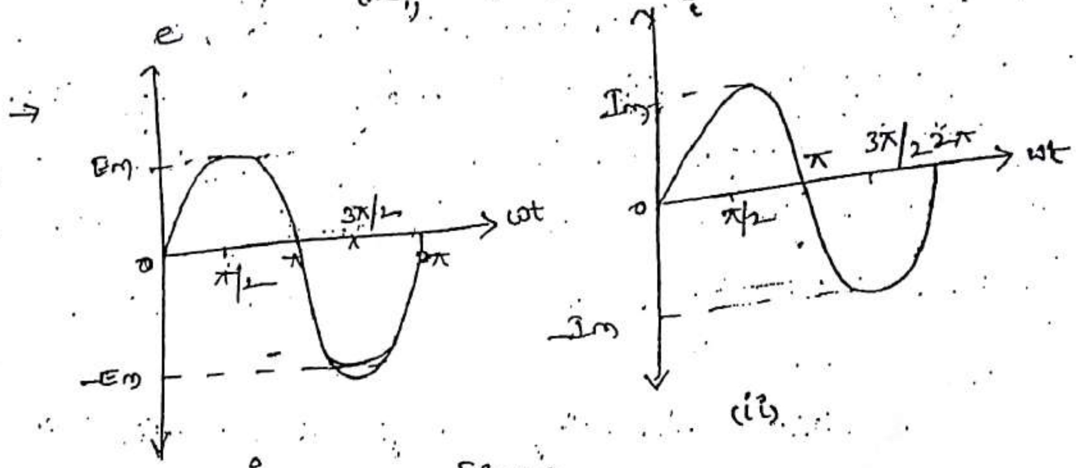


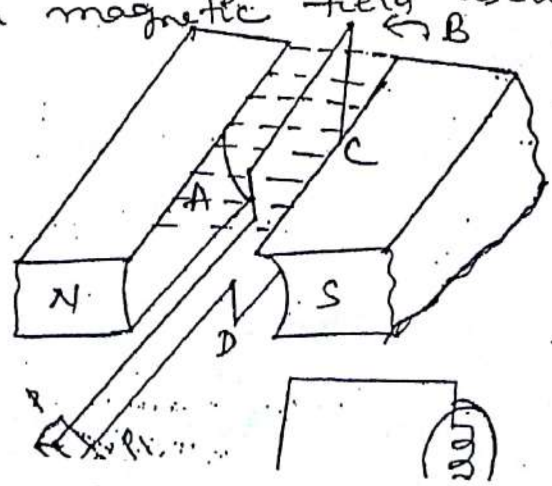
Fig (a).

→ The fig a (i) shows the waveform of sinusoidal voltage whereas fig. a (ii) show's the waveform of sinusoidal current.

NOTE:- Sinusoidal voltage & current not only changes direction at regular intervals but the magnitude is also changing continuously.

→ Principles of Production of ac waveform

→ An Alternating voltage may be generated by rotating a coil at constant angular velocity in a uniform magnetic field as shown in below Fig (b).



The magnitude of generated voltage will depend upon the number of turns of coil, the strength of magnetic field and the speed of rotation.

→ The corresponding waveform's should be shown in fig a (i) and (ii).

→ Important a.c. Terminology

→ An alternating voltage or current changes continuously in magnitude and alternates in direction at regular intervals of time.

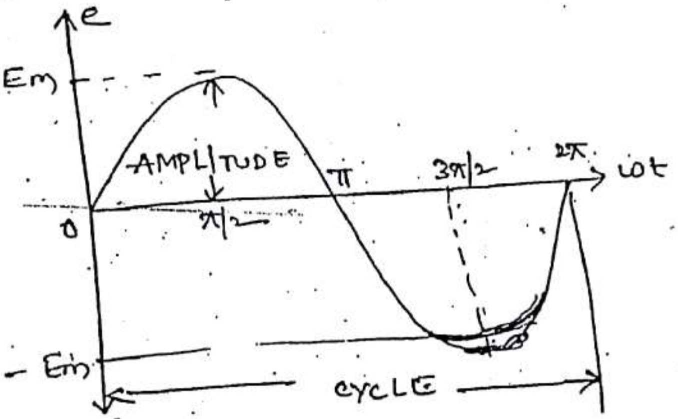


Fig (C).

(a) Waveform:- The shape of the curve obtained by plotting the Instantaneous values of voltage or current against time as abcissa is called it's "waveform" or "wave shape".

Fig (c) shows the waveform of an alternating voltage varying sinusoidally.

(b) Instantaneous Value:- The value of an alternating quantity at any instant is called "instantaneous value". The instantneous values of alternating voltage and current are represented by e and i respectively.

(c) Cycle:- one complete set of positive and negative values of an alternating quantity is known as a "cycle."

(d) Alternation:- one half cycle of an alternating quantity is called an alternation.

(e) Time Period :- The time taken in seconds to complete one cycle of an alternating quantity is called it's time period.

It is generally represented by T.

(f) Frequency :- The number of cycles that occur in one second is called the frequency (f) of the alternating quantity.

It is measured in cycles / seconds (c/s) or Hertz (Hz).

(g) Amplitude :- The maximum value (positive or negative) attained by an alternating quantity is called it's Amplitude (or) Peak value.

The amplitude of an alternating voltage or current is designated by E_m (or V_m) or I_m.

→ Important Relation's

(i) Time Period and frequency :- consider an alternating quantity having a frequency of f c/s and time in T second.

Time taken to complete f cycles = 1 second

Time taken to complete 1 cycle = 1/f second.

∴ But time taken to complete one cycle is the time period T.

$$\boxed{T = 1/f \text{ or } f = 1/T}$$

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(ii) Angular velocity and frequency:-

Angular velocity, $\omega = \frac{\text{Angle Turned}}{\text{Time Taken}} = \frac{2\pi}{T}$

$\omega = 2\pi f \quad (\because f = 1/T)$

(iii) frequency and speed: Consider a coil rotating at a speed of N r.p.m. in the field of P Poles. As the coil moves past a North and South pole, one complete cycle is generated, in one revolution of the coil, P/2 cycles will be generated.

frequency, f = No of cycles / sec.

= (No of cycles / revolution) x (No of revolutions / sec)

$= \left(\frac{P}{2}\right) \times \left(\frac{N}{60}\right) = \frac{PN}{120}$

$$\boxed{f = \frac{PN}{120}} \text{ Hz}$$

→ Values of Alternating voltage and current

→ In a d.c. system, the voltage and current so that there is no problem of specifying their magnitudes. However, an alternating voltage or current varies from instant to instant.

→ There are three ways of expressing it, namely;

(i) Peak value.

(ii) Average value (or) Mean value.

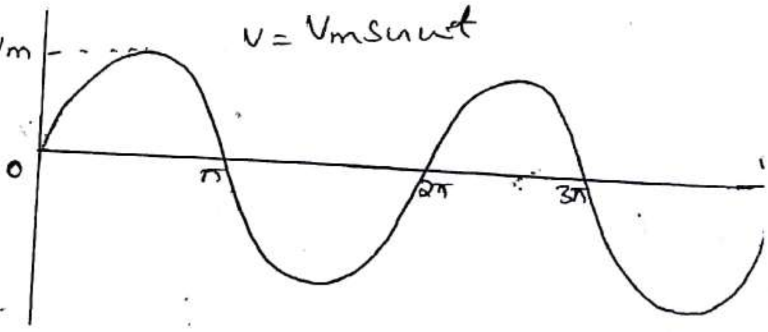
(iii) R.M.S. value or effective value.

Average Value:

The average value of a time varying quantity is the average of instantaneous value for a particular time period. Usually for periodic waveforms the average is taken for one time period.

→ In alternating quantities the average value for one time period is zero because in one period it has equal positive and negative values. Therefore for alternating quantities the average is taken over half the period.

The instantaneous value of the sinusoidal voltage is expressed by $v = V_m \sin \omega t$. The total value over half period (π) is obtained by integrating the instantaneous value between limits 0 to π. Then the average is obtained by dividing this total value by half period (π).



$$V_{avg} = \frac{1}{\pi}\int_0^{\pi} v \, d\omega t$$

$$= \frac{1}{\pi}\int_0^{\pi} V_m \sin \omega t \, d\omega t$$

$$= \frac{V_m}{\pi}\left[-\cos \omega t\right]_0^{\pi} = \frac{V_m}{\pi}\left[-\cos\pi + \cos 0\right]$$

$$= \frac{V_m}{\pi}\left[1+1\right] = \frac{2V_m}{\pi}$$

$$V_{avg} = \frac{2V_m}{\pi}$$, Ily for $I_{avg} = \frac{2I_m}{\pi}$

RMS value

The rms value of a time varying quantity is the equivalent dc value of that quantity. The rms value is also known as effective value.

The rms stands for root-mean-square, which means that the value is obtained by taking the root of the mean of the squared function.

The instantaneous value of the sinusoidal voltage is expressed by $v = V_m \sin\omega t$. The total value of the squared function over half period(π) is obtained by integrating v^2 between limits 0 to π.

The mean (avg) is obtained by dividing the total value of squared function by half period (π).

The rms value is obtained by taking square root of this mean value.

$$V = \sqrt{\frac{1}{\pi}\int_0^{\pi} v^2 \, d\omega t}$$

$$= \left(\frac{1}{\pi}\int_0^{\pi} (V_m \sin\omega t)^2 \, d\omega t\right)^{1/2} = \left(\frac{V_m^2}{\pi}\int_0^{\pi} \sin^2\omega t \, d\omega t\right)^{1/2}$$

$$= \left(\frac{V_m^2}{\pi}\int_0^{\pi} \frac{(1-\cos 2\omega t)}{2} \, d\omega t\right)^{1/2}$$

$$= \left(\frac{V_m^2}{2\pi}\int_0^{\pi} (1-\cos 2\omega t) \, d\omega t\right)^{1/2} = \left(\frac{V_m^2}{2\pi}\left[\omega t - \frac{\sin 2\omega t}{2}\right]\right.$$

$$= \frac{V_m^2}{2\pi}\left[\pi - \frac{\sin 2\pi}{2} - 0 + \frac{\sin 0}{2}\right] = \frac{V_m}{\sqrt{2}}$$

$V_{rms} = V_m/\sqrt{2}$. Similarly for current $I_m/\sqrt{2}$

Form factor and Peak factor.

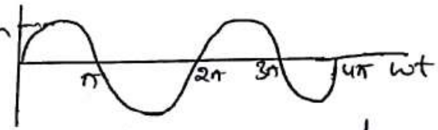
The form factor is defined as the ratio of rms va[lue] and average value of a periodic waveform.

$$\therefore \text{Form factor} = \frac{\text{rms value}}{\text{avg value}} \quad \text{—(1)}$$

The peak factor is defined as the ratio of peak value to the rms value of a periodic waveform

$$\text{Peak factor} = \frac{\text{Peak value}}{\text{rms value}} \quad \text{—(2)}$$

Similarly for average value of sinusoidal current is given by $I_{avg} = \frac{2I_m}{\pi}$



lly for rms value of sinusoidal current is given by

$$I_{rms} = \frac{I_m}{\sqrt{2}}.$$

The form and Peak factor for sinusoidal voltage can be estimated by using eq (1) & (2)

$$\text{Form factor} = \frac{V_{rms}}{V_{avg}} = \frac{\frac{V_m}{\sqrt{2}}}{2V_m/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

$$\text{Peak factor} = \frac{V_{peak} \text{ or } V_m}{V_{rms}} = \frac{V_m}{V_m/\sqrt{2}} = \sqrt{2} = 1.414$$

V.V.Imp

IMPEDANCE TRIANGLE

(18) | (2) 17

→ The phasor diagram of a R-L series circuit is shown in fig a (ii).

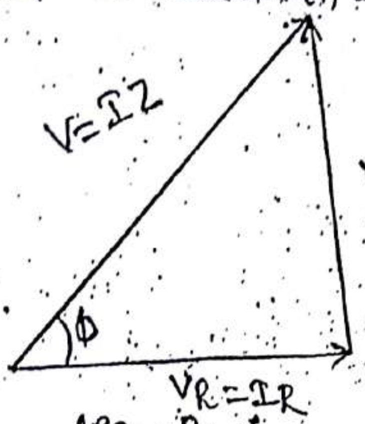


fig. (B) (i)

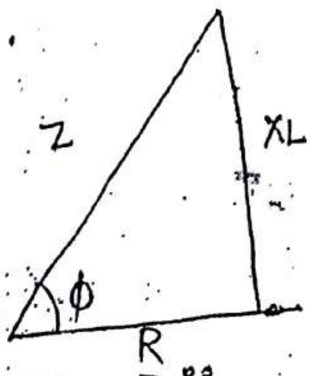


fig. B (ii)

$Z = R + jX$

$Z = R + XL$

→ Dividing each side of the phasor diagram by the same factor I, we get a triangle whose sides represent R, X_L, and Z. Such a triangle is known as impedance triangle. [see fig b (ii)]

> → (i) The impedance of the circuit i.e. $Z = \sqrt{R^2 + X_L^2}$
>
> (ii) power factor of the circuit i.e. $\cos\phi = \frac{R}{Z}$
>
> (iii) phase angle ϕ i.e. $\tan\phi = \frac{X_L}{R}$

V.V.Imp

POWER FACTOR

→ The power factor of a circuit can be defined in one of the following ways.

(i) power factor $= \cos\phi =$ cosine of angle between V and I.

(ii) power factor $= \frac{\text{Resistance}}{\text{Impedance}} = \frac{R}{Z}$ [See fig B (ii)]

(iii) power factor $= \frac{VI\cos\phi}{VI} = \frac{\text{True power}}{\text{Apparent power}}$

> NOTE:- POWER-factor should always less than 1.

True Power and Reactive Power

→ True power = voltage × Current in phase with voltage

Reactive power = voltage × Current 90° out of phase with voltage.

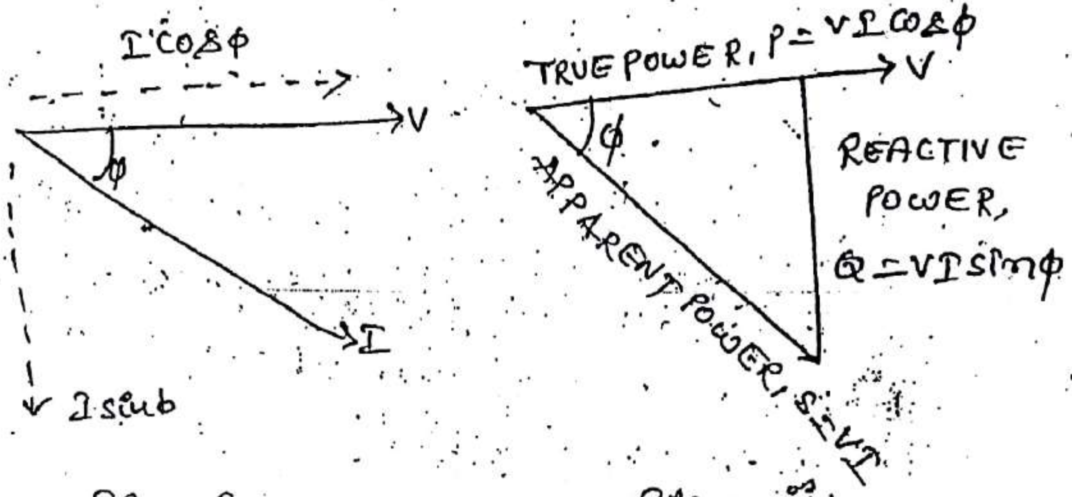
→ 

fig c(i) fig c(ii)

→ Consider an inductive circuit in which current I lags behind voltage V by $\phi°$. The phasor diagram of the circuit is shown in fig c(i).

→ The current I can be resolved into two components.

(i) $I\cos\phi$ inphase with V and

(ii) $I\sin\phi$; 90° out of phase with V.

$$\boxed{\begin{aligned}&\text{TRUE POWER (or Active power)}, P = V \times I\cos\phi = VI\cos\phi \text{ Watts}\\ &\text{REACTIVE POWER}, Q = V \times I\sin\phi = VI\sin\phi \text{ VAR}\\ &\text{APPARENT POWER}, S = V \times I = VI \text{ VA or kVA}\end{aligned}}$$

→ The power curve is similar to that for a pure inductor because now current leads the voltage by 90°.

→ It is clear that the positive power is equal to the negative power over one cycle. Hence net power absorbed in a pure capacitor is zero.

Series A.C. Circuits

→ A circuit in which the same alternating current flows through all the circuit elements (i.e. R, L, C) is called a series a.c. circuit.

→ In this case our main focused on the

(i) Phase angle (ϕ) between the applied voltage and circuit current.

(ii) circuit impedance and current and

(iii) Power consumed.

→ Since current is common in a series circuit, it shall be taken as the reference phasor in drawing the phasor diagram.

V.V.Imp

→ ## R-L Series Circuit:

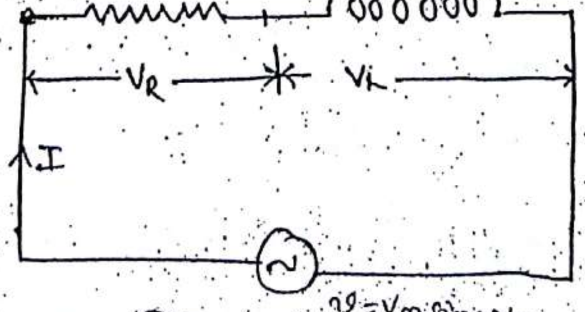
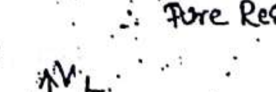
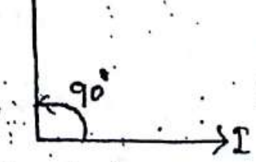


fig a (i)



Pure Resistance



Pure inductance

→ Fig a(i) shows a pure resistance R ohms connected in series with a coil of pure inductance of L henry.

→ Let

V = r.m.s. value of the applied voltage.

I = r.m.s. value of the circuit current.

∴ $V_R = IR$ ..... where V_R is in phase with I.

$V_L = IX_L$ ...... where V_L leads I by 90°.

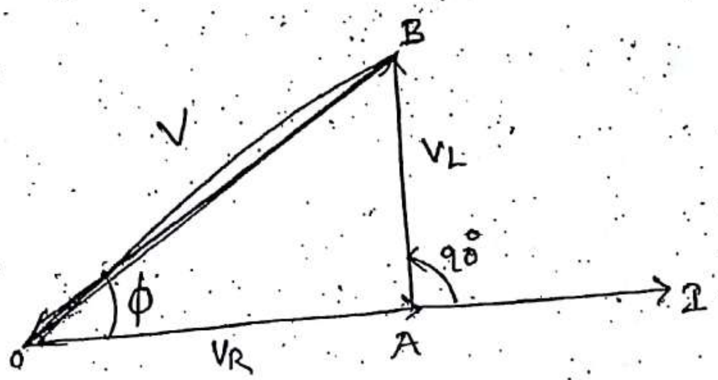


Fig a(ii) phasor diagram.

→ Taking current as the reference phasor, the phasor diagram of the circuit can be drawn as shown in Fig a(ii).

→ The voltage drop V_R (=IR) is in phase with current and is represented in magnitude and direction by the phasor OA.

→ The voltage drop V_L ($=IX_L$) leads current by 90° and represents in magnitude and direction by the phasor AB.

→ The applied voltage V is the phasor sum of these v.v. Imp

R–C. Series Circuit

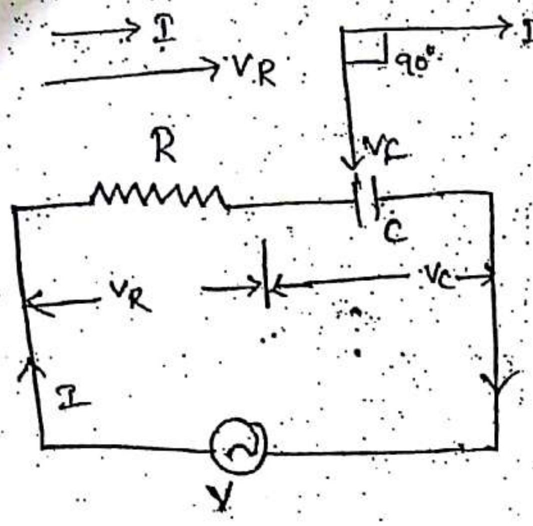


fig D (i)

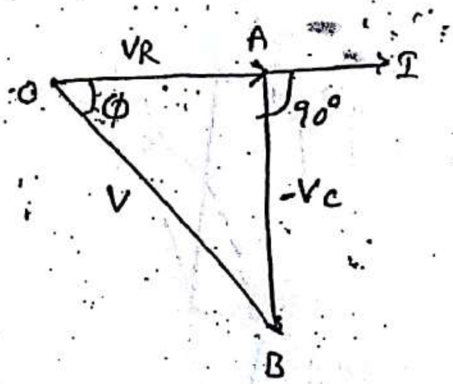


fig D (ii)
Phasor (or) Vector diagram

→ Fig. D (i) shows a resistance of R ohms connected in series with a capacitor of C farad.

→ Let

V = r.m.s. value of the applied voltage

I = r.m.s. value of the circuit current.

$V_R = IR$ -------- where V_R is inphase with I.

$V_C = IX_C$ -------- where V_C lags I by 90°.

→ The phasor (or) Vector diagram of the circuit is shown in fig D (ii). The supply voltage V is the phasor sum of V_R ($= IR$) and V_C ($= IX_C$) drops i.e.,

$$V = \sqrt{V_R^2 + V_C^2}$$

$$= \sqrt{IR^2 + (-X_C)^2}$$

$$V = I\sqrt{R^2 + X_C^2}$$

$$I = V / \sqrt{R^2 + X_C^2}$$

→ The quantity $\sqrt{R^2+X_C^2}$ offers opposition to current and is called impedance of the circuit.

$$\therefore \quad I = \frac{V}{Z} \qquad \text{where } Z = \sqrt{R^2+X_C^2}$$

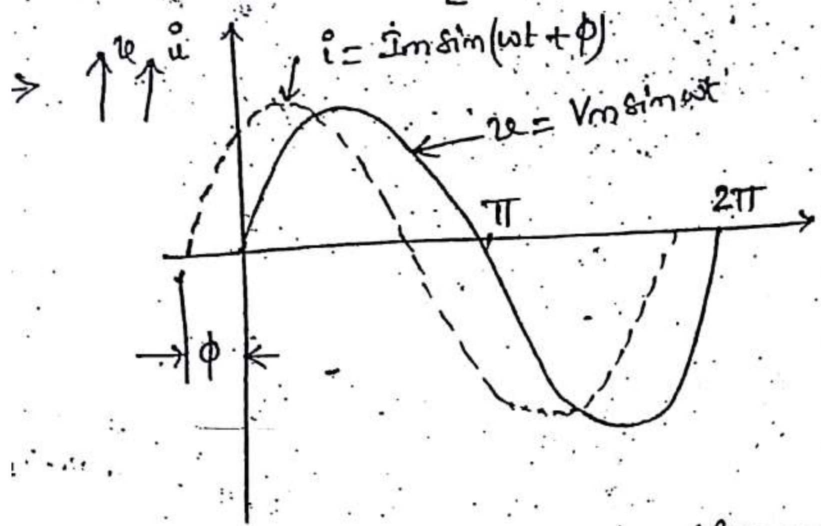
→ 

fig D(iii) wave diagram.

It is clear from the phasor diagram that circuit current I leads the applied voltage V by ϕ° where

$$\tan\phi = \frac{-V_C}{V_R} = \frac{-IX_C}{IR} = \frac{-X_C}{R}$$

__Note__ :- Since current is taken as the reference phasor negative phase angle implies that voltage lags behind the current.

__Power__ :-

The equations for voltage and current are

$$v = V_m \sin\omega t$$
$$i = I_m \sin(\omega t + \phi)$$

Average power, P = Average of vi

$$P = VI\cos\phi$$

Alternatively P = power in R + power in C

$$= I^2R + 0 = IR \times I$$

$$= IR \times V/2 = VI \times R/2 = VI\cos\phi$$

R-L-C Series Circuit

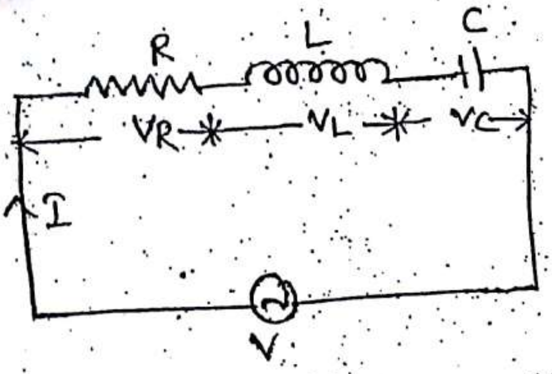


Fig E (i)

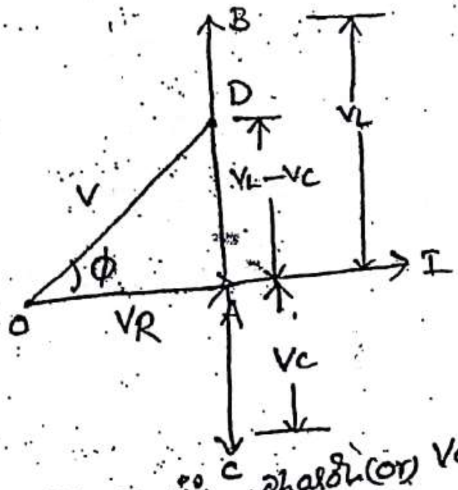


Fig E (ii) phasor (or) Vector diagram.

→ Fig E (i) shows R, L, and C connected in series across a supply voltage V (r.m.s), the resulting current is I (r.m.s).

→ ∴ Voltage across R, $V_R = IR$ ..... V_R is in phase with I.

Voltage across L, $V_L = IX_L$ ... where V_L leads I by 90°.

Voltage across C, $V_C = IX_C$ ... where V_C lags I by 90°.

→ In the phasor diagram [fig E (ii)], OA represents VR, AB represents VL and AC represents VC. It follows that the circuit can either be effectively inductive (or) capacitive depending upon which voltage drop is (VL or VC) pre dominant.

→ The applied voltage V is the phasor sum of V_R and $V_L - V_C$ and is represented by OD,

$$\therefore V = \sqrt{(V_R)^2 + (V_L - V_C)^2}$$

$$V = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

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

$$I = V \Big/ \sqrt{R^2 + (X_L - X_C)^2}$$

→ The Quantity $\sqrt{R^2+(X_L-X_C)^2}$ offers opposition to current flow and is called impedance of the circuit.

Circuit power factor, $\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2+(X_L-X_C)^2}}$

$$\tan\phi = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R}$$

→ Circuit power factor, $\cos\phi = \frac{R}{Z}$

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

$$\tan\phi = \frac{V_L-V_C}{R} = \frac{X_L-X_C}{R}$$

→ Power consumed, $P = VI\cos\phi = I^2R$

$$P = VI\cos\phi = (IZ)I \times \frac{R}{Z} = I^2R$$

Parallel A.C. Circuits

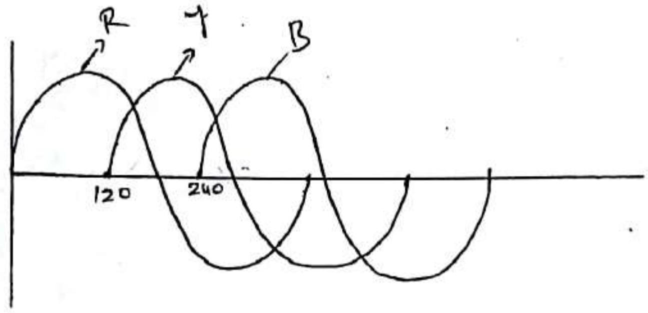
→ ~~The voltage is the same across each branch of a parallel ac circuit.~~

→ ~~The total line current supplied to the circuit is equal to the phasor sum of the branch currents.~~

→ ~~The total line current supplied to a parallel circuit may be determined by determining the current in each branch and adding them, taking into account their phase relations.~~

Three Phase Sources:

The three phase sources are three phase alternator generating three emf having equal magnitude but with a phase difference of 120° with respect to each other.



For operational convenience the three sources can be connected either in star or delta. The three sources are named as R-Phase, Y-Phase and B-Phase. (R, Y, B stands Red, Yellow, Blue). The emf generated by the sources varies sinusoidally and so they are represented by the following equation

$$e_R = E_m \sin \omega t$$

$$e_Y = E_m \sin(\omega t - 120°)$$

$$e_B = E_m \sin(\omega t - 240°)$$

Connection of 3-ϕ system:-

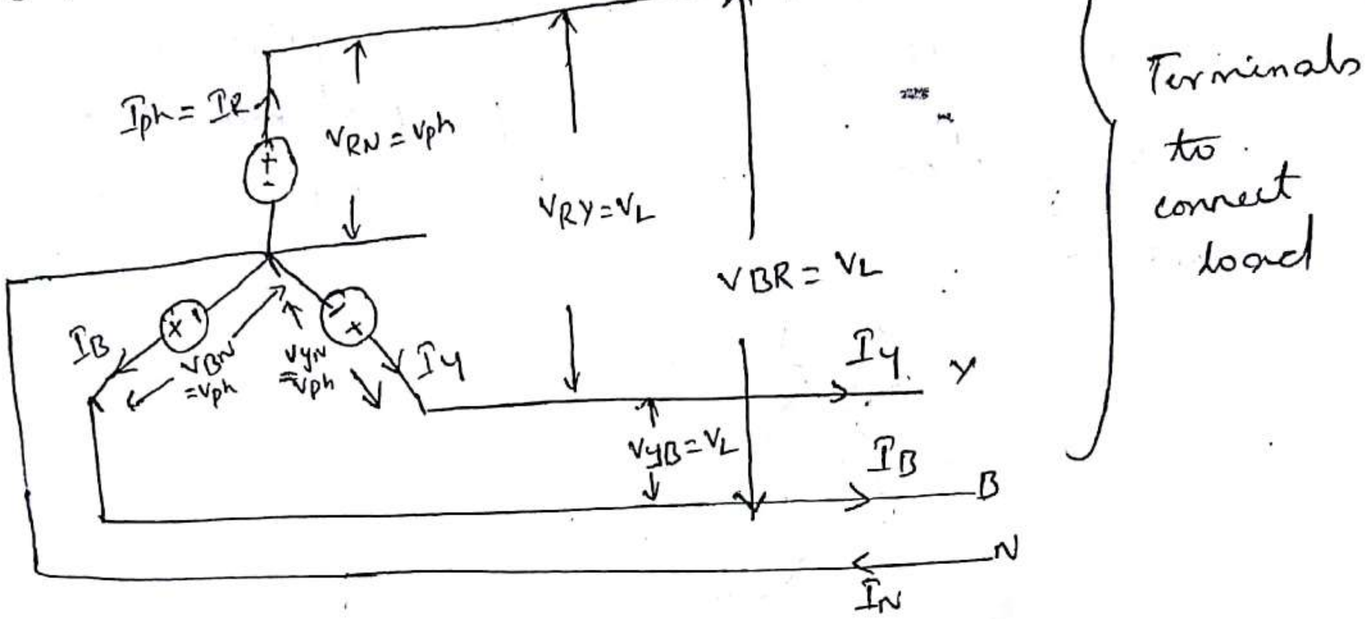
1) Star connected 3-ϕ system

Ex: Electrical distribution system

2) Delta connected 3-ϕ system

Ex: Electrical transmission system.

1) 3-ϕ star connected system :-



→ The voltage in one phase is called phase voltage.

→ The current flowing from phase is called phase current

→ The current in the line is called line current.

→ The potential difference between line to neutral in star connected system is called phase voltage

→ The potential difference between line to line in star connected system is called line voltage

→ The phase voltages are V_{RN}, V_{YN}, V_{BN}

→ The line voltages are V_{RY}, V_{YB}, V_{BR}

→ In star connected system line current is equal to phase current

$$I_L = I_{ph}$$

Note: In a balanced system I_R, I_Y, I_B are equal magnitude and are displaced by 120°

then $I_R + I_Y + I_B = I_N = 0$ (zero).

Relation between phase voltage and line voltage.

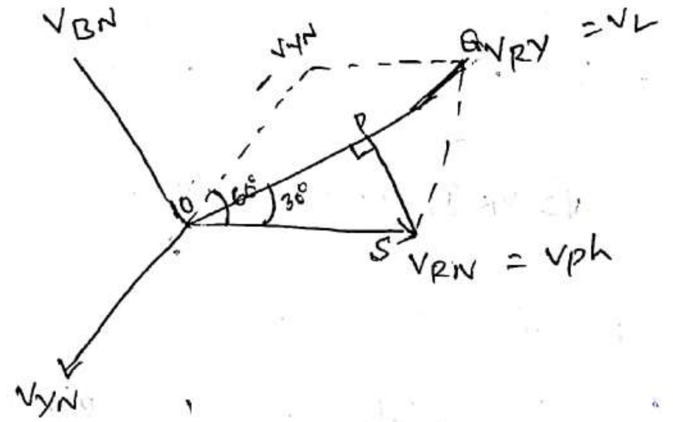
The line voltages are V_{RY}, V_{YB} and V_{BR}

where $V_{RY} = V_{RN} - V_{YN} = V_{RN} + (-V_{YN})$

$V_{YB} = V_{YN} - V_{BN} = V_{YN} + (+V_{BN})$

$V_{BR} = V_{BN} - V_{YN} = V_{BN} + (-V_{YN})$

Thus line voltages are obtained on phase diagram



line and phase relation:

From point S of figure perpendicular SP is drawn on line OQ.

line voltage $V_L = V_{RY} = OQ = 2 \cdot OP$

$= 2 \cdot OS \cos 30$ (from ΔOSP.

$V_L = \cancel{2} \cdot V_{RN} \times \frac{\sqrt{3}}{\cancel{2}}$

$= \sqrt{3}\, V_{RN}$

$V_L = \sqrt{3}\, V_{ph}$

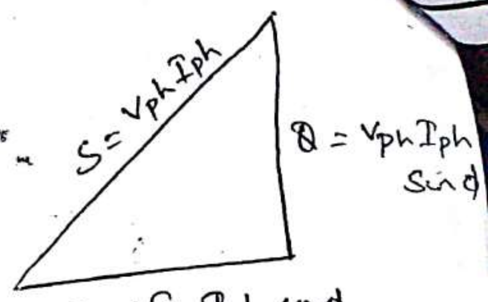
For star connection

$V_L = \sqrt{3}\, V_{ph}$.

Note: The same procedure have to followed for V_{YN}, V_B

Power relation :

The various power of star connected system are given by



Power triangle for single phase

(a) Total active power

$$P = 3 \times \text{Active power of one phase}$$

$$= 3 \times V_{ph} I_{ph} \cos\phi \text{ (watt)}$$

$$= 3 \times \frac{V_L}{\sqrt{3}} I_L \cos\phi \text{ watt}$$

$$= \sqrt{3} V_L I_L \cos\phi \text{ watt.}$$

$V_L = \sqrt{3} V_{ph}$

$V_{ph} = \frac{V_L}{\sqrt{3}}$

b) Total 3-phase reactive power

$$Q = 3 V_{ph} I_{ph} \sin\phi \text{ (VAR)}$$

$$= 3 \frac{V_L}{\sqrt{3}} I_L \sin\phi \text{ (VAR)}$$

$$= \sqrt{3} V_L I_L \sin\phi \text{ (VAR)}$$

VAR : Volt Ampere Reactive

c) Total 3-phase apparent power.

$$S = 3 V_{ph} I_{ph} \text{ (VA)}$$

$$= \sqrt{3} V_L I_L \text{ (VA)}$$

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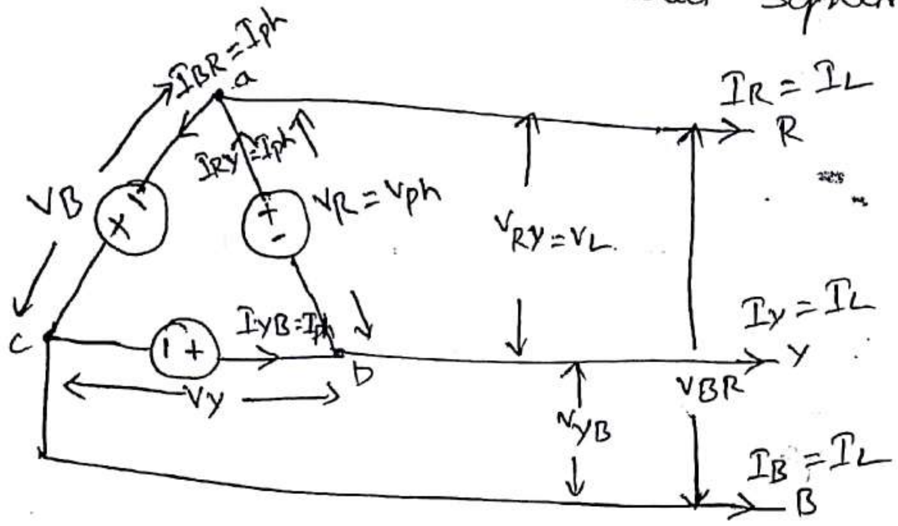
2) 3-ϕ (3-phase) delta connected system :-



→ In delta connection system $V_L = V_{ph}$

→ The line voltage in Δ system are

V_{RY}, V_{YB}, V_{BR}

→ The phase voltage are V_R, V_Y, V_B.

→ The line current are I_R, I_Y, I_B

→ The phase current are I_{RY}, I_{YB}, I_{BR}

Relationship between the line current and phase current

By applying KCL at a

$$I_{RY} = I_R + I_{BR}$$

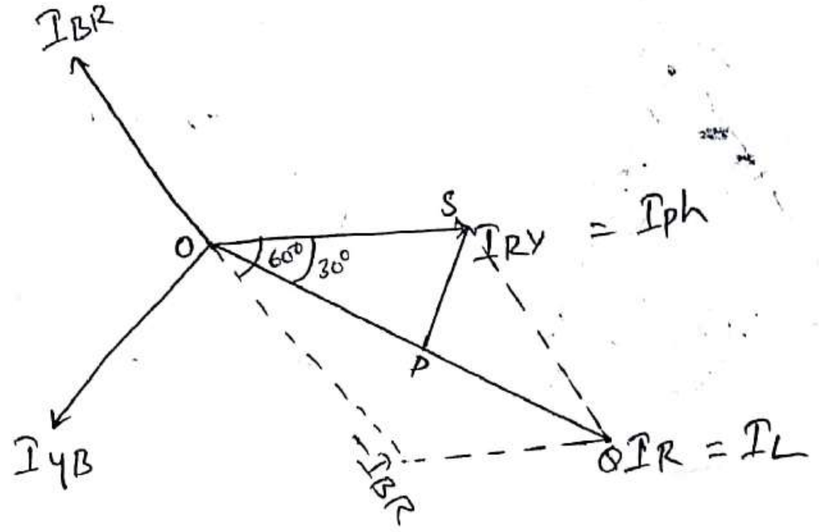
$$I_R = I_{RY} - I_{BR}$$

By applying KCL at b & c

$$I_Y = I_{YB} - I_{RY}$$

$$I_B = I_{BR} - I_{YB}$$

The line currents are obtained on phasor diagram.



line current $I_L = OQ = 2 . OP$

$= 2 . OS \cos 30$

$= 2 . I_{RY} \frac{\sqrt{3}}{2}$

$= \sqrt{3}\, I_{RY}$

$I_L = \sqrt{3}\, I_{ph}$

In delta connection

line current = $\sqrt{3}$ phase current

Note: The same procedure has to followed for

I_{YB} & I_{BR}.

Power Relation:

The various power of delta connected system are given by

a) Total active power

$P = 3 \times$ Active power of one phase.

$= 3 \times V_{ph} I_{ph} \cos \phi$ (watt)

$= 3 \times V_{ph} I_{ph} \cos\phi$ watt

$= 3 \times V_L \times \frac{I_L}{\sqrt{3}} \cos\phi$ where $V_{ph} = V_L$

$I_{ph} = \frac{I_L}{\sqrt{3}}$

$= \sqrt{3} V_L I_L \cos\phi$ watt.

b) Total 3-phase reactive power

$Q = 3 V_{ph} I_{ph} \sin\phi$ (VAR)

$= 3 V_L \frac{I_L}{\sqrt{3}} \sin\phi$ (VAR)

$= \sqrt{3} V_L I_L \sin\phi$ (VAR)

c) Total 3 phase apparent power.

$S = 3 V_{ph} I_{ph}$ (VA)

$= 3 V_L \frac{I_L}{\sqrt{3}}$ (VA)

$= \sqrt{3} V_L I_L$ (VA).

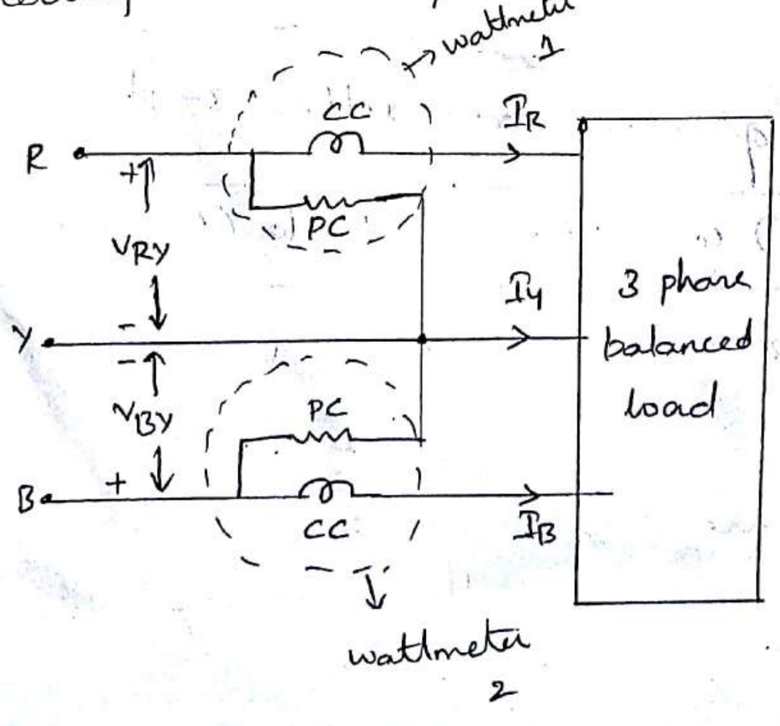
Comparision of star and delta 3-phase connection.

Star (Y) connection	Delta (Δ) connection
1) $V_L = \sqrt{3} V_{ph}$ & $I_L = I_{ph}$	1) $V_L = V_{ph}$ & $I_L = \sqrt{3} I_{ph}$
2) line voltages are 120^0 apart	2) Same

Star (Y) connection	Delta (Δ) connection
3. line voltages are 30° ahead of the respective phase voltage	3. line current are 30° behind the respective phase current.
4. Apparent power $= \sqrt{3} V_L I_L$	4. Same
5, $P_{total} = \sqrt{3} V_L I_L \cos\phi$	5. Same
6. System can be arranged to suit both lighting & power circuit simultaneously.	6. System can be arranged only to suit either lighting or power.

Power Measurement in Balanced load.

Consider a balanced three phase load (star or delta connected). Let us connect wattmeters in the line R & B and line Y be the ~~conn~~ common line for connecting the voltage coil (or pressure coil).

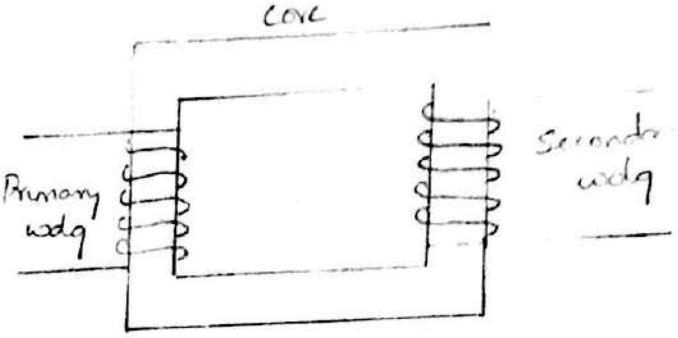


Transformer

Principle of operation of a transformer:

A transformer is a static (or stationary) piece of apparatus by means of which electric power in one circuit is transformed to electric power of the same frequency in other circuit.

It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in a current.



The physical basis of a
transformer is mutual induction between two circuits
linked by a common magnetic flux. In its simplest
form it consists of two inductive coils which are
electrically separated but magnetically linked through
a path of low reluctance as shown in figure. The
two coil possess high ~~mutual~~ mutual inductance. If
one coil is connected to a source of alternating
voltage, an alternating flux is set up in the
laminated core, most of which is linked with the
other coil in which it produces mutually induced
emf (according to Faraday's law of electromagnetic
induction $e = M\frac{dI}{dt}$, $e = N\frac{d\phi}{dt}$) If the second coil
circuit is closed, a current flows in it and so
electrical energy is transferred from first coil to the
second coil. The first coil, in which electric energy is

fed from the ac supply mains, is called primary winding and the other from which energy is drawn out, is called secondary winding.

In brief, a transformer is a device that

1. transfers electric power from one circuit to another
2. It does so without a change of frequency.
3. it accomplishes this by electromagnetic induction &
4. where the two electric current circuits are in mutual inductive influence of each other.

E.M.F Equation of a transformer:

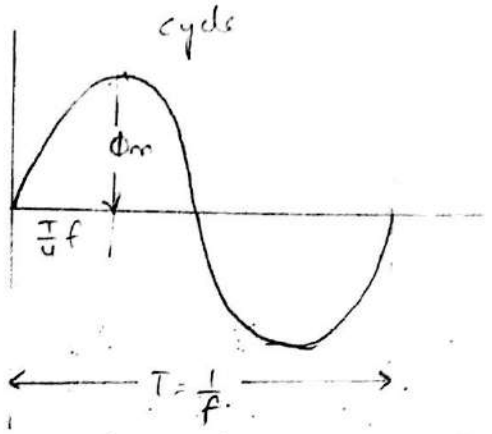
let N_1 = No. of turns in Primary

N_2 = No. of turns in Secondary

Φ_m = Maximum flux in core in webers

$= B_m \times A$

f = Frequency of a.c input in Hertz



As shown in figure flux increases from its zero value to maximum value Φ_m in one quarter of the cycle ie in $1/4f$ second.

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

$= 4f\Phi_m$ wb/s or volt.

Now, rate of change of flux per turn means induced emf in volt

$\therefore$ Average emf / turn $= 4f\phi_m$ volt.

If flux ϕ varies sinusoidally, then rms value of induced emf is obtained by multiplying the average value with form factor.

$$\text{Form factor} = \frac{\text{rms value}}{\text{average value}} = 1.11$$

$\therefore$ rms value of emf / turn $= 1.11 \times 4f\phi_m$ volt

$= 4.44 f\phi_m$ volt

Now rms value of the induced emf in the whole of primary winding = (induced emf / turn) × No of primary turn

$$E_1 = 4.44 f N_1 \phi_m = 4.44 f N_1 B_m A. \quad — (1)$$

Similarly, rms value of the emf induced in secondary is

$$E_2 = 4.44 f N_2 \phi_m = 4.44 f N_2 B_m A \quad — (2)$$

From (1) & (2) that $\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 f \phi_m$. It means that emf/turn is the same in both the primary and secondary windings.

In an ideal transformer on no-load, $V_1 = E_1$ and $E_2 = V_2$ where V_2 is the terminal voltage.

Voltage Transformation Ratio (K)

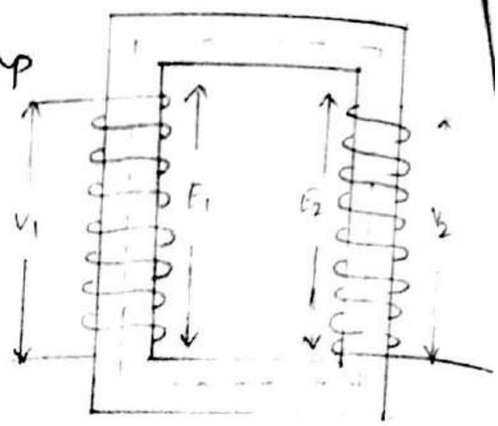
From eq (1) & (2) we get

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

This constant K is known as voltage transformation ratio

(i) If $N_2 > N_1$ ie $K > 1$

then transformer is called Step up transformer



(ii) If $N_1 > N_2$ ie $K < 1$

then transformer is called Step down transformer.

Again, for an ideal transformer

input VA = output VA

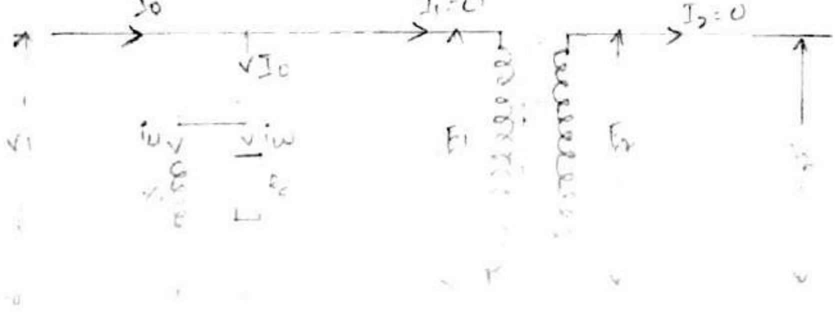
$$V_1 I_1 = V_2 I_2$$

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

Hence, currents are in the inverse ratio of the (voltage) transformation ratio.

Transformer on No load

In an ideal transformer ie. one in which there were no core losses and copper losses. But practical conditions require that certain modification be made in the foregoing theory.

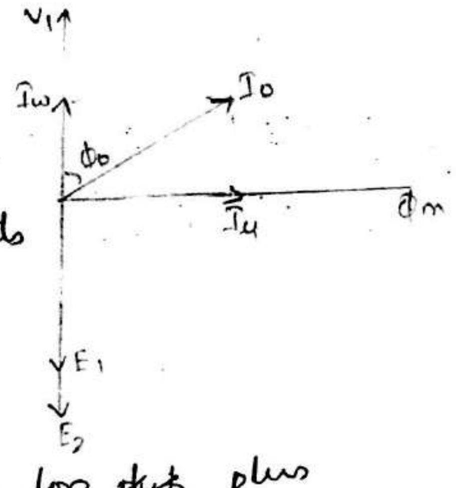


when an actual transformer is put on load, there is iron loss in the core and copper loss in the winding (both primary & secondary) and these losses are not entirely negligible.

Even when the transformer is on no load, the primary input current is not wholly reactive. The primary input current under no load condition has to supply (i) iron losses in the core i.e. hysteresis & eddy current loss and

(ii) a very small amount of copper loss in primary (there is no copper loss in the secondary as it is open).

Hence no load primary input current I_0 is not at 90° behind V_1 but lags it by an angle $\phi_0 < 90^\circ$.



No load input power is

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

Primary current I_0 has two components

(i) One in phase with V_1

This is known as active or working or iron loss component I_w because it mainly supplies the iron loss ~~plus~~ plus small quantity of primary Cu loss.

$$I_w = I_0 \cos\phi_0$$

(ii) The other componed is in quadrature with V_1 and is known as magnetising componend I_μ because its function is to produce the alternating flux in the core. It is wattless.

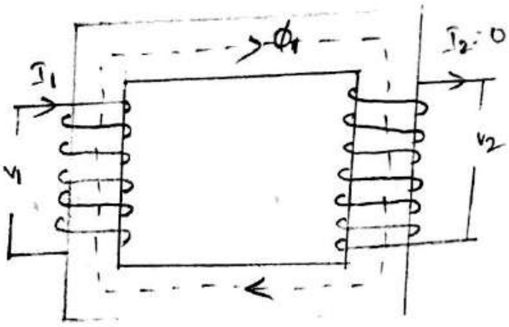
$$I_\mu = I_0 \sin\phi_0$$

I_0 is the vector sum of I_w & I_μ

hence $I_0^2 = I_w^2 + I_\mu^2$.

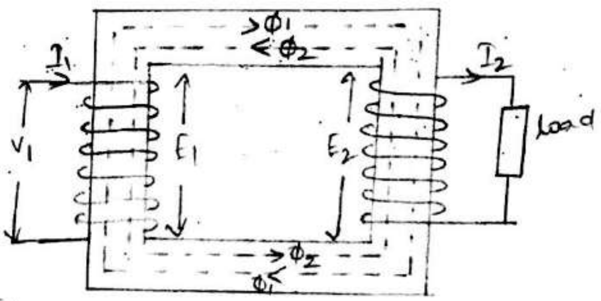
⇒ Transformer on load:

when the transformer under no load ~~condition~~ condition. The primary current I_1 will setup the flux ϕ_1 and links the secondary coil.

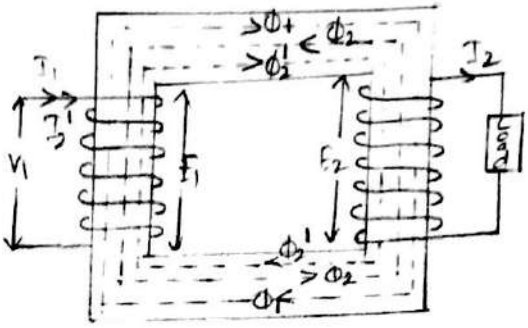


when the secondary is loaded, the secondary current I_2 is set up.

The secondary current setup its own mmf (N_2I_2) and hence own flux ϕ_2 which is in opposition to the main primary flux ϕ_1. The secondary ampere-turns N_2I_2 are known as demagnetising amp-turn. The opposing secondary flux ϕ_2 weakens the primary flux ϕ_1 momentarily, Hence primary back emf E_1 tends to reduce. For a moment V_1 gains the upper hand over E_1 and hence causes more current to flow in Primary.



Let the additional primary current be I_2'. It is known as load component of primary current. This current is antiphase with I_2'. The additional primary mmf $N_1 I_2$ set up its own flux Φ_2' which is in opposition to Φ_2 and is equal to it in magnitude.



Hence two cancel each other out.

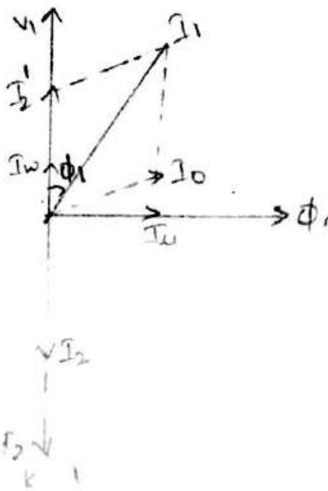
Hence whatever the load conditions, the net flux passing through the core is approximately the same as at no load. An important deduction is that due to constancy of core flux at all loads, the core loss is also practically the same under all load condition

As $\Phi_2 = \Phi_2'$

$$N_2 I_2 = N_1 I_2'$$

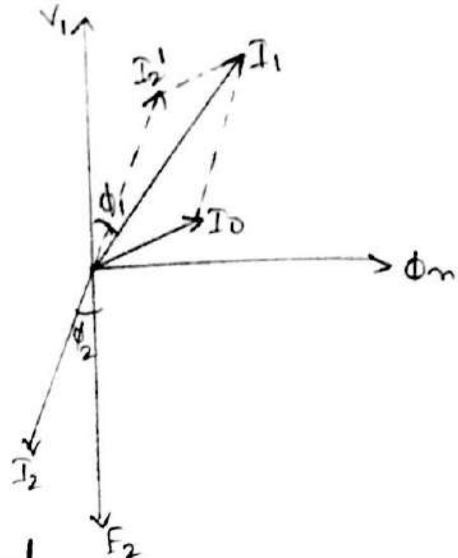
$$I_2' = \frac{N_2}{N_1} \times I_2 = K I_2 .$$

The vector diagram for a load transformer when the load is non inductive



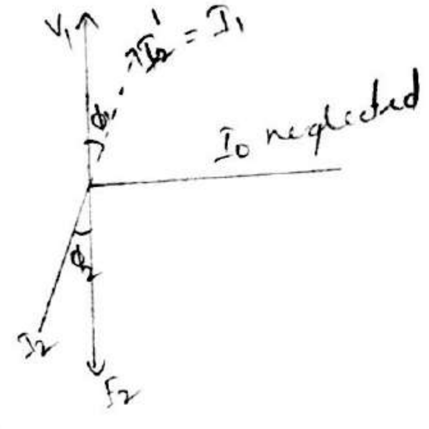
I_2 is secondary current in phase with E_2. It causes a primary current I_2' which is anti-phase with it and equal to it in magnitude ($K=1$). Total primary current I_1 is the vector sum of I_0 and I_2' and lag behind V_1 by angle ϕ_1.

The vector diagram for load transformer when the load is inductive.



k=1

Here I_2 lags E_2 by Φ_2.
current I_2' is again antiphase with I_2 and equal to it in magnitude.
As before I_1 is vector sum of I_2' & I_0 and lags behind V_1 by Φ_1.
It will observed that Φ_1 is slightly greater than Φ_2.
But if we neglect I_0 as compared to I_2' then $\Phi_1 = \Phi_2$



$$N_2 I_2' = N_2 I_1 = N_1 I_2$$

$$\frac{I_2'}{I_2} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = k.$$

It shows that under full load conditions, the ratio of primary and secondary current is constant.

Efficiency of a transformer:

The efficiency of a transformer at a particular load and power factor is defined as the output divided by the input - the two being measured in the same units (either watt or kilowatts).

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

But a transformer being a highly efficient piece of equipment, has very small loss, hence it is impractical to try to measure transformer, efficiency by measuring input and output.

A better method is to determine the losses and then to calculate the efficiency from:

$$\text{Efficiency} = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{\text{output}}{\text{output} + \text{cu losses} + \text{iron losses}}$$

$$\eta = \frac{\text{Input} - \text{losses}}{\text{Input}} \qquad \therefore \text{input} = \text{output} + \text{losses}$$

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

condition for Maximum efficiency

$$\text{cu losses} = I_1^2 R_{01} \text{ or } I_2^2 R_{02}$$

Iron losses = Hysterisis losses + Eddy current loss

$$W_i = W_h + W_e$$

Open

considering primary side,

Primary input $= V_1 I_1 \cos\phi_1$

$$\eta = \frac{V_1 I_1 \cos\phi_1 - \text{losses}}{V_1 I_1 \cos\phi_1}$$

$$= \frac{V_1 I_1 \cos\phi_1 - I_1^2 R_{01} - W_i}{V_1 I_1 \cos\phi_1}$$

$$= 1 - \frac{I_1^2 R_{01}}{V_1 I_1 \cos\phi_1} - \frac{W_i}{V_1 I_1 \cos\phi_1}$$

$$= 1 - \frac{I_1 R_{01}}{V_1 \cos\phi_1} - \frac{W_i}{V_1 I_1 \cos\phi_1}$$

Differentiating both sides with respect to I_1, we get

$$\frac{d\eta}{dI_1} = 0 - \frac{R_{01}}{V_1 \cos\phi_1} + \frac{W_i}{V_1 I_1^2 \cos\phi_1}$$

For η to be maximum, $\frac{d\eta}{dI_1} = 0$

Hence above equation becomes

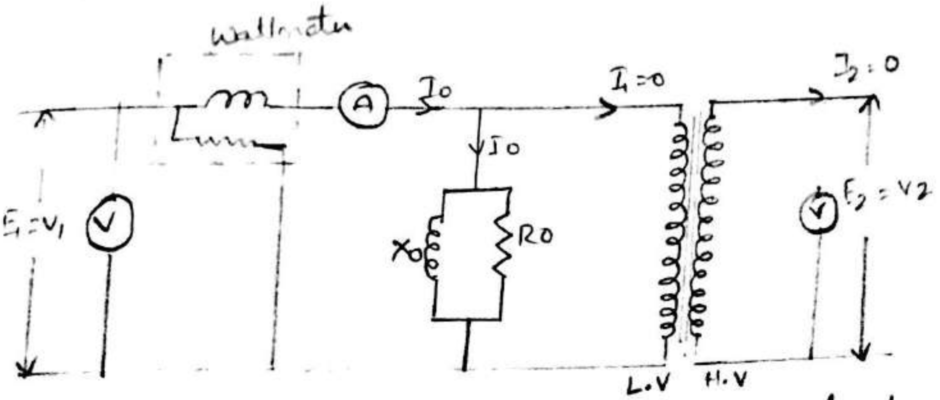
$$\frac{R_{01}}{\cancel{V_1} \cos\phi_1} = \frac{W_i}{\cancel{V_1} I_1^2 \cancel{\cos\phi_1}}$$

$$I_1^2 R_{01} = W_i$$

Cu losses = Iron losses.

pen circuit or No load Test.

The purpose of this test is to determine no load loss or core loss and no load I_0 which is helpful in finding X_0 and R_0.



One winding of the transformer whichever is convenient but usually high voltage winding is left open and low voltage winding is connected to its supply of normal voltage and frequency. A wattmeter W, voltmeter 'V' and an ammeter 'A' are connected to the low voltage winding i.e primary winding in the present case. with normal voltage applied to the primary, normal flux will be set up in the core. hence normal iron losses will occur which are recorded by the wattmeter.

As the primary no load current I_0 as measured by ammeter (usually 2 to 10% of rated load current). cu losses are negligibly small in primary and nil in secondary (it being open). Hence the wattmeter reading represents practically the core loss under no load condition.

$W = V_1 I_0 \cos\phi_0$

$\cos\phi_0 = \dfrac{W}{V_1 I_0}$

$VA = E_1 I_0$ drawn from the source.

Q (reactive power) $= \sqrt{(VA)^2 - P^2}$.

$R_0 = \dfrac{V_1 \text{ or } (E_1)}{I_w} \rightarrow I_w = I_0 \cos\phi_0$

$X_0 = \dfrac{V_1 (E_1)}{I_\mu} \rightarrow I_\mu = I_0 \sin\phi_0$.

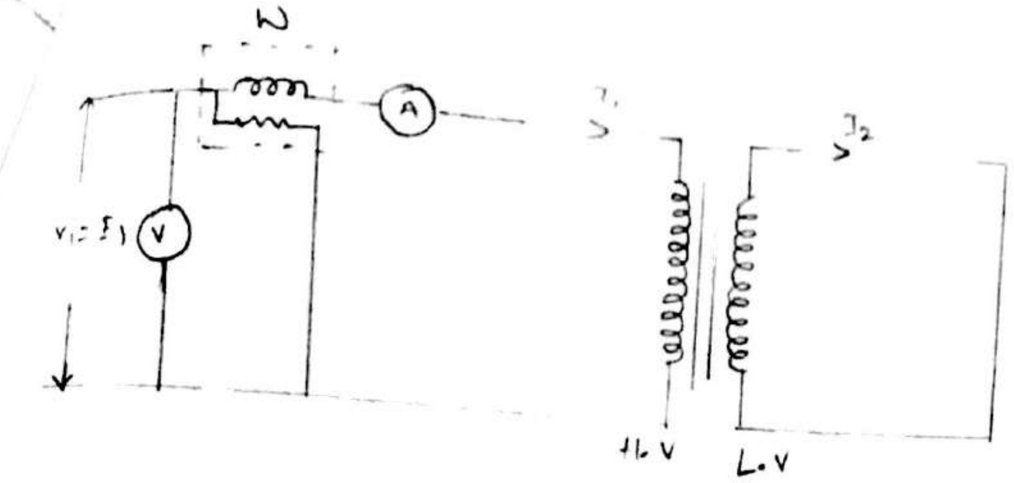
Short circuit or Impedence Test:

This is an economical method for determing the following.

(i) Equivalent Impedance (Z_{01} or Z_{02}), leakage reactance (X_{01} or X_{02}) and Total resistance (R_{01} or R_{02}) of the transformer as referred to the winding in which measuring instruments are placed.

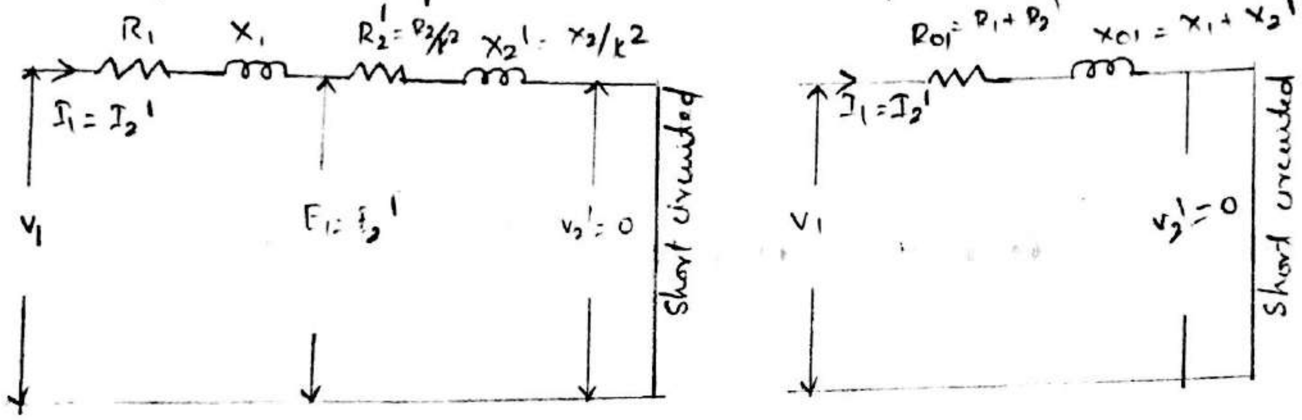
(ii) Cu loss at full load (and at any desired load) This loss is used in calculating the efficiency of the transformer.

(iii) knowing Z_{01} or Z_{02} the total voltage drop in the transformer are referred to primary or secondary can be calculated and hence regulation of transformer determined.



Here $I_2 \neq 0$
so $I_1 \neq 0$
$I_1 >> I_0$
so I_0 is neglected

In this test, one winding, usually the low voltage winding is solidly short circuited by a thick conductor.



A low voltage (usually 5 to 10% of normal primary voltage) at correct frequency (through for cu losses it is not essential) is applied to the primary and is cautiously increased till the full load currents are flowing both in primary and secondary.

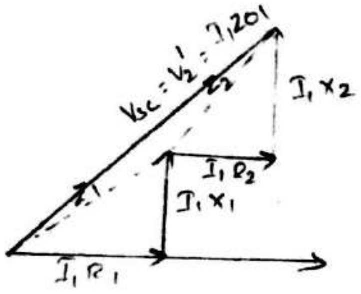
In this test, the applied voltage is small, the mutual flux ϕ is also small, hence core losses are very small with result that the wattmeter reads the full load copper (cu) loss or I^2R loss for the whole transformer ie both primary cu loss & secondary cu loss.

V_{sc} or $\frac{E_1}{I_1} = Z_{01}$

$R_{01} = \frac{P}{I_1^2}$ where $P = I_1^2 R_{01}$ (This power value will show wattmeter)

$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$.

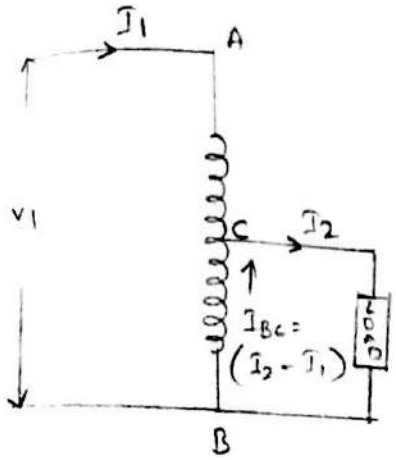
The equivalent circuit vector diagram for short circuit test is shown.



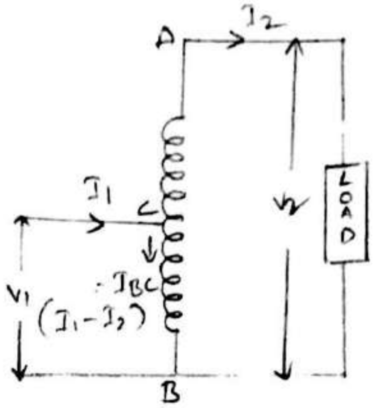
Auto Transformer

It is a transformer with one winding only, part of this being common to both primary and secondary. In this transformer the primary and secondary are not electrically isolated from each other as is the case with a 2-winding transformer. But its theory and operation are similar to those of a two winding transformer.

Because of one winding, it uses less copper and hence is cheaper.



Step down autotransformer



Stepup autotransformer.

Saving of copper:

Volume and hence weight of cu, is proportional to the length and area of the cross section of the conductors. Now, length of conductor is proportional to the number of turns, & cross section area depends on current.

wt of cu in section AC $\propto (N_1 - N_2) I_1$

wt of cu in section BC $\propto N_2 (I_2 - I_1)$

Total wt of cu in auto transformer $\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$

If a two winding transformer were to perform the same duty, then

wt of cu on its primary $\propto N_1 I_1$

" " " " " secondary $\propto N_2 I_2$

Total wt of cu $\propto N_1 I_1 + N_2 I_2$

$$\therefore \frac{\text{wt of cu in auto transformer}}{\text{wt of cu in 2-wdg transformer}} = \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

$$= 1 - \frac{2\frac{N_2}{N_1}}{1 + \frac{N_2}{N_1} \times \frac{I_2}{I_1}}$$

$$= 1 - \frac{2k}{1 + k \times \frac{1}{k}}$$

$$= 1 - \frac{2k}{2} = 1 - k.$$

wt of cu in auto t/f = (1-k) wt of cu in 2-wdg t/f.

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

$$\text{Saving} = W_o - W_a$$

$$= W_o - (1-k) W_o$$

$$= k W_o.$$

Saving = k(wt of cu in 2 wdg t/f).

Hence saving will increase as k approaches to unity.

It can be proved that,

Power transfer inductively is input (1-k).

The rest of the power = (k × input) is conducted directly from source to the load.

Important formulae in transformers.

$$\frac{E_2}{E_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = k.$$

2. Stacking factor = $\frac{\text{Net cross section area of core}}{\text{Gross cross section area of core}}$.

3) $E = 4.44\,\phi_m f N$

where ϕ_m = max flux $\phi_m = B \times A$ = flux density × Area of core

f = frequency

N = No. of turns.

3) $I_w = I_0 \cos\phi_0$

$I_\mu = I_0 \sin\phi_0$

$I_0 = \sqrt{I_\mu^2 + I_w^2}$

4) secondary referred to primary

$R_{01} = R_1 + R_2' = R_1 + R_2/k^2$

$X_{01} = X_1 + X_2' = X_1 + X_2/k^2$.

$Z_{01}^2 = R_{01}^2 + X_{01}^2$

5) primary referred to secondary

$R_{02} = R_2 + R_1' = R_2 + k^2 R_1$

$X_{02} = X_2 + X_1' = X_2 + k^2 X_1$

$Z_{02}^2 = R_{02}^2 + X_{02}^2$.

6) $\%\ \text{reg down} = \dfrac{{}_0V - V}{{}_0V} = \dfrac{\text{no load voltage} - \text{full load voltag}}{\text{no load voltage}}$

$\%\ \text{reg up} = \dfrac{{}_0V - V}{V}$

Note: untill unless mention always find the reg down only.

7) $\%\ \text{reg} = V_r \cos\phi \pm V_x \sin\theta$ + leading
− lagging.

$V_r = \dfrac{I_1 R_{01}}{V_1}$, $V_x = \dfrac{I_1 X_{01}}{V_1}$ } referred to primary | $V_r = \dfrac{I_2 R_{02}}{V_2}$, $V_x = \dfrac{I_2 X_{02}}{V_2}$ } referred to secondary

8) wt of cu of auto t/f = (1−k) wt of cu of 2-wdg t/f.
$W_a = (1-k) W_0$

9) Saving $= k W_0$

10) Power transferred inductively = input×(1−k)

11) " " conductively = input×(k)

where input ≅ output (load).

Production of Rotating Magnetic field

when stationary coils, wound for two or three phases are supplied by two or three phase supply respectively, a uniform-rotating (or revolving) magnetic flux of constant value is produced.

Three phase supply:

when three phase windings displaced in space by 120°, are fed by three phase currents, displaced in time by 120°, they produce a resultant magnetic flux, which rotates in space as if actual magnetic ~~poles~~ poles were being rotated mechanically.

The principle of a 3 phase two pole stator having three identical windings place 120 space degree apart as shown in figure1. The flux due to three phase winding is shown in figure 2.

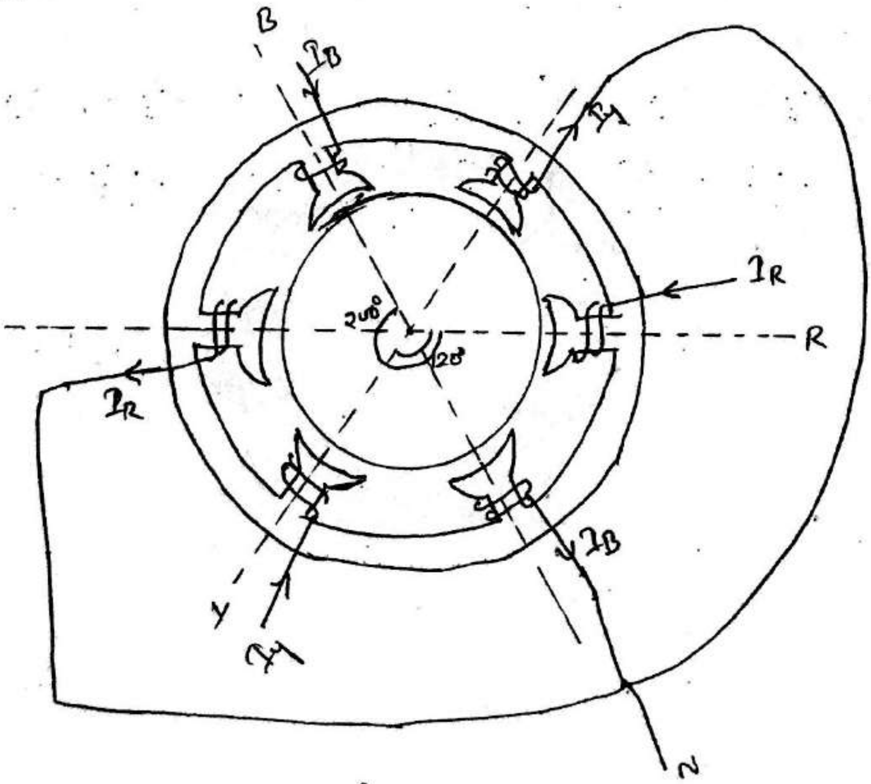


fig 1

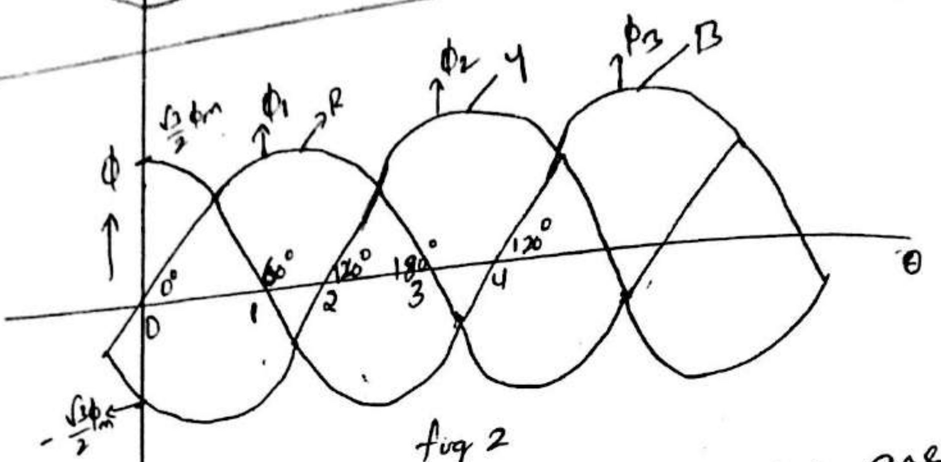


fig 2

The assumed positive direction of the fluxes are shown in fig 2. let the maximum value of flux due to any one of the three phases be ϕ_m. The resultant flux ϕ_r at any instant, is given by the vector sum of the individual fluxes ϕ_1, ϕ_2 and ϕ_3 due to three phases. we will consider value of ϕ_r at four instants $1/6$ th time period apart corresponding to points marked 0, 1, 2 and 3 in fig 2.

(i) when $\theta = 0^\circ$ ie corresponding to point in fig 2

Here $\phi_1 = 0$, $\phi_2 = -\frac{\sqrt{3}}{2}\phi_m$, $\phi_3 = \frac{\sqrt{3}}{2}\phi_m$

The vector for ϕ_2 in fig 4(i) is drawn in a direction opposite to the direction assumed positive in fig 3.

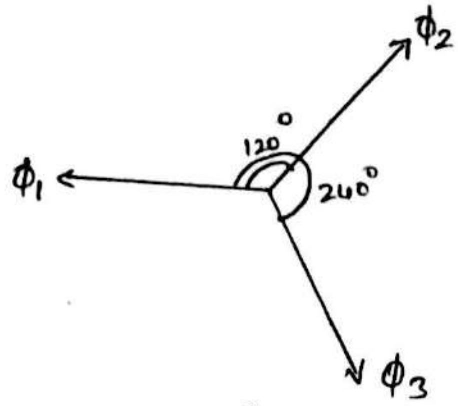


fig 3

$$\left(\because \sqrt{a^2+b^2+2ab\cos\theta}\right.$$

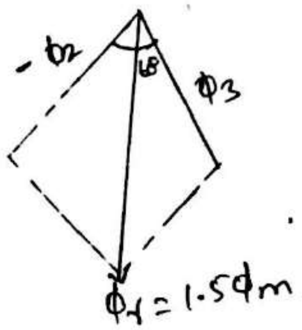
$a=b$

$$= \sqrt{a^2+a^2+2a^2\cos\theta}$$
$$= \sqrt{2a^2(1+\cos\theta)}$$
$$= \sqrt{2a^2 \times 2\cos^2\frac{\theta}{2}}$$
$$= 2a\cos\frac{\theta}{2}\,,$$

$$\phi_r = 2\times\frac{\sqrt{3}}{2}\phi_m \cos\frac{60}{2}$$

$$= \sqrt{3}\,\phi_3 \times\frac{\sqrt{3}}{2} = \frac{3}{2}\phi_m$$

$$= 1.5\,\phi_m$$



when $\theta = 0°$

fig 4(i)

(ii) when $\theta = 60°$ ie corresponding to point 1 in fig 2

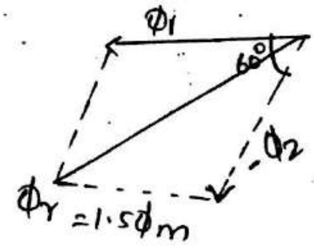
$$\phi_1 = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_2 = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_3 = 0$$

$$\phi_r = 2\times\frac{\sqrt{3}}{2}\phi_m \cos\frac{60}{2}$$

$$= \frac{3}{2}\phi_m$$



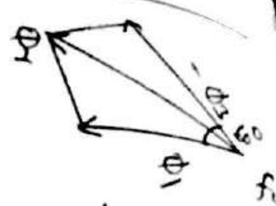
when $\theta = 60°$

fig 4(ii)

(iii) when $\theta = 120°$ ie corresponding to point 2 in fig 2

Here $\phi_1 = \frac{\sqrt{3}}{2}\phi_m$ $\quad \phi_2 = 0$ $\quad \phi_3 = -\frac{\sqrt{3}}{2}\phi_{3m}$

It can be again proved that

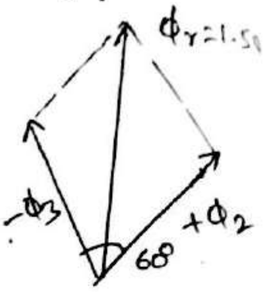


$$\phi_r = \frac{3}{2}\phi_m$$

So the resultant is again of the same value, but further rotated clockwise through an angle of 60°.

(iv) when $\theta = 180°$ ie corresponding to point 3 in fig 2

$$\phi_1 = 0 \quad \phi_2 = \frac{\sqrt{3}}{2}\phi_m \quad \phi_3 = -\frac{\sqrt{3}}{2}\phi_m$$



$\theta = 180°$.
fig 4(iv)

The resultant is $\frac{3}{2}\phi_m$ and has rotated clockwise through an additional angle 60° or through an angle 180° from the start.

Hence we conclude that.

1) the resultant flux is of constant value $= \frac{3}{2}\phi_m$ ie 1.5 times the maximum value of the flux due to any phase

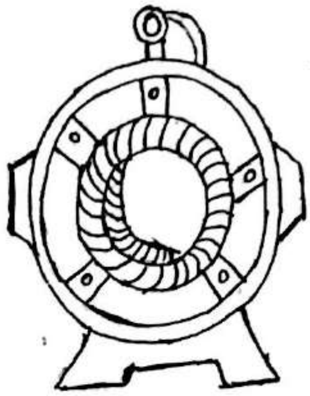
2) The resultant flux rotates around the stator at Synchronous speed given by $N_s = \frac{120 f}{P}$.

Induction motor : General Principle.

As a general rule, conversion of electrical power into mechanical power take place in the rotating part of an electric motor. In dc motor the electric power is conducted directly to the armature through brushes and commutator. Hence in this case, dc motor can be called as conduction motor.

The rotor is seperated from the stator by a small air gap which ranges from 0.4mm to 4mm, depending on the power of the motor.

1. Stator: It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses.



The insulated conductors are placed in the stator slots and are suitably connected to form a balanced 3-ϕ (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, less is the speed of the rotor and vice versa $\left(N_s = \frac{120f}{P}\right)$. f → frequency, P → poles

→ when 3-phase supply is given to the stator winding a rotating magnetic field of constant magnitude is produced. This rotating field induces current in the rotor by electromagnetic induction.

Rotor: The rotor, mounted on a shaft, is a hollow laminated core having slots on its outer periphery. The winding placed in these slots (called rotor winding) may be one of the following two types

(i) Squirrel cage rotor type

ii) wound rotor or phase wound type. or slip ring type

However in ac motors, the rotor does not rec
electric power by conduction but by induction in
exactly the same way as the secondary of a 2-w
transform receives its power from the primary. That
why such motors are known as induction motors.

In fact induction motors can be treated as a rotating transformer i.e one winding (primary) is stationary but the other winding (secondary) is free to rotate.

Advantages:

i) It has simple and rugged construction.

ii) It is relatively cheap.

iii) It requires little maintenance.

iv) It has high efficiency and reasonable good power factor

v) It has self starting torque.

Disadvantages:

i) Its speed cannot be varied without sacrificing some of its efficiency

ii) Just like a d.c shunt motor, its speed decreases wi increase in load

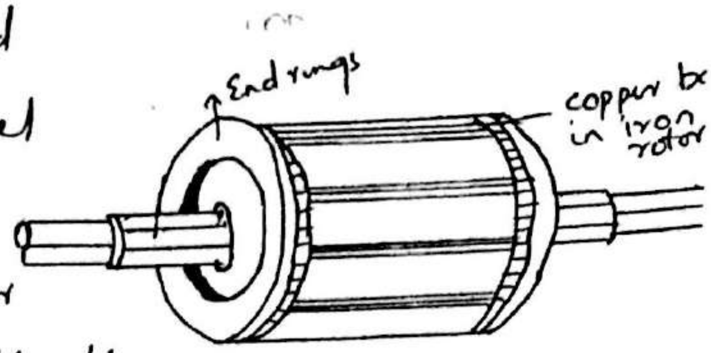
iii) Its starting torque is somewhat inferior to that of a dc shunt motor.

Construction:

An induction motor has two main parts (i) stator a (ii) rotor.

(i) Squirrel cage rotor:

It consists of a laminated cylindrical core having parallel slots on its outer pheriphery. One copper or aluminium bar is placed in each slot. All these

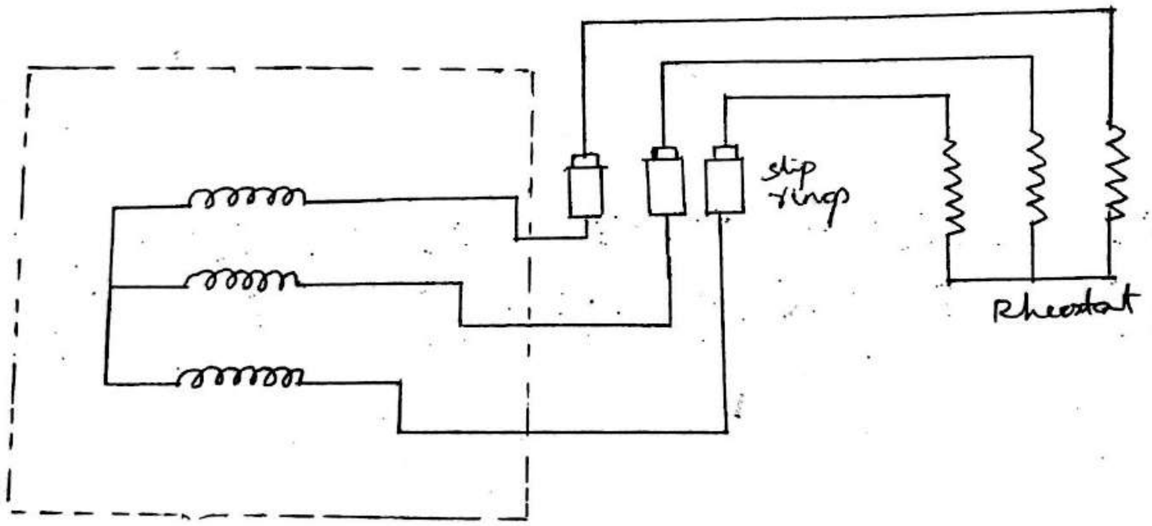


bars are joined at each end by metal rings called end rings. This forms a permanently short circuited winding which is indestructible. The entire construction resembles a squirrel cage and hence the name. The rotor is not connected electrically to the supply but has current induced in it by tranformer action from the stator.

Those induction motor which employ squirrel cage rotor are called squirrel cage induction motor. Most of the 3-phase induction motor uses squirrel cage rotor as it has a remarkabley simple and robust constructions enabling it to operate in the most adverse circumstance

It suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque.

(ii) <u>wound rotor</u>: It consists of a laminated cylindr,
core and carries a 3 phase winding similar to
one on the stator. The rotor winding is uniformly
distributed in the slots and is usually star conn.
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. The three brushes are connected to a 3 phase
star connected rheostat. At starting, the external
resistance are included in the rotor circuit to give
a large starting torque. These resistance are graduall
reduced to zero as the motor runs up to speed.



Rotor winding

slip: The
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Slip: The ratio of the difference between the synchronous speed N_s and the actual speed N of the rotor to the synchronous speed is known as slip. Though it may be expressed in so many revolution/s yet it is usual to express it as a percentage of the synchronous speed.

$$\% \text{ slip} = s = \frac{N_s - N}{N_s} \times 100$$

$N_s - N$ is called slip speed.

rotor speed (or motor) speed $= N = N_s(1-s)$

Frequency of rotor current.

When the rotor is stationary, the frequency of the rotor current is the same as the supply frequency. But when the rotor starts revolving, then the frequency depend upon the relative speed or on slip speed.

Let any ~~spke~~ slip speed, the frequency of the rotor current be f'. Then

$$N_s - N = \frac{120f'}{P} \quad \text{Also} \quad N_s = \frac{120f}{P}$$

Dividing one by other $\dfrac{N_s - N}{N_s} = \dfrac{120f'}{P} \Big/ 120f/P$

$$\frac{N_s - N}{N_s} = f'/f$$

where $\dfrac{N_s - N}{N_s} = s \qquad s = f'/f$

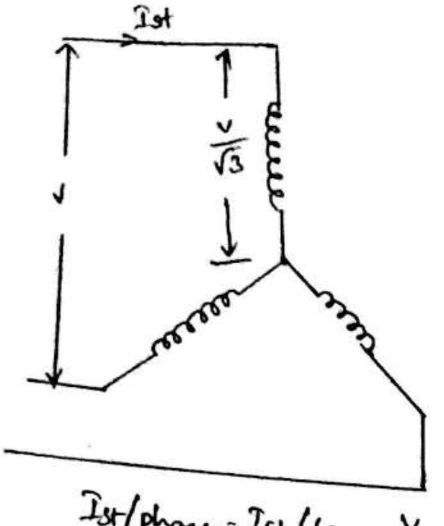
So rotor current frequency $f' = sf$.

Star delta Starter:

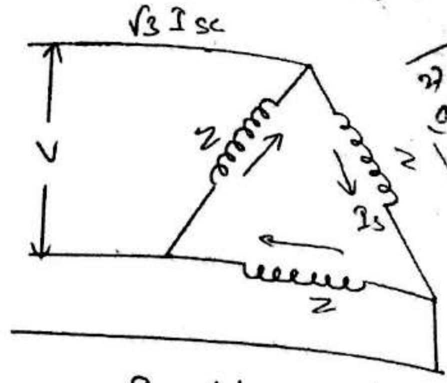
This method is used in the case of motor which are built to run normally with delta connected stator winding. It consists of two way switch which connect the motor in star for starting and then in delta for normal running.

When star connected the applied voltage over each motor phase is reduced by a factor of $1/\sqrt{3}$ and hence torque developed becomes $1/3$ of that which would have developed if motor were directly connected in delta. The line current is reduced to $1/3$.

Hence during starting period when motor is Y conne-
cted it takes $1/3$rd as much starting current and
$1/3$ as much torque as would have been developed
were it directly connected in delta.



$I_{st}/\text{phase} = I_{st}/\text{line} = \frac{V}{\sqrt{3}Z}$



$I_{sc}/\text{phase} = \frac{V}{Z}$

$I_{sc}/\text{Line} = \sqrt{3}\frac{V}{Z}$

$$I_{st} \text{ per phase} = \frac{1}{\sqrt{3}} I_{sc} \text{ per phase.}$$

$$T_{st} \propto I_{st}^2 \quad (s=1)$$

$$T_f \propto I_f^2/s_f$$

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 \times s_f$$

$$= \left(\frac{I_{sc}}{\sqrt{3}I_f}\right)^2 \times s_f = \frac{1}{3}\left(\frac{I_{sc}}{I_f}\right)^2 \times s_f.$$

Speed control of Induction motor:

Different methods by which speed control of induction motor is achieved, may be grouped under two main headings:

1) control from stator side

a) by changing the applied voltage

b) " " " " frequency

c) " " " numbers of poles.

2) Control from rotor side
(a) charg'
a) rotor rheostat control
b) by operating two motors in concatenation or cascade
c) by injecting an emf in the rotor circuit.

a) <u>change in applied voltage.</u>

This method, though the cheapest and the easiest is rarely used because.

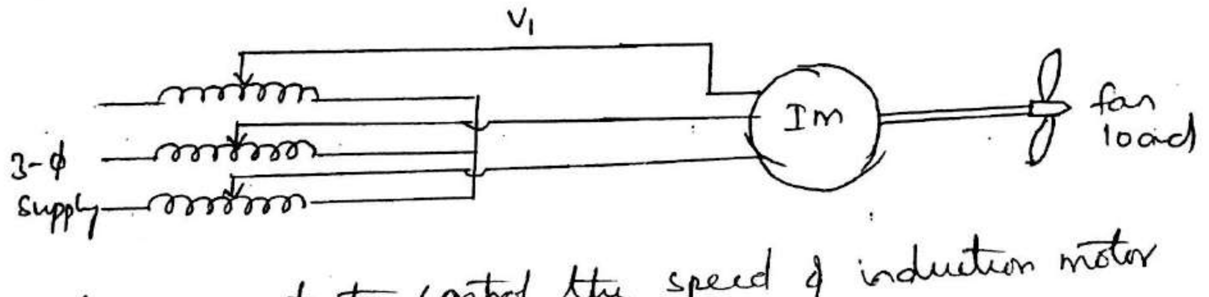
(i) a large change in voltage is required for a relatively small change in speed.

(ii) this large change in voltage will result in large change in flux density thereby seriously disturbing the magnetic condition of the motor.

→ we know that torque developed (T) by an induction motor is directly proportional to the square of applied voltage

$$T \propto V^2$$

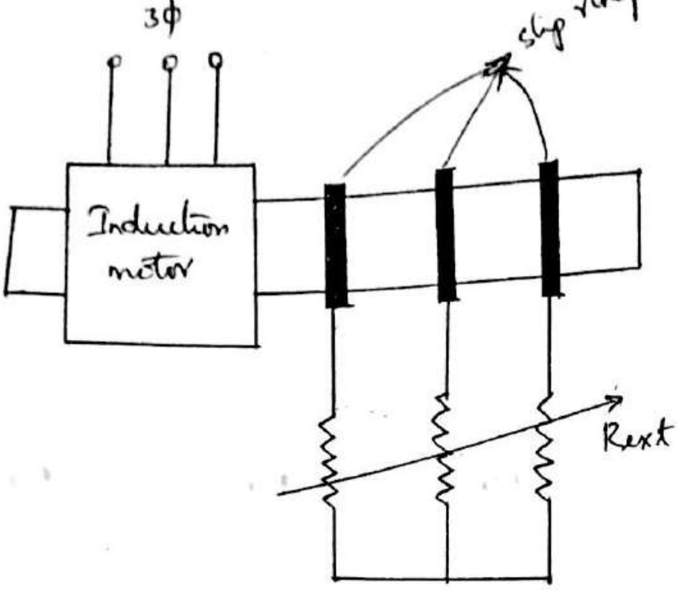
Therefore by changing torque and hence speed of the motor can be changed.



Arrangement to control the speed of induction motor by changing applied voltage.

Speed control by changing Rotor circuit resistance:

This method of speed control is suitable only for Slip ring motors. The speed of the motor can be decr.. by adding external resistance to the rotor as shown in figure.



Under normal running condition, the relation b/w Torque and slip of an induction motor is given by

$$T \propto S/R_2$$

Here R_2 is the rotor resistance/phase

It is clear from above relation for a given torque $S \propto R_2$. Therefore Slip can be increased (ie motor speed decreases) by increasing rotor resistance.

Drawbacks:

i) There is increase in rotor copper losses.

(ii) due to increase in " " " efficiency will decrea

(iii) There is increase in the temperature of the motor.

Applicat

US

1)

2)

3)

Application of 3-phase Induction motor.

1) Used in Robotics
2) Used in Rolling mills
3) Used in Grinding machines
4) Used in varying load machines
5) Printing machines
6) lathe machines
7) Drives of fan.

Single phase Motors

Introduction:

As the name suggests, these motors are used on single phase supply. Single phase motors are the most familiar of all electric motor because they are extensively used in home appliance, shops, offices etc.

Types of single phase induction motors.

i) Split phase type

ii) Capacitor type

iii) Shaded pole type.

Single phase Induction motor

A single phase induction motor is very similar to a 3-phase squirrel cage induction motor

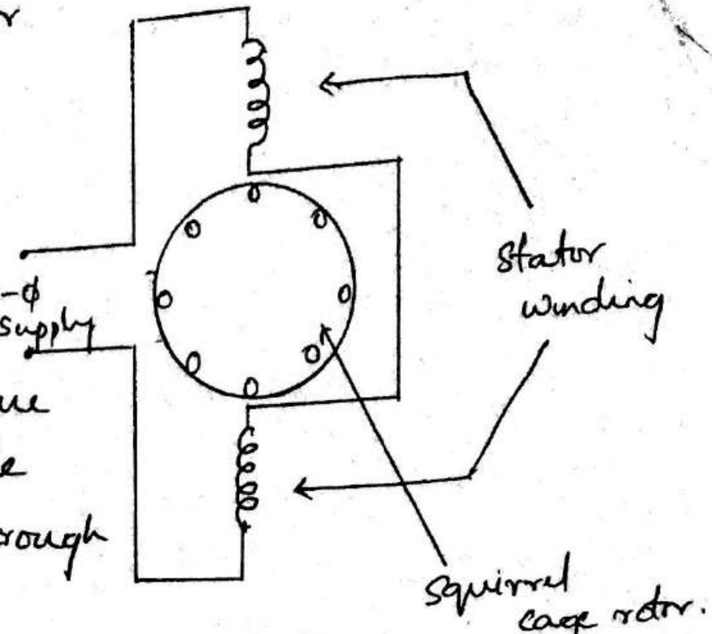
It has (i) a squirrel cage rotor identical to a 3-phase motor and (ii) a single phase winding on the stator.

~~Unli~~ Unlike a 3-phase induction motor, a single phase induction motor is not self starting but requires some starting means.

→ The single phase stator winding produces a magnetic field that pulsates in strength in a sinusoidal manner.

→ The field polarity reverses after each half ~~cycle~~ cycle but the field does not rotate. Consequently, the alternating flux cannot produce rotation in a stationary squirrel cage rotor. However, if the rotor of a single phase motor is rotated in one direction by some mechanical means, it will continue to run in the direction of rotation

As a matter of fact, the rotor quickly accelerates until it reaches a speed slightly below the synchronous speed. Once the motor is running at this speed, it will continue to rotate even though single phase current is flowing through the stator winding.



This method of starting is generally not convinient for large motors. Nor can it be employed for a motor located at some inaccessible spot.

Figure shows the single phase induction motor having a squirrel cage rotor and a single phase distributed stator winding.

Such motor does not develop any starting torque and, therefore, will not start to rotate if the stator winding is connected to a single phase a.c supply.

However if the rotor is started by auxillary means, the motor will quickly attain the final speed. This strange behaviour of a single phase Induction motor can be explained on the basis of double field revolving theory.

Double field revolving theory:-
This theory makes us of the idea that an alternating uni-axial quantity can be represented by two oppositely rotating vectors of half magnitude. According an alternating Sinusoidal flux can be -

represented by two *revolving* fluxes, each equal to half the value of the alternating flux and each rotating synchronously ($N_s = 120f/P$) in opposite direction*.

As shown in Fig. 36.1 (a), let the alternating flux have a maximum value of Φ_m. Its component fluxes A and B will each be equal to $\Phi_m/2$ revolving in anticlockwise and clockwise directions respectively.

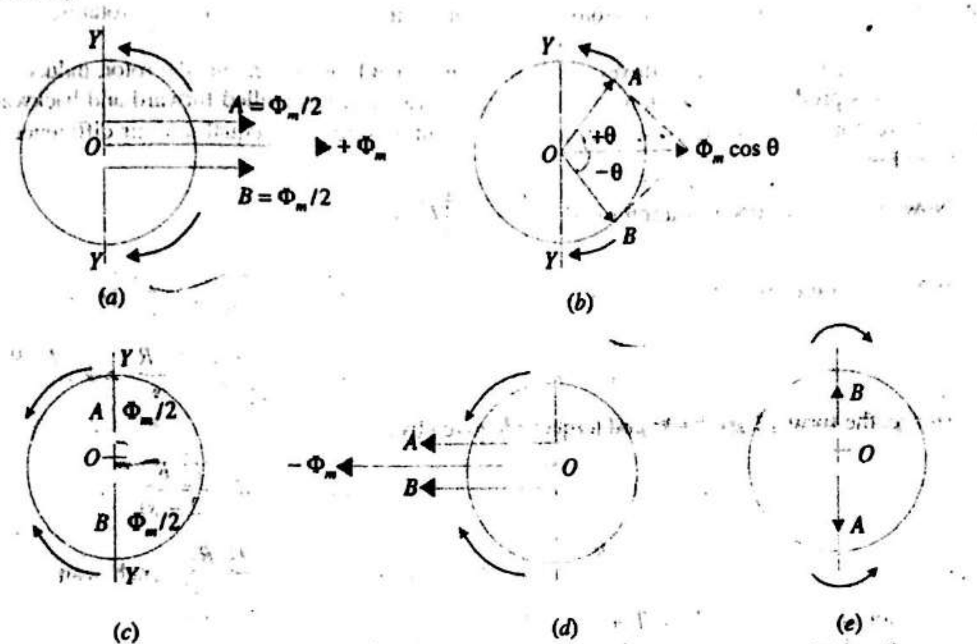


Fig. 36.1

After some time, when A and B would have rotated through angle $+\theta$ and $-\theta$, as in Fig. 36.1 (b), the resultant flux would be

$$= 2 \times \frac{\Phi_m}{2} \cos \frac{2\theta}{2} = \Phi_m \cos \theta$$

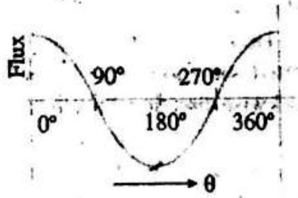


Fig. 36.2

After a quarter cycle of rotation, fluxes A and B will be oppositely-directed as shown in Fig. 36.1 (c) so that the resultant flux would be zero.

After half a cycle, fluxes A and B will have a resultant of $-2 \times \Phi_m/2 = -\Phi_m$. After three-quarters of a cycle, again the resultant is

* For example, a flux given by $\Phi = \Phi_m \cos 2\pi ft$ is equivalent to two fluxes revolving in opposite directions, each with a magnitude of $1/2\Phi$ and an angular velocity of $2\pi f$. It may be noted that Euler's expressions for $\cos\theta$ provides interesting justification for the decomposition of a pulsating flux. His expression is

$$\cos\theta = \frac{e^{j\theta} + e^{-j\theta}}{2}$$

The term $e^{j\theta}$ represents a vector rotated clockwise through an angle θ whereas $e^{-j\theta}$ represents rotation in anticlockwise direction. Now, the above given flux can be expressed as

$$\phi_m \cos 2\pi ft = \frac{\Phi_m}{2}\left(e^{j2\pi ft} + e^{-j2\pi ft}\right)$$

The right-hand expression represents two oppositely-rotating vectors of half magnitude.

zero, as shown in Fig. 36.1 (*e*) and so on. If we plot the values of resultant flux against θ between limits $\theta = 0°$ to $\theta = 360°$, then a curve similar to the one shown in Fig. 36.2 is obtained. That is why an alternating flux can be looked upon as composed of two revolving fluxes, each of half the value and revolving synchronously in opposite directions.

It may be noted that if the slip of the rotor is s with respect to the forward rotating flux (*i.e.* one which rotates in the same direction as rotor) then its slip with respect to the backward rotating flux is $(2 - s)$*.

Each of the two component fluxes, while revolving round the stator, cuts the rotor, induces an e.m.f. and this produces its own torque. Obviously, the two torques (called forward and backward torques) are oppositely-directed, so that the net or resultant torques is equal to their difference as shown in Fig. 36.3.

Now, power developed by a rotor is $P_g = \left(\frac{1-s}{s}\right) I_2^2 R_2$

If N is the rotor r.p.s., then torque is given by $$T_g = \frac{1}{2\pi N} \cdot \left(\frac{1-s}{s}\right) I_2^2 R_2$$

Now, $N = N_s (1-s)$ $\quad \therefore \quad T_g = \frac{1}{2\pi N_s} \cdot \frac{I_2^2 R_2}{s} = k \cdot \frac{I_2^2 R_2}{s}$

Hence, the forward and backward torques are given by

$$T_f = K \frac{I_2^2 R_2}{s} \quad \text{and} \quad T_b = -K \cdot \frac{I_2^2 R_2}{(2-s)}$$

or $$T_f = \frac{I_2^2 R_2}{s} \text{ synch.watt} \quad \text{and} \quad T_b = -\frac{I_2^2 R_2}{(2-s)} \text{ synch. watt}$$

Total torque $\quad T = T_f + T_b$

Fig. 36.3 shows both torques and the resultant torque for slips between zero and +2. At standstill, $s = 1$ and $(2 - s) = 1$. Hence, T_f and T_b are numerically equal but, being oppositely directed, produce no resultant torque. That explains why there is no *starting* torque in a single-phase induction motor.

However, if the rotor is started somehow, say, in the clockwise direction, the clockwise torque starts increasing and, at the same time, the anticlockwise torque starts decreasing. Hence, there is a certain amount of net torque in the clockwise direction which accelerates the motor to full speed.

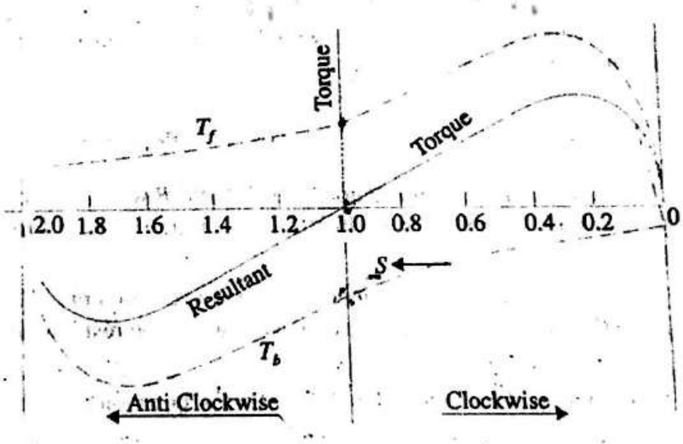


Fig. 36.3

* It may be proved thus : If N is the r.p.m. of the rotor, then its slip with respect to forward rotating flux is

$$s = \frac{N_s - N}{N_s} = 1 - \frac{N}{N_s} \text{ or } \frac{N}{N_s} = 1 - s$$

Keeping in mind the fact that the backward rotating flux rotates opposite to the rotor, the rotor slip with respect to this flux is

$$s_b = \frac{N_s - (-N)}{N_s} = 1 + \frac{N}{N_s} = 1 + (1 - s) = (2 - s)$$

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Making single phase Induction motor self starting.

The single phase induction motor is not self starting and it is undesirable to resort to mechanical spinning of the shaft or pulling a belt to start it.

To make a single phase induction motor self starting we should somehow produce a revolving stator magnetic field. This may be achieved by converting a single phase supply into two phase supply through the use of an additional winding.

When the motor attains sufficient speed, the starting means (ie additional winding) may be removed depending upon the type of the motor.

As a matter of fact, single phase induction motor are classified and named according to the method employed to make them self starting.

(i) Split phase motor: started by two phase motor action through the use of an auxillary winding and a capacitor. (or) starting winding.

(ii) Capacitor motor: started by two phase motor action through the use of an auxillary winding and a capacitor

(iii) Shaded pole motor: started by the motion of the magnetic field produced by means of a shading coil around a portion of the pole structure.

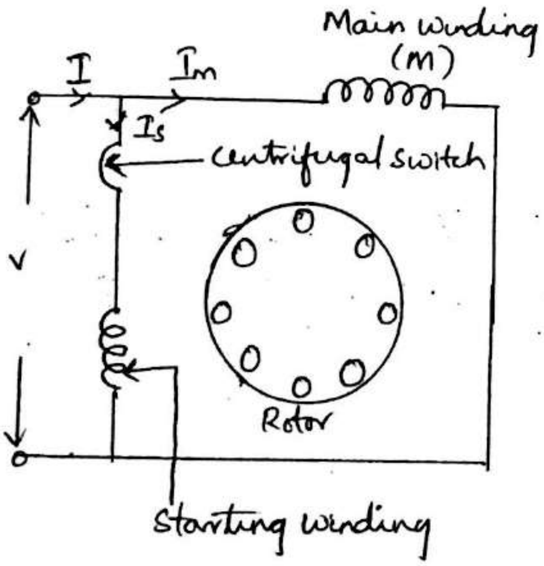
Split phase Induction motor:

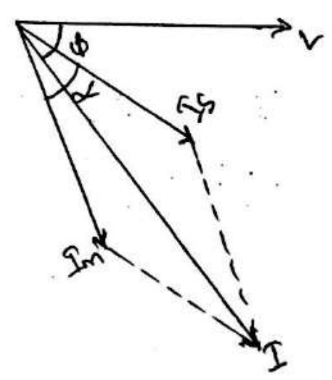
The stator of a split phase induction motor is provided with an auxillary or starting winding S in addition to the main or running winding M.

The starting winding is located 90° electrical from the main winding and operates only during the brief period when the motor starts up.

The two windings are so designed that the starting winding 'S' has a ~~regl~~ high resistance and relatively small reactance while the main winding 'M' has low resistance and large reactance

The current flows in the two windings have reasonable phase difference α (25° to 30°) as shown in phasor diagram





Operation

(i) when the two stator winding are energised from a single phase supply, the main winding carries current I_m while the starting winding carries current I_s

provide additional ... the

ii) Since main winding is made highly inductively while the starting winding highly resistive, the current I_m & I_s have a reasonable phase angle α (25° to 30°) between them as shown in phasor diagram

The starting torque is given by

$$T_s = k I_m I_s \sin\alpha$$

where k is a constant whose magnitude depends upon the design of the motor.

iii) when the motor reaches about 75% of synchronous speed, the centrifugal switch opens the circuit of the starting winding. The motor then operates as a single phase induction motor and continues to accelerate till it reaches the normal speed.

Characteristics

i) The starting torque is 1.5 to 2 times the full load torque and starting current is 6 to 8 times the full load current.

ii) Due to their low cost, split phase induction motors are most popular single phase motors in the market.

iii) An important characteristic of these motor are essentially constant speed motors. The speed variation is 2-5% from no load to full load.

iv) These motors are suitable to drive

a) fans b) washing machines c) oil burners

d) small machine tools etc.

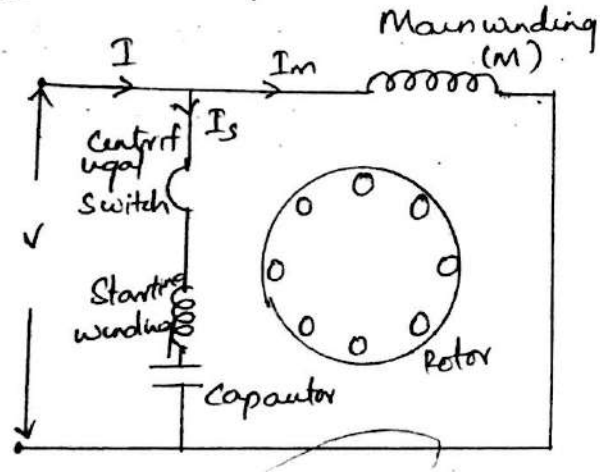
Capacitor Start Motor:

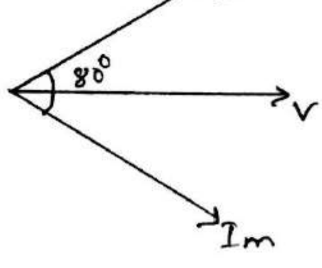
The capacitor start motor is identical to a split phase motor except that the starting winding has as many turns as main winding.

Moreover a capacitor C is connected in series with the starting winding. The value of capacitor is so choosen that I_s leads I_m by about 80° which is considerably greater than 25° found in split phase Induction motor.

consequently, starting torque ($T_s = k I_m I_s \sin\alpha$) is much more than that of a split phase Induction motor.

Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of the synchronous speed. The motor then operates as a single phase motor and continues to accelerate till it reaches the normal speed.





Characteristics:

(i) The phase angle between the two current is about compared to about 25° in a split phase motor. Consequen for the same starting torque, the current in the starting winding is only about half that in a split phase motor. Therefore the starting winding of a capacitor-start motor heats up less quickly and is well suitable to application involving either frequent or prolonged starting periods.

iii) Capacitor start motors are used where high starting torque is required and where the starting period may be long eg., to drive

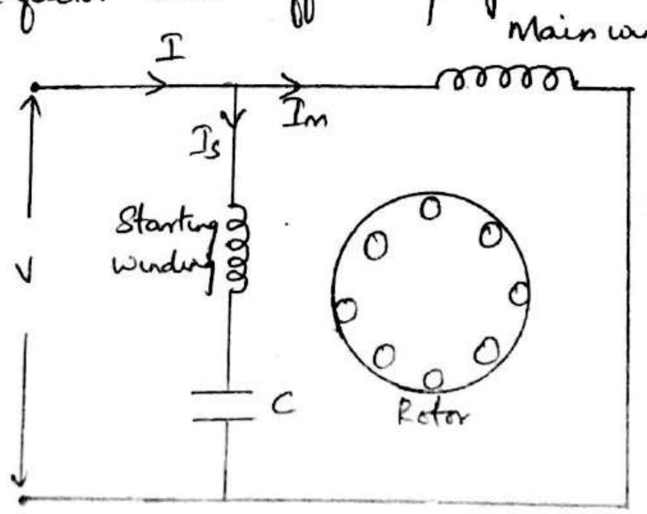
a) compressor b) large fans c) pumps d) high inertia load

Capacitor start Capacitor run motor:

The motor is identical to capacitor start motor except that starting winding is not opened after starting so that both the winding remain connected to the supply when running as well as at starting

Two designs are generally used

i) In one design, a single capacitor C is used for both starting and running. This design eliminates the need of centrifugal switch and at the same time improves the power factor and efficiency of the motor.

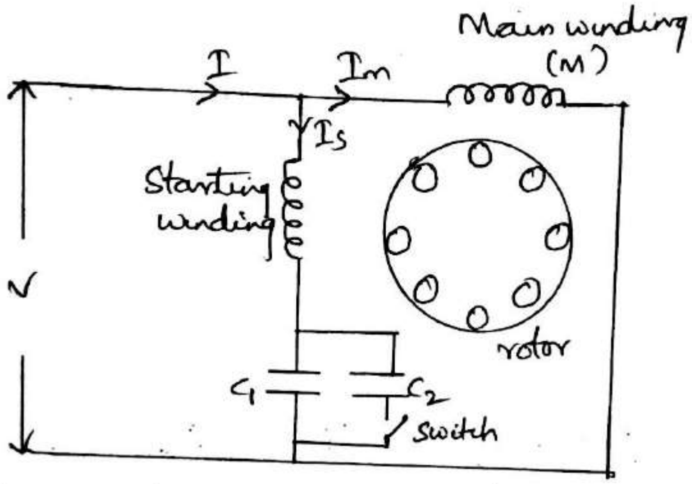


ii) In the other design, two capacitors C_1 and C_2 are Produ in the starting winding.

The smaller capacitor C_1 required for optimum running Condition is permanently connected in series with the starting winding

The much larger capacitor C_2 is connected in parallel with C_1 for optimum ~~running~~ starting and remains in the circuit during starting.

The capacitor C_2 is disconnected when the motor approach about 75% of synchronous speed. The motor then runs as a single phase Induction motor.



Characteristics:-

i) 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 motor

ii) Because of constant torque, the motor is vibration free and can be used in

a) hospitals b) Studios and c) other places where silence is important.

1.Explain the construction of 3-Φ induction motor & give the advantages?

Ans

Construction

A 3-phase induction motor has two main parts (i) stator and (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 which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses. A number of evenly spaced slots are provided on the inner periphery of the laminations [See Fig. (8.1)]. The insulated 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. When 3-phase supply is given to the stator winding, a rotating magnetic field (See Sec. 8.3) of constant magnitude is produced. This rotating field induces currents in the rotor by electromagnetic induction.

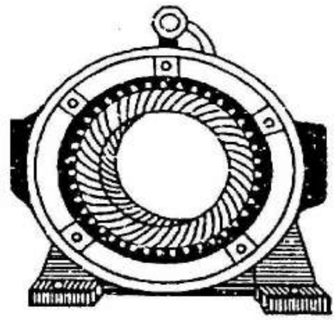


Fig.(8.1)

2. Rotor

The rotor, mounted on a shaft, is a hollow laminated core having slots on its outer periphery. The winding placed in these slots (called rotor winding) may be one of the following two types:

(i) Squirrel cage type (ii) Wound type

(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 [See Fig. (8.2)]. This forms a permanently short-circuited winding which is indestructible. The entire construction (bars and end rings) resembles a squirrel cage and hence the name. The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator.

Those induction motors which employ squirrel cage rotor are called squirrel cage induction motors. Most of 3-phase induction motors use squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances. However, it suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque.

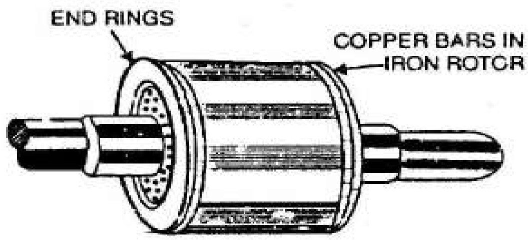


Fig.(8.2)

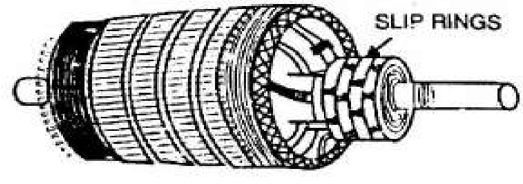
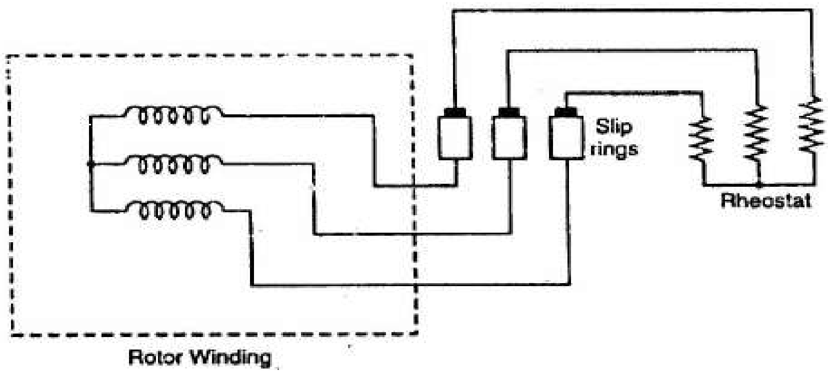


Fig.(8.3)

(ii) **Wound rotor**. It consists of a laminated cylindrical core and carries a 3-phase winding, similar to the one on the stator [See Fig. (8.3)]. 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. The three brushes are connected to a 3-phase star-connected rheostat as shown in Fig. (8.4). 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.



3 winding, the field makes one revolution in one cycle of current. In a 4-pole stator winding, it can be shown that the rotating field makes one revolution in two cycles of current. In general, fur P poles, the rotating field makes one revolution in P/2 cycles of current.

$$\therefore \quad \text{Cycles of current} = \frac{P}{2} \times \text{revolutions of field}$$

or $$\text{Cycles of current per second} = \frac{P}{2} \times \text{revolutions of field per second}$$

Since revolutions per second is equal to the revolutions per minute (N_s) divided by 60 and the number of cycles per second is the frequency f,

$$\therefore \quad f = \frac{P}{2} \times \frac{N_s}{60} = \frac{N_s P}{120}$$

or $$N_s = \frac{120\,f}{P}$$

2 Rotating Magnetic Field Due to 3-Phase Currents

When a 3-phase winding is energized from a 3-phase supply, a rotating magnetic field is produced. This field is such that its poles do no remain in a fixed position on the stator but go on shifting their positions around the stator. For this reason, it is called a rotating Held. It can be shown that magnitude of this rotating field is constant and is equal to 1.5 ϕ_m where ϕ_m is the maximum flux due to any phase.

To see how rotating field is produced, consider a 2-pole, 3i-phase winding as shown in Fig. 34.12). The three phases X, Y and Z are energized from a 3-phase source and currents in these phases are indicated as I_x, I_y and I_z [See Fig. 34.12)]. Referring to Fig. 34.12), the fluxes produced by these currents are given by:

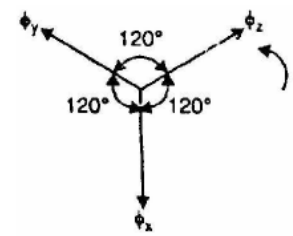


Fig.(8.5)

$$\phi_x = \phi_m \sin \omega t$$

$$\phi_y = \phi_m \sin (\omega t - 120°)$$

$$\phi_z = \phi_m \sin (\omega t - 240°)$$

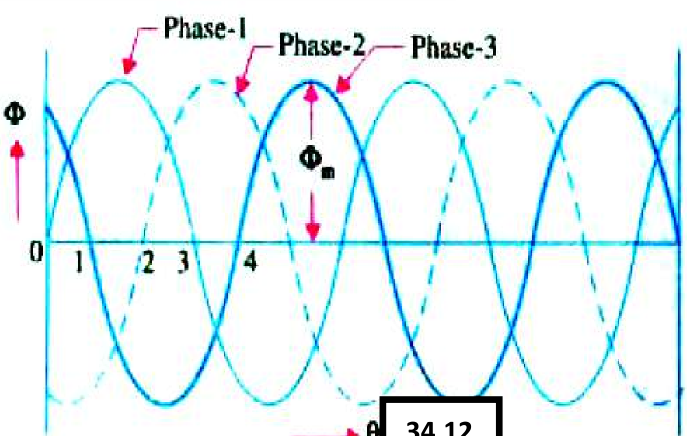
Here ϕ_m is the maximum flux due to any phase. Fig. (8.5) shows the phasor diagram of the three fluxes. We shall now prove that this 3-phase supply

nitude equal to 1.5 ϕm.

(i) When $\theta = 0°$ *i.e.* corresponding to point 0 in Fig. 34.12.

Here $\Phi_1 = 0$, $\Phi_2 = -\frac{\sqrt{3}}{2}\Phi_m$, $\Phi_3 = \frac{\sqrt{3}}{2}\Phi_m$. The vector for Φ_2 in Fig. 34.14 (*i*) is drawn in a direction opposite to the direction assumed positive in Fig. 34.13.

$$\therefore \quad \Phi_r = 2 \times \frac{\sqrt{3}}{2}\Phi_m \cos\frac{60°}{2} = \sqrt{3} \times \frac{\sqrt{3}}{2}\Phi_m = \frac{3}{2}\Phi_m$$



34.12

(ii) when $\theta = 60°$ *i.e.* corresponding to point 1 in Fig. 34.12.

Here $\Phi_1 = \frac{\sqrt{3}}{2}\Phi_m$ ...drawn parallel to *OI* of Fig. 34.13 as shown in Fig. 34.14 (*ii*)

$\Phi_2 = -\frac{\sqrt{3}}{2}\Phi_m$ ...drawn in opposition to *OII* of Fig. 34.13.

$\Phi_3 = 0$

$$\therefore \quad \Phi_r = 2 \times \frac{\sqrt{3}}{2}\Phi_m \times \cos 30° = \frac{3}{2}\Phi_m \quad \text{[Fig. 34.14 (ii)]}$$

It is found that the resultant flux is again $\frac{3}{2}\Phi_m$ but has rotated clockwise through an angle of 60°.

(*iii*) When $\theta = 120°$ *i.e.* corresponding to point 2 in Fig. 34.12.

Here, $\Phi_1 = \frac{\sqrt{3}}{2}\Phi_m$, $\quad \Phi_2 = 0, \quad \Phi_3 = -\frac{\sqrt{3}}{2}\Phi_m$

It can be again proved that $\Phi_r = \frac{3}{2}\Phi_m$.

So, the resultant is again of the same value, but has further rotated clockwise through an angle of 60° [Fig. 34.14 (*iii*)].

(*iv*) When $\theta = 180°$ *i.e.* corresponding to point 3 in Fig. 34.12.

$$\Phi_1 = 0, \Phi_2 = \frac{\sqrt{3}}{2}\Phi_m, \Phi_3 = -\frac{\sqrt{3}}{2}\Phi_m$$

The resultant is $\frac{3}{2}\Phi_m$ and has rotated clockwise through an additional angle 60° or through an angle of 180° from the start.

Hence, we conclude that

1. the resultant flux is of constant value = $\frac{3}{2}\Phi_m$ *i.e.* *1.5* ***times the maximum value of the flux due to any phase.***
2. ***the resultant flux rotates around the stator at synchronous speed given by $N_s = 120\ f/P$.***

Fig. 34.15 (*a*) shows the graph of the rotating flux in a simple way. As before, the positive directions of the flux phasors have been shown separately in Fig. 34.15 (*b*). Arrows on these flux phasors are reversed when each phase passes through zero and becomes negative.

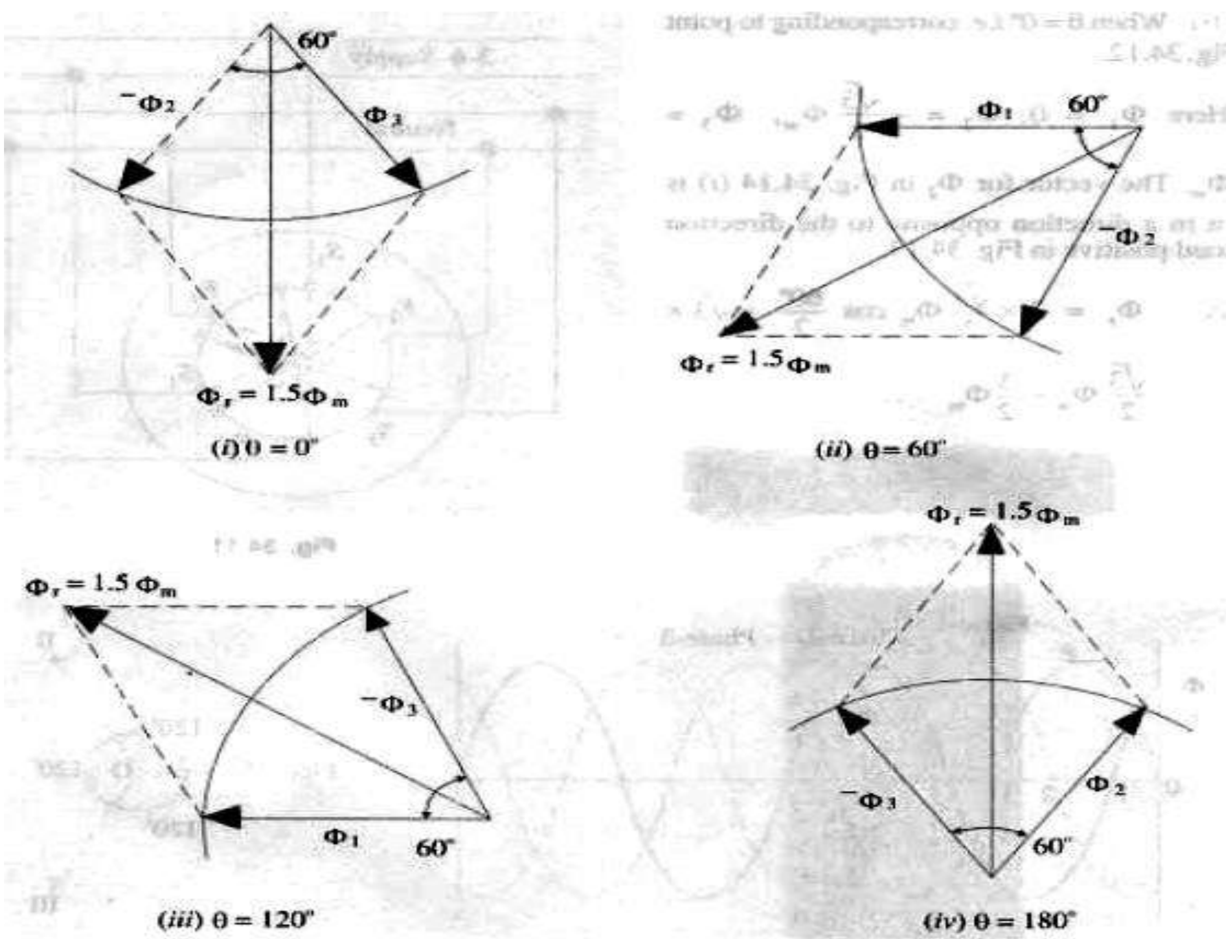


Fig. 34.14

4 Principle of Operation

Consider a portion of 3-phase induction motor as shown in Fig. (8.13). The operation of the motor can be explained as under:

(i) When 3-phase stator winding is energized from a 3-phase supply, a rotating magnetic field is set up which rotates round the stator at synchronous speed N_s (= 120 f/P).

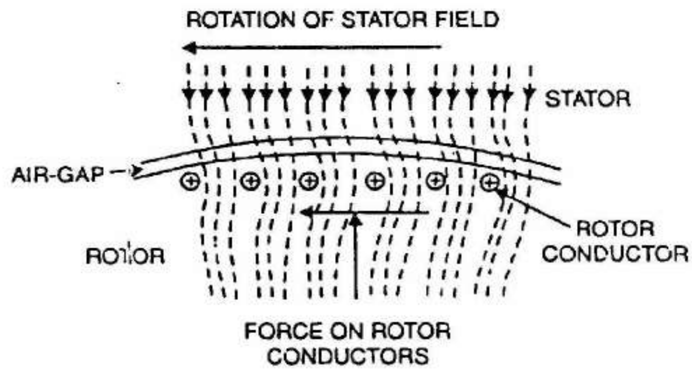


Fig.(1-)

(ii) The rotating field passes through the air gap and cuts the rotor conductors, which as yet, are stationary. 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. Consequently, mechanical force acts on the rotor conductors. The sum of the mechanical forces on all the rotor conductors produces a torque which tends to move the rotor in the same direction as the rotating field.

(iv) The fact that rotor is urged to follow the stator field (i.e., rotor moves in the direction of stator field) can be explained by Lenz's law. According to this 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. Hence to reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch it.

5. SLIP

The difference between the synchronous speed N_s of the rotating stator field and the actual rotor speed N is called slip. It is usually expressed as a percentage of synchronous speed i.e.,

$$\%\text{ age slip, } s = \frac{N_s - N}{N_s} \times 100$$

(i) The quantity $N_s - N$ is sometimes called slip speed.

(ii) When the rotor is stationary (i.e., N = 0), slip, s = 1 or 100 %.

(iii) In an induction motor, the change in slip from no-load to full-load is hardly 0.1% to 3% so that it is essentially a constant-speed motor.

12.6 Fuse

The electrical equipments are designed to carry a particular rated value of current under normal conditions. Under abnormal conditions such as short circuit, 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 a short piece of metal, inserted in the circuit, which melts when excessive current flows through it and thus breaks the circuit. Under normal operating conditions it is 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 for fuse wires must have the following characteristics:

- Low melting point e.g., tin, lead.
- High conductivity e.g., silver, copper.
- Free from deterioration due to oxidation e.g., silver.
- Low cost e.g., lead, 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

(i) Re-wireable or kit-kat fuse and
(ii) High rupturing capacity (H.R.C.) cartridge fuse

12.6.1 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 (12.7).

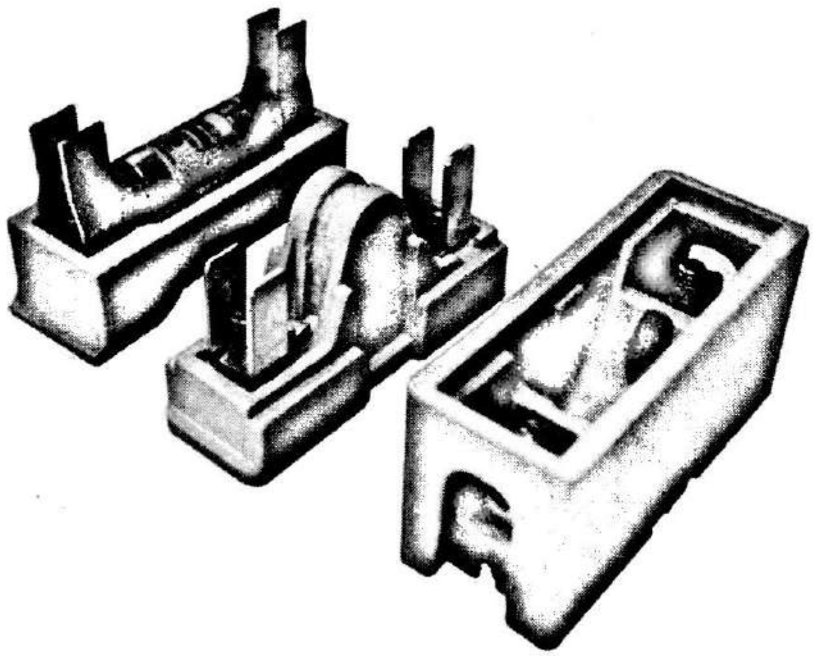


Figure (12.7): *Re-wireable or kit-kat fuse*

12.7 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. The modern power system deals with a huge power network and huge numbers of associated electrical equipments. During short circuit 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 fault is 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 which does 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 energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

The main types of circuit breakers are

- Miniature circuit breakers (MCB)
- Earth leakage circuit breakers (ELCB) or Residual Current Circuit Breaker (RCCB)
- Air blast Circuit Breaker (ACB)
- Molded Case Circuit Breaker (MCCB)
- Vacuum Circuit Breaker (VCB)
- SF_6 Circuit Breaker

12.7.1 Miniature Circuit Breaker (MCB)

Miniature circuit breakers are electromechanical devices which protect an electrical circuit from over currents. Over currents in an electrical circuit may result from short circuit, overload, or faulty design. An MCB is a better alternative than fuse, since it does not require replacement once an overload is detected. An MCB functions by interrupting the continuity of electrical flow through the circuit 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 circuit.

Operation:
An image of MCB is as shown in figure (12.10) and internal parts of an MCB are shown in figure (12.11). 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 or trip coil - then moving contact - then fixed contact and - lastly right hand side power terminal, and all are arranged in series.

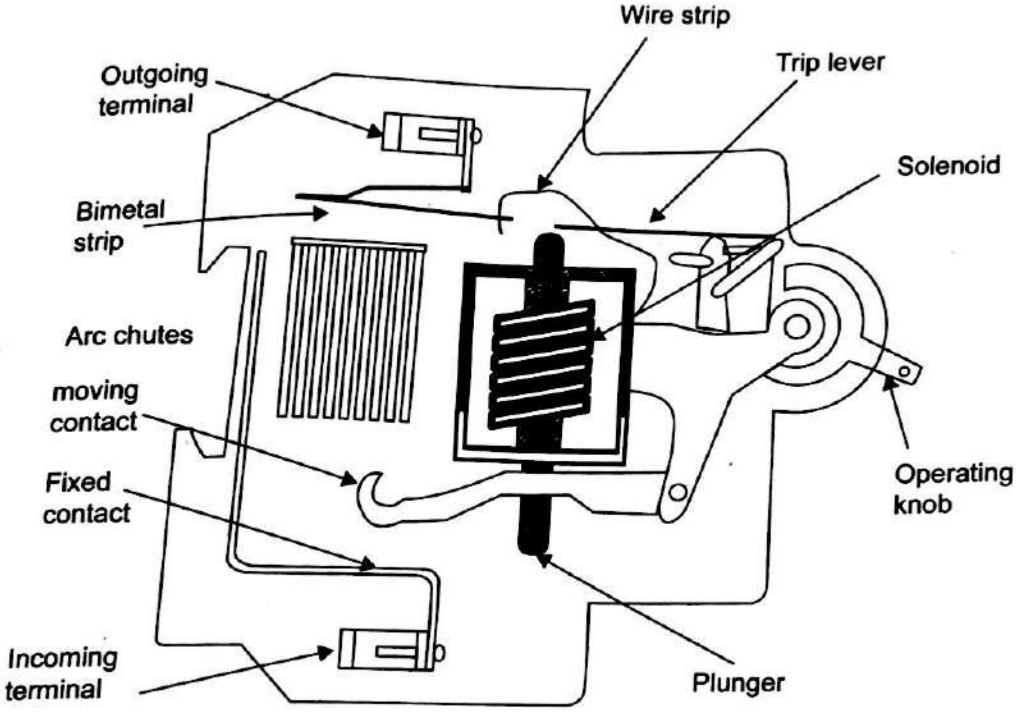


Figure (12.11): *Cross-section of MCB*

If circuit is overloaded 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 release of spring and makes the moving contact to move for opening the MCB. The current coil or trip coil is placed in such a manner that during SC fault, 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 same deformed spring is released, which is ultimately responsible for movement of the moving contact. When the moving contact is separated from fixed contact, there may be a high chance of arc. This arc then goes up through 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 symmetrical short circuit 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-wirable 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 a combination of all three functions in a wiring system like switching, overload and short circuit protection. Overload protection can be obtained by using bi-metallic strips where as short circuit protection can be obtained by using solenoid.

12.7.2 Earth Leakage Circuit Breaker (ELCB)

None of the protection devices like MCB, MCCB, etc. can protect the human life against electric shocks or avoid fire due to leakage current. The human resistance noticeably drops with an increase in voltage. It also depends upon the duration of impressed voltage and drops with increase in time. As per IS code, a contact potential of 65V is within tolerable limit of human body for 10 seconds, where as 250V can be withstood by human body for 100 milliseconds. The actual effect of current through human body varies from person to person with reference to magnitude and duration. The body resistance at 10V is assessed to be 19 kΩ for 1 second and 8kΩ for 15 min. At 240V, it is 3 to 3.6 kΩ for dry skin and 1–1.2 kΩ for wet skin.

An Earth Leakage Circuit Breaker (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 Circuit Breaker (voltage-ELCB)

(ii) Current Earth Leakage Circuit Breaker (Current-ELCB)

(i) Voltage Earth Leakage Circuit Breaker (Voltage-ELCB)

Voltage-ELCB is a voltage operated circuit breaker. 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 (12.12). 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. This voltage difference will produce an electric current from the load metallic body and passes through the relay loop to the Earth. When voltage on the equipment metallic body rises to the danger level i.e., which exceed to 50V, the flowing current through relay loop could move the relay contact by disconnecting the supply current to 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 currents from line to any other earthed body.

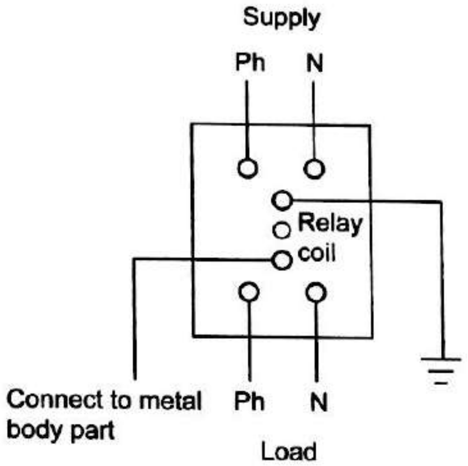


Figure (12.12): *Voltage earth leakage circuit breaker*

(ii) Current Earth Leakage Circuit 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 (12.13). Neutral and line wires act as the two primary windings. A wire wound coil is the secondary winding. The current through the secondary winding is zero at the balanced condition. In the balanced condition, the flux due to the 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 unbalance 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 circuit. This will sense the leakage and send a signal to the tripping system and trips the contact.

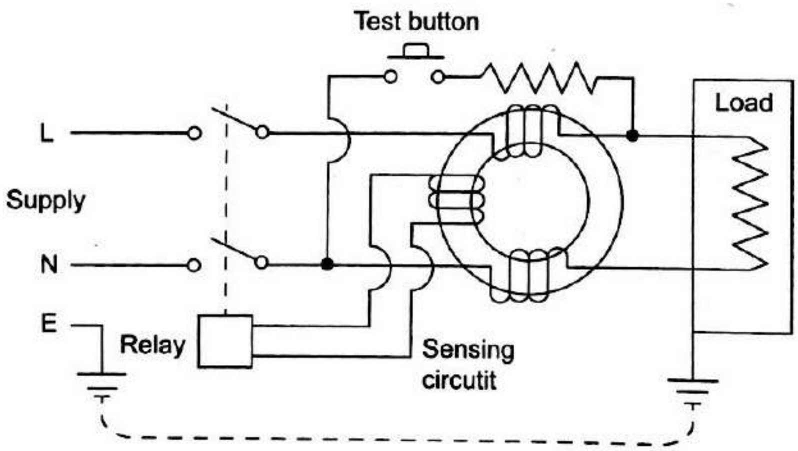


Figure (12.13): *Current earth leakage circuit breaker*

12.7.3. Molded Case Circuit Breaker (MCCB)

Molded case circuit breakers are electromechanical devices which protect a circuit from over current and short circuit. They provide over current and short circuit 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 circuit conditions respectively. The over current, in an electrical circuit, may result from short circuit, overload or 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 offers improved operational safety and convenience without incurring operating cost.

Molded case circuit breakers generally have a

- Thermal element for over current and
- Magnetic element for short circuit 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 (12.14).

MCCBs 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 two halves are riveted together to form the whole. Inside the plastic shell is a 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 circuit.

Operating Mechanism:

At its core, the protection mechanism employed by MCCBs is based on the same physical principles used by all types of thermal-magnetic circuit breakers.

Overload protection is accomplished by means of a thermal mechanism. MCCBs have a bimetallic contact that expands and contracts in response to changes in 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 expand until the circuit 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. However, any over current conditions that last more than what is normally expected represent an overload, and the MCCB is tripped to protect the equipment and personnel.

On the other hand, 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 is interrupted. As a complement to the magnetic protection mechanism, MCCBs have internal arc dissipation measures 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 circuit 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 applications that require adjustable trip settings and motor protection

12.9 Batteries

A battery is a device which converts chemical energy into electrical energy and is made up of a number of cells. Batteries consist of two or more voltaic cells that are connected in series to provide a steady DC voltage at the battery's output terminals. The voltage is produced by a chemical reaction inside the cell. Electrodes are immersed in an electrolyte, which forces the electric charge to separate in the form of ions and free electrons. A battery's voltage output and current rating are determined by the elements used for the electrodes, the size of the electrodes, and the type of electrolyte used. Whether a battery may be recharged or not depends on the cells used to make up the battery.

Batteries are classified into two types such as primary batteries and secondary batteries.

(i) Primary Batteries

As the name indicates, these batteries are meant for single usage. Once these batteries are used they cannot be recharged as the devices are not easily reversible and active materials may not return to their original forms. Other name for these batteries is disposable batteries.

Some of the examples for the disposable batteries are the normal AA, AAA batteries which we use in wall clocks, television remote, etc.

(ii) Secondary Batteries

Secondary batteries are also known as rechargeable batteries. These batteries can be used and charged simultaneously. A secondary battery or storage battery can be recharged because its chemical reaction is reversible. Rechargeable batteries are (re)charged by applying electric current, which reverses the chemical reactions that occur during discharge/use. Some of the examples for rechargeable batteries are the batteries used in mobile phones, MP3 players, etc.

12.9.1 Types of Primary Cells/Batteries

There are several types of primary cells in use today, such as

(i) Carbon-zinc dry cell
(ii) Alkaline cell
(iii) Zinc chloride cell
(iv) Mercury cell
(v) Silver oxide cell
(vi) Lithium cell

(i) Carbon-zinc dry cell

- This is one of the most popular primary cells (often used for type AAA, AA, C, D).
- The negative electrode is made of zinc.
- The positive electrode is made of carbon.
- The output voltage of a single cell is about 1.5 V.
- Performance of the cell is better with intermittent operation.

(ii) Alkaline cell

- The alkaline cell is another popular type also used for type AA, C, D, etc.
- It has the same 1.5V output as carbon-zinc cells, but they are longer-lasting.
- It consists of a zinc anode and manganese dioxide cathode in an alkaline electrolyte (potassium hydroxide).
- It works with high efficiency even with continuous use, due to low internal resistance.

(iii) Zinc chloride cell

- This cell is also referred to as a "heavy-duty" type battery.
- It is a modified zinc-carbon cell.
- It has little chance of liquid leakage because the cell consumes water along with the chemically active materials. The cell is usually dry at the end of its useful life.

(iv) Mercury cell

- This cell consists of a zinc anode, mercury compound cathode, and potassium or sodium hydroxide electrolyte.
- It is becoming obsolete due to the hazards associated with proper disposal of mercury.

(v) Silver oxide cell

- This cell consists of a zinc anode, silver oxide cathode, and potassium or sodium hydroxide electrolyte.

- It is typically available as 1.5V, miniature button form.
- Applications include hearing aids, cameras, and watches

(vi) **Lithium cell**

- This cell offers high output voltage, long shelf life, low weight, and small volume.
- It comes in two forms of 3V output in widespread use:
  (a) Lithium-sulfur dioxide ($LiSO_2$).
  (b) Lithium-thionyl chloride.
- $LiSO_2$ type batteries contain methyl cyanide liquid solvent; if its container is punctured or cracked, it can release toxic vapors.
- Safe disposal of these cells is critical.

12.9.2 Types of Secondary Cells/Batteries

There are several types of secondary cells in use today, such as

(i) Lead-acid cell
(ii) Nickel cadmium (NiCd) cell
(iii) Lithium-ion battery
(iv) Nickel-metal-hydride (NiMH) cell
(v) Nickel-iron (Edison) cell
(vi) Fuel cell
(vii) Solar cell

(i) **Lead-acid cell**

- This cell is a widely applied type of secondary cell, used extensively in automobiles, inverters, backup power systems, etc. requiring high values of load current.
- Anode: Porous lead
- Cathode: Lead-dioxide
- Electrolyte: Sulfuric acid, 6 molar H_2SO_4
- The output is about 2.1 V per cell.
- Cells are typically used in series combinations of 3 (6V battery) or 6 (12V battery).

(ii) **Nickel Cadmium (NiCd) cell**

- This type of cell delivers high current.
- It can be recharged many times.
- Anode: Nickel hydroxide, $Ni(OH)_2$
- Cathode: Cadmium hydroxide, $Cd(OH)_2$
- Electrolyte: Potassium hydroxide, KOH
- Maintain a steady voltage of 1.2V per cell until completely depleted
- It can be stored for long periods of time.
- Its specific gravity does not change with the state of charge.
- Applications include portable power tools, alarm systems, portable radio and TV equipment.

(iii) **Lithium-Ion Battery**

- Li-based cells are most compact ways of storing electrical energy.
- Lower in energy density than lithium metal, lithium-ion is safe.

12.10 Power Factor Improvement

The cosine of angle between voltage and current in an AC circuit is known as power factor. It refers to the fraction of total power (apparent power) which is utilized to do the useful work called active power. In an AC circuit, there is generally a phase difference ϕ between voltage and current. The term cosϕ is called the power factor of the circuit. If the circuit is inductive, the current lags behind the voltage and the power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and power factor is said to be leading.

$$\cos\phi = \frac{Active\ power}{Apparent\ power}$$

12.10.1 Disadvantages of Low Power Factor

The power factor plays an importance role in AC circuits since power consumed depends upon this factor.

$$P = VI\cos\phi$$

$$\Rightarrow \cos\phi = \frac{P}{VI}$$

It is clear from above that for fixed power and voltage, the load current is inversely proportional to the power factor. Lower the power factor, higher is the load current and vice versa. A power factor less than unity results in the following disadvantages:

(i) Overloading of cables and transformers
(ii) Greater conductor size
(iii) Large copper losses
(iv) Poor voltage regulation i.e., decreased line voltage at point of application
(v) Reduces the handling capacity of all the elements of the system.

12.10.2 Causes of Low Power Factor

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system in lower than 0.8. The following are the causes of low power factor:

(i) Most of the AC motors are of induction type (1-phase and 3-phase induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0.2–0.3) and rises to 0.8 or 0.9 at full load.
(ii) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.
(iii) The load on the power system is varying; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetisation current. This results in the decreased power factor.

12.10.3 Methods of Improving Power Factor

Normally, the power factor of the whole load on a large generating station is in the region of 0.8–0.9. However, sometimes it is lower and in such cases it is generally desirable to take special steps to improve the power factor. This can be achieved by the following methods:

(i) Static capacitors

Improving power factor means reducing the phase difference between voltage and current. Since the majority of loads are of inductive nature, they require some amount of reactive power for them to function. The capacitor or bank of capacitors installed parallel to the load provides this reactive power. They act as a source of local reactive power, and thus less reactive power flows through the line. They reduce the phase difference between the voltage and current.

(ii) Synchronous Condenser

A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved.

(iii) Phase Advancer

This is an AC exciter mainly used to improve power factor of induction motor. They are mounted on the shaft of the motor and connected to the rotor circuit of the motor. It improves the power factor by providing the exciting ampere turns to produce required flux at slip frequency. Further, if ampere-turns increases, it can be made to operate at leading power factor.

12.11 Energy Consumption Calculation

Energy and power are closely related. Electrical energy can be measured only when electrical power is known. So first, we understand the electrical power. Electrical power is the amount of electrical current that results from a certain amount of voltage or we can say that power is the rate at which energy is delivered. It is measured in watts. Mathematically it is written as

$$Power = Voltage \times Current$$

The measurement of electrical energy is completely dependent on power which is measured in watt, kilowatts, megawatts, gigawatts, and time which is measured in an hour. Joule is the smallest unit of energy. But for some bigger calculation, some better unit is required. So, the unit used for electrical energy is watt-hour.

Electrical energy is the product of electrical power and time, and it is measured in joules. It is defined as "1 joule of energy is equal to 1 watt of power is consumed for 1 second". i.e.,

$$Energy = Power \times Time$$

$$1\ Joule = 1\ watt \times 1\ \text{second}$$

Watts are the basic unit of power in which electrical power is measured or we can say that rate at which electric current is being used at a particular moment.

Watt-hour is the standard unit used for measurement of energy, describing the amount of watts used over a time. It shows how fast the power is consumed in the period of time.

$$\textit{Energy in watt hours} = \textit{Power in watts} \times \textit{Time in hours}$$

Kilowatt-hour is simply a bigger unit of energy when large appliances drawn power in kilowatts. It can be described as one kilowatt hour is the amount of energy drawn by the 1000 watts appliance when used for an hour.

Where, One kilowatt = 1000 watts

$$\textit{Energy in kilowatt hours} = \textit{Power in kilowatts} \times \textit{Time in hours}$$

The electrical supply companies take electric energy charges from their consumer per kilowatt hour unit basis. This kilowatt hour is board of trade (BOT) unit.

Illustration for Energy Consumption: A consumer uses a 10 kW geezer, a 6 kW electric furnace and five 100 W bulbs for 15 hours. How many units (kWh) of electrical energy have been used?

Explanation: Given that

Load-1 = 10 kW geezer

Load-2 = 6 kW electric furnace

Load-3 = 500 watt (five 100 watt bulbs)

Total load $= 10kW + 6kW + 0.5kW = 16.5kW$

Time taken = 15 hours

$$\therefore \textit{Energy consumed} = \textit{Power in kW} \times \textit{Time in hours}$$
$$= 16.5 \times 15 = 247.5\ kWh$$

For above electrical energy consumption, the tariff can be calculated as follows:

1 unit = 1kWh

So, the total energy consumption = 247.5 units

If the cost per unit is ₹ 2.5, then the total cost of energy consumption

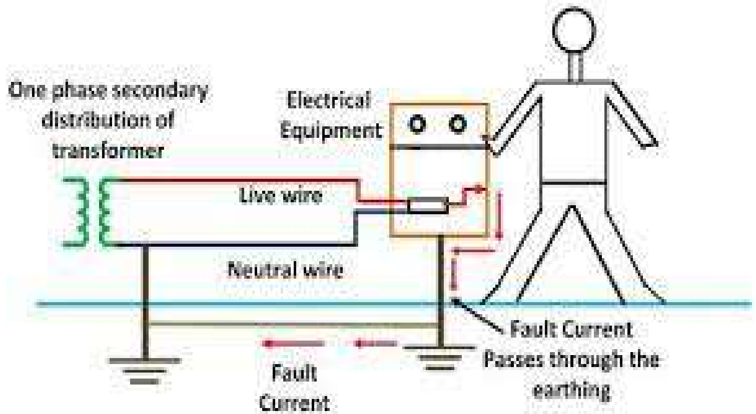
= 247.5 × 2.5 = ₹ 618.75/-

Review Questions

1. What do you meant by earthing? Explain various methods of earthing.
2. Mention the different types of wiring. Explain conduit wiring.
3. What is a fuse? Discuss the advantages and disadvantages of a fuse.
4. What is circuit breaker? Describe its operating principle.
5. Explain the construction and operation of a miniature circuit breaker (MCB).

UNIT-V

Electrical Installations



Electrical System With Earthing

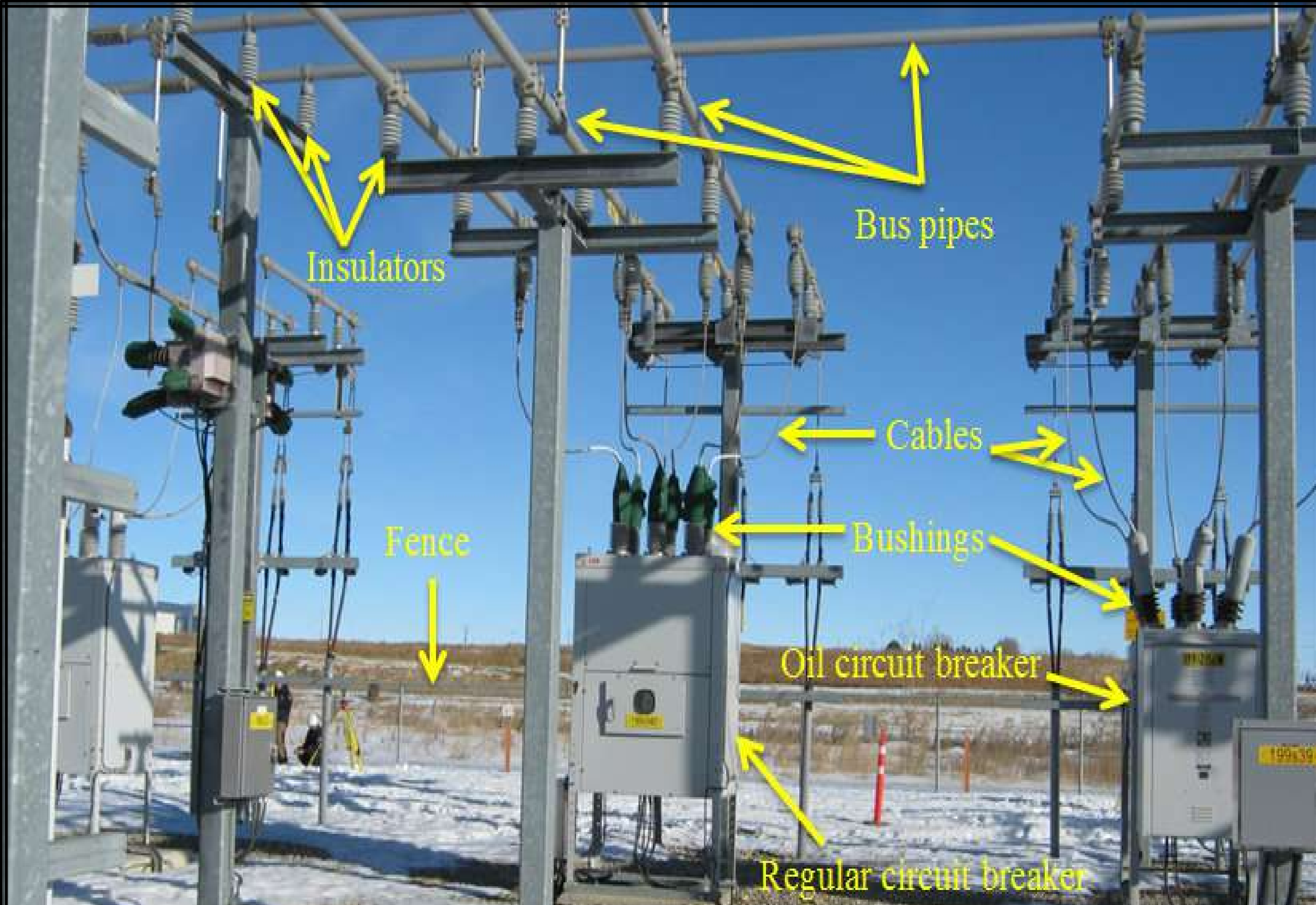
CONTENTS

ELECTRICAL INSTALLATIONS

SWITCH GEAR

- In an electric power system, switchgear is the combination of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment.
- Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. This type of equipment is directly linked to the reliability of the electricity supply

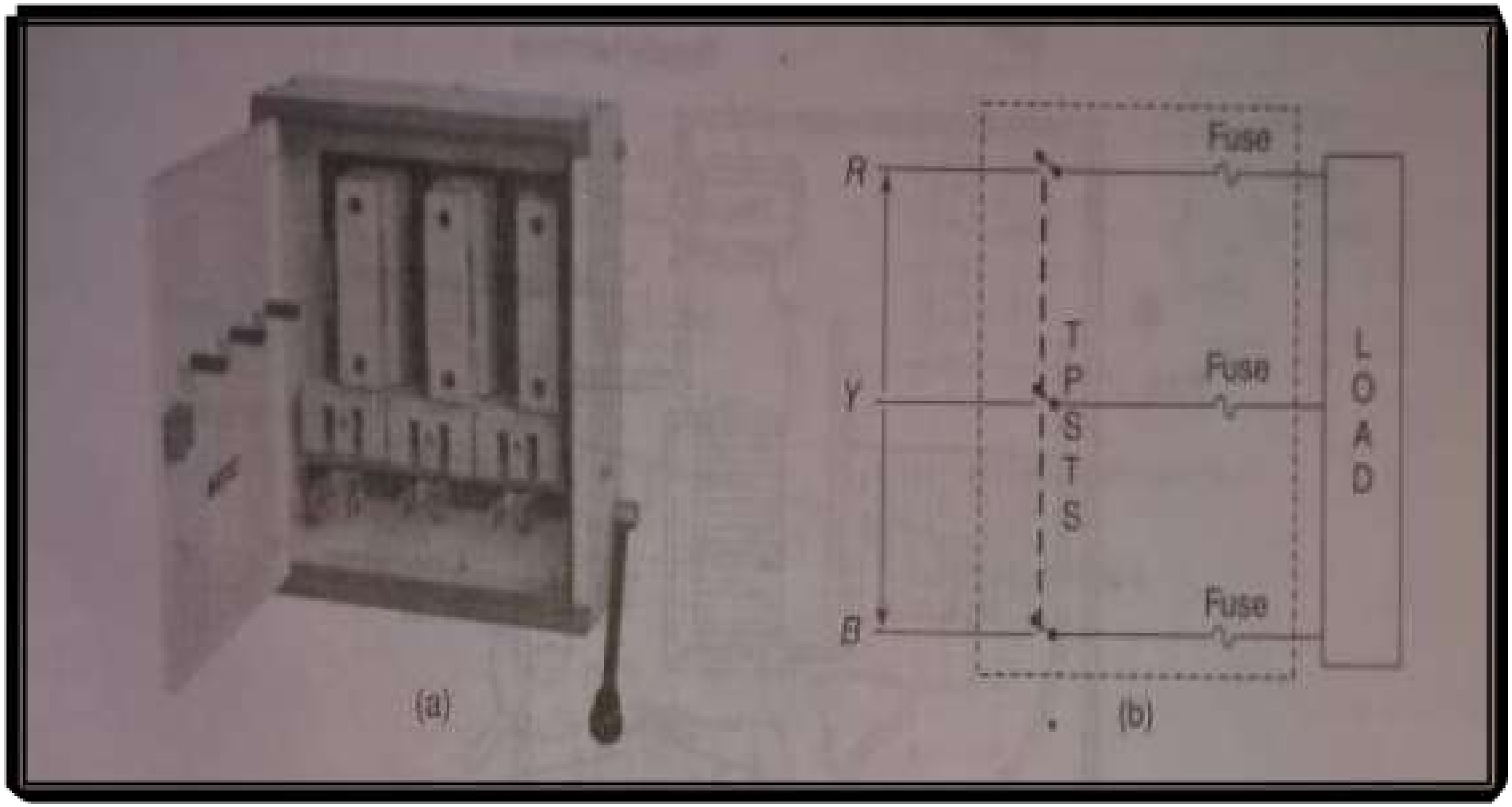
SWITCH GEAR UNIT



COMPONENTS OF LT SWITCH GEAR

1. SFU (SWITCH FUSE UNIT):

- Switch fuse unit (SFU) is a low voltage A.C Fuse unit which is used to protect the electrical device or equipment from different fault conditions.
- This fuse unit is housed in an enclosure made using quality CR steel sheet.
- This fuse unit is most commonly used for low and medium voltage applications.
- SFU consists of porcelain rewireable fuse fitted with their conducting parts.

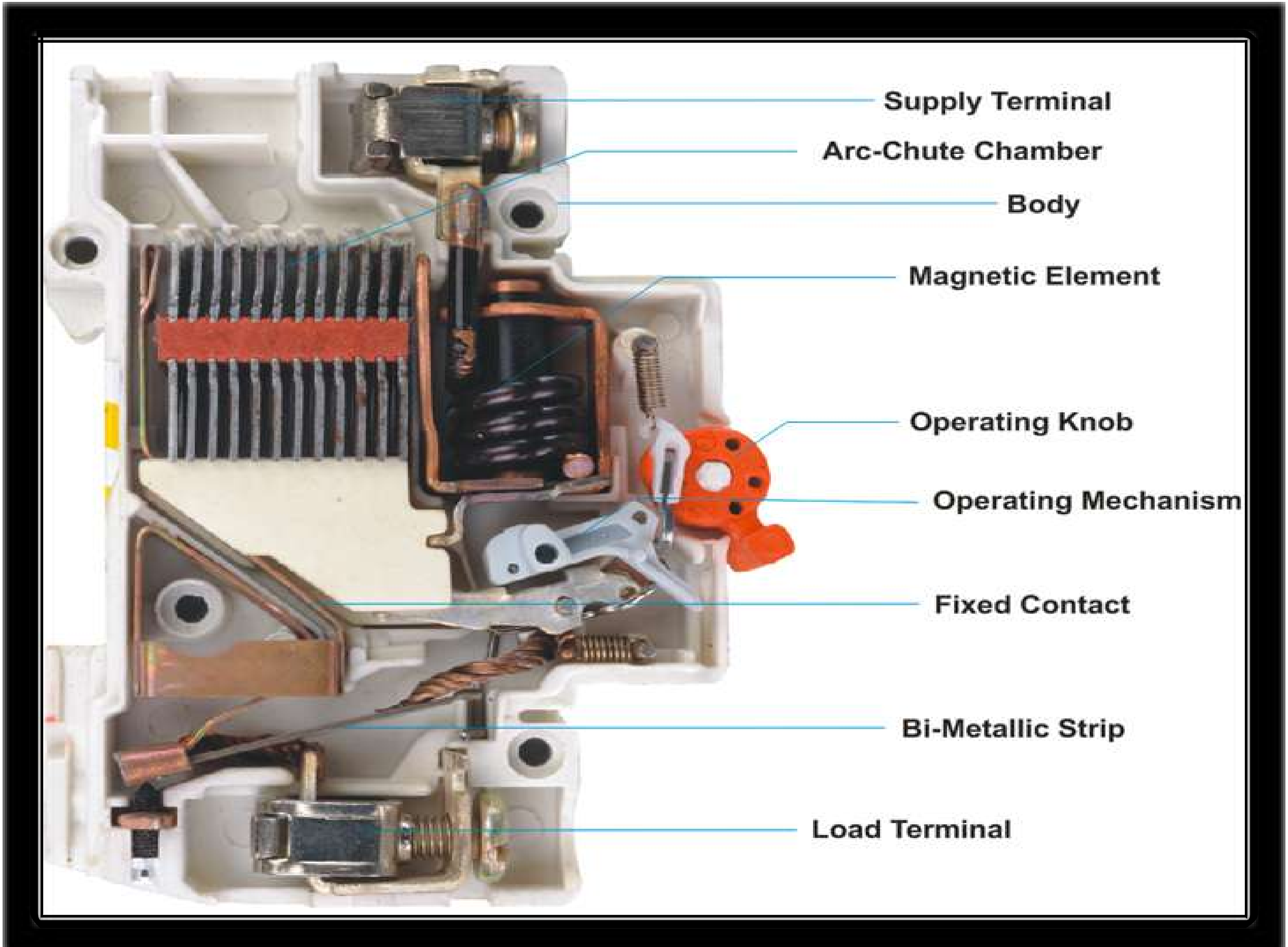


Schematic diagram of SFU

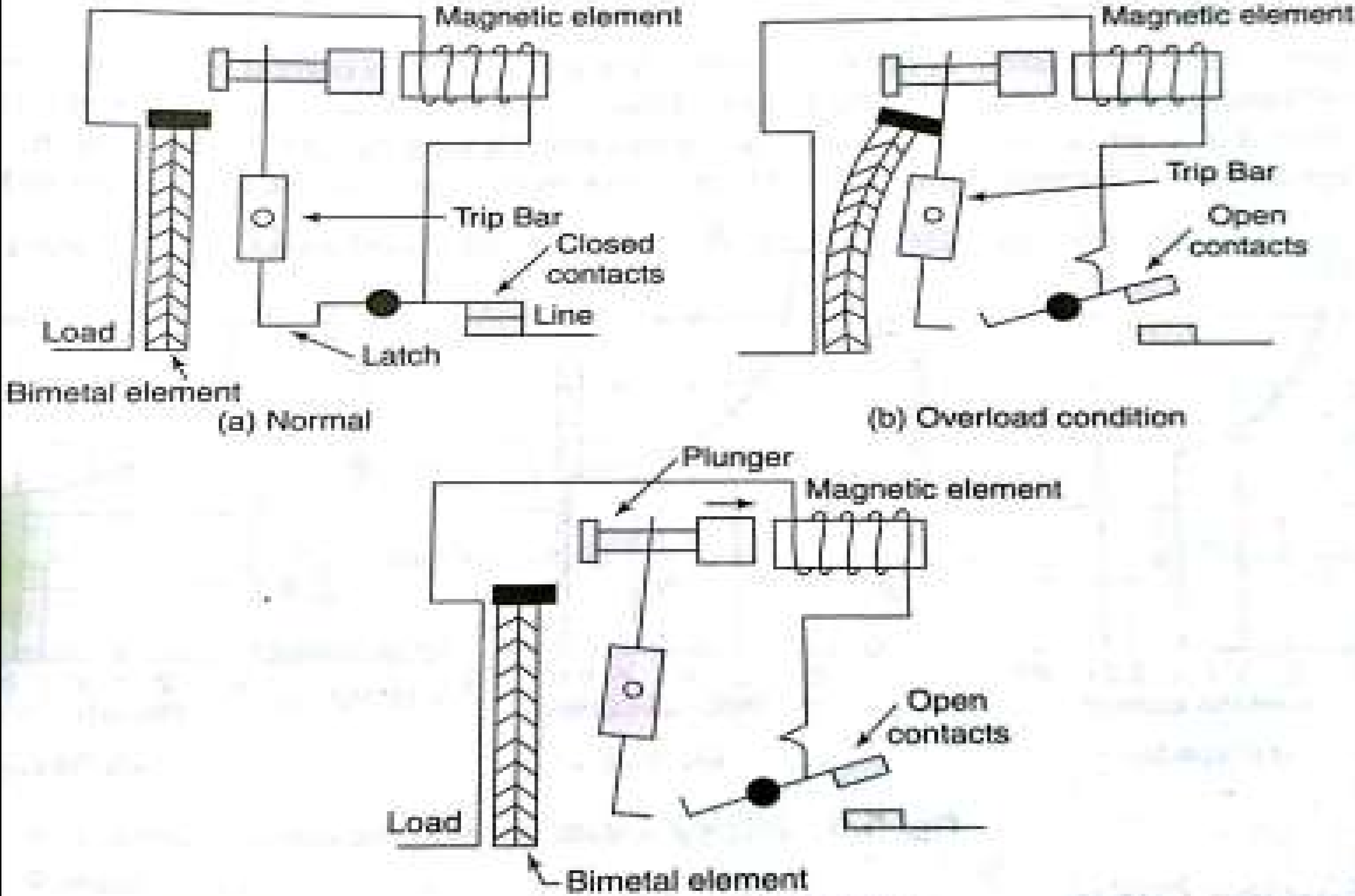
2. MCB(Miniature Circuit Breaker)

- An electromagnetic device that is used in the protection of electrical circuit from an over current is called MCB.
- Over current in an electrical circuit occur due to the short circuit, overload or any faulty condition.
- When compared to fuse , MCB is considered as a better alternative in protecting the circuit since no replacement is required when an over current occurrence is detected in the circuit.
- An MCB functions by interrupting the continuity of electrical flow through the circuit once a fault is detected.
- It is used for up to 100 Amps

PARTS OF MCB



Supply Terminal
Arc-Chute Chamber
Body
Magnetic Element
Operating Knob
Operating Mechanism
Fixed Contact
Bi-Metallic Strip
Load Terminal



(a) Normal

(b) Overload condition

(c) Short circuit condition

1-pole, 2-pole, 3&4-pole MCB'S

MCCB (Moulded Case Circuit Breaker)

- A moulded-case circuit breaker (**MCCB**) is a circuit breaker that uses a molded case to house and supports its current-carrying components as well as to be a part of the insulation system.
- The MCCB is an electromechanical device that protects the circuit from over-current and short circuit conditions ranging from few amperes to 2000 amperes.
- The main difference MCB & MCCB is their capacity.
- With the MCB rated under 100 amps with an interrupting rating of under 18,000 amps. Consequently, their trip characteristics may not be adjusted since they basically cater to low circuits.

MCCB

The selection of MCCB for a particular application is based on its specifications:

The specifications of MCCB are:

1. Current rating in amperes
2. Current setting range in amperes
3. Short circuit rating in kilo amperes
4. Operating characteristics
   (a). Normal
   (b). Current limiting type.


Schneider
Electric


ABB
SACE Tmax
on
off


MCCB
MCB
VS
HAVELLS
Difference between MCCB and MCB

MCB vs MCCB

MCB	MCCB
helps in protecting the circuit from overloaded current.	helps in protecting the equipment from over-current and short circuit condition
possess a fixed tripping circuit	Possess a movable tripping circuit
one to three pole configuration is possible	one to four pole configuration is possible
the current till which the circuit can be interrupted is 1800 A	the current till which the circuit can be interrupted is between 10k -200k A
remote operation is not possible	remote operation is possible
the rated current of the device is 100A	the rated current of the device is 10 to 200A
can be installed in domestic purpose where lightning circuit and low loads exist	can be installed in commercial and industrial purpose where high value of current flows through the circuit

ELCB (Earth Leakage Circuit Breaker)

- 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 a dangerous voltage is detected..
- Types of ELCB. There are **two different types** of Earth Leakage Circuit Breakers, They are: Voltage Operate Earth Leakage Circuit Breaker. Current Operate Earth Leakage Circuit Breaker.
- Voltage Earth Leakage Circuit Breaker.
  The **working** principle of voltage **ELCB** is quite simple. One terminal of the relay coil is connected to the metal body of the equipment to be protected against earth leakage and other terminal is connected to the earth directly.

Types of ELCB'S

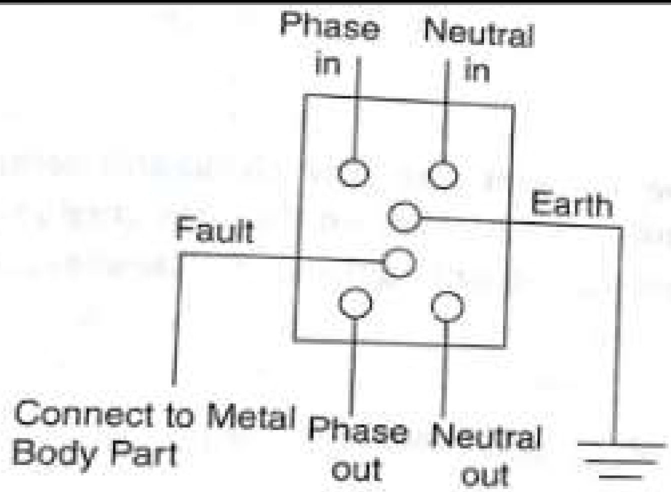


Fig. 5.8 Voltage Operated ELCB

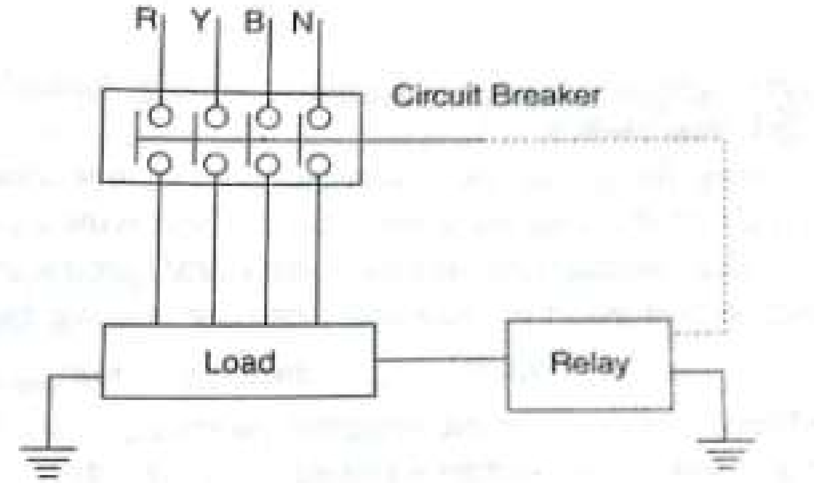
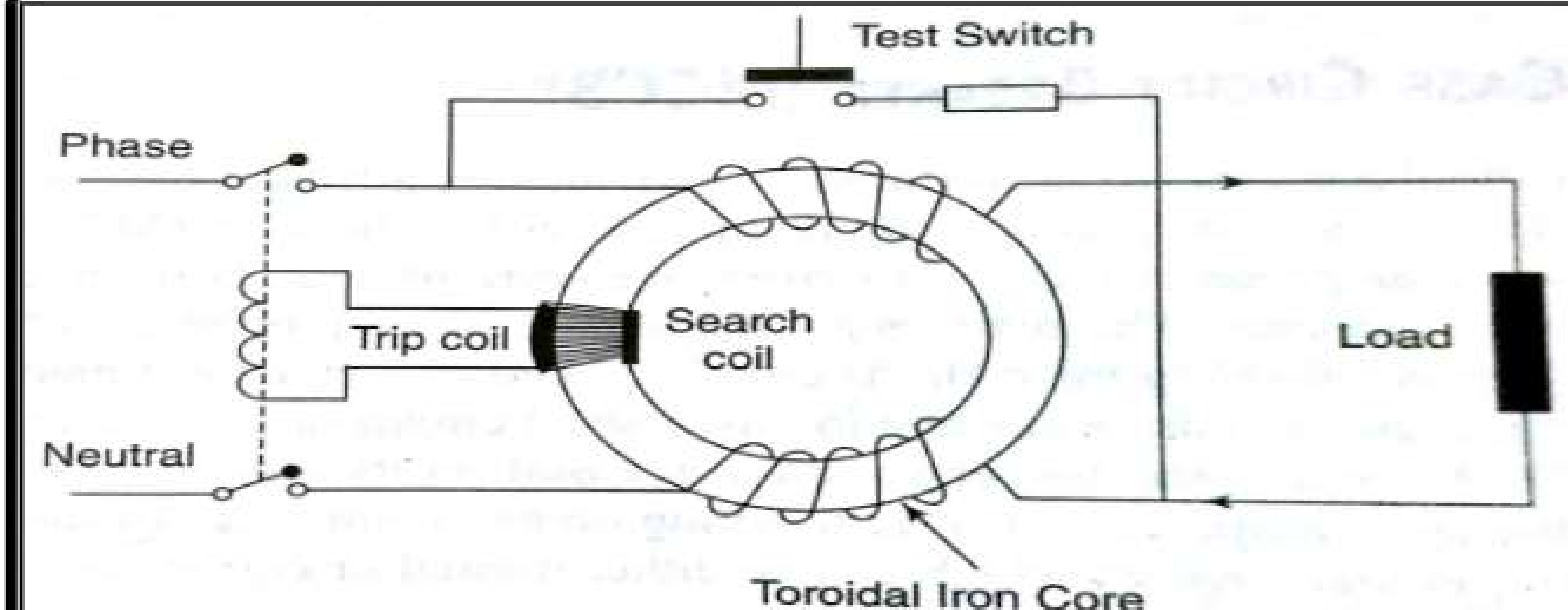


Fig. 5.9 Circuit Diagram of three phase Voltage ELCB



Current operated ELCB

ELCB vs MCB

TYPES OF WIRES AND CABLES

According to National Electrical Code (NEC),

- wire: is defined as a single electrical conductor

- cable: is defined as a group of wires enclosed in a sheathing.

- WIRES: A single conductor or a group of thin conductor strands covered by an insulations material to prevent it from making unwanted contacts is called wire.

- In general wires are used to carry electrical and telecommunication signals.

Types of wires

1. Solid, 2. Stranded

1. Solid wire: A single conductor that is either bare or covered by a protective coloured insulation is called solid wire.

- It is most commonly used in high frequency application since it offers a low resistance.

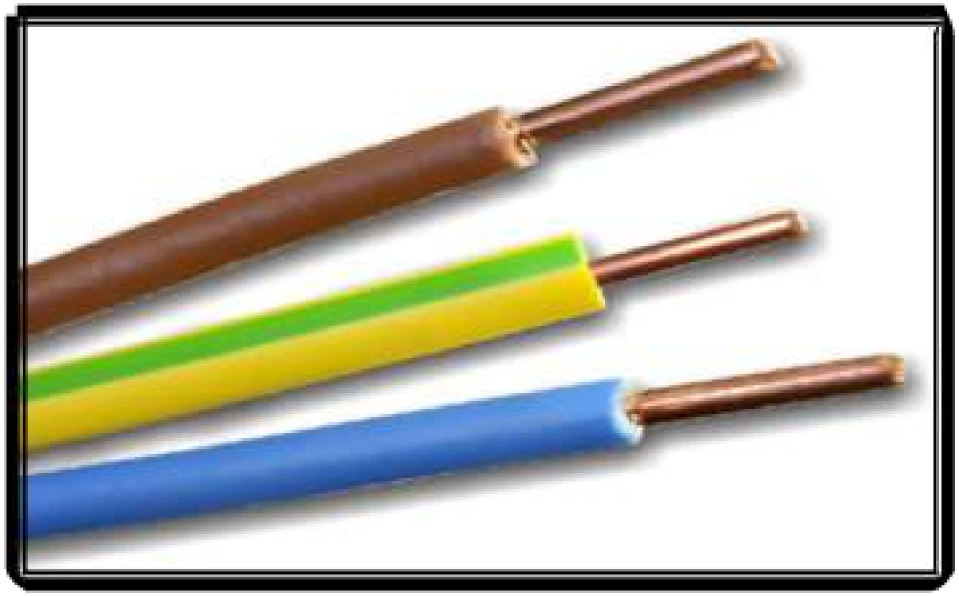
2. Stranded wire: when many thin strands of a wire of equal size are twisted and covered by a insulation sheath is called stranded wire.

- Flexibility of stranded wire is high.
- Where the wire is used for longer period.
- Stranded wire has large cross sectional area when compared to solid wire.

Types of wires

Bare wire/ conductor

Starnded conducto



Solid wire/ conductor

CABLES

- When two or more wires combined or bonded together, twisted and sheathed together it forms the cables.
- Types of cables:

I. Based on the type of conductor:

1. Copper or 2. Aluminum.

II. Based on number of cores:

1. Single core 2. two core 3. three core 4. three and a half core and 4. four core cables.

III. Based on voltage grading:

1. low voltage cables 250/440 V
2. High voltage cables 650/1100 V.

TYPES OF CABLES

IV. Type of insulation material:

1. Vulcanized Indian Rubber(VIR) insulated cables.
2. Tough rubber sheathed(TRS) cables.
3. Cab tyre Sheathed(CTS) Cables.
4. Polyvinyl chloride (PVC) cables.
5. Lead sheath cables.
6. Weather proof cables.
7. Cross linked polyethylene (XLPE) cables.
8. Flexible Cords and cable.

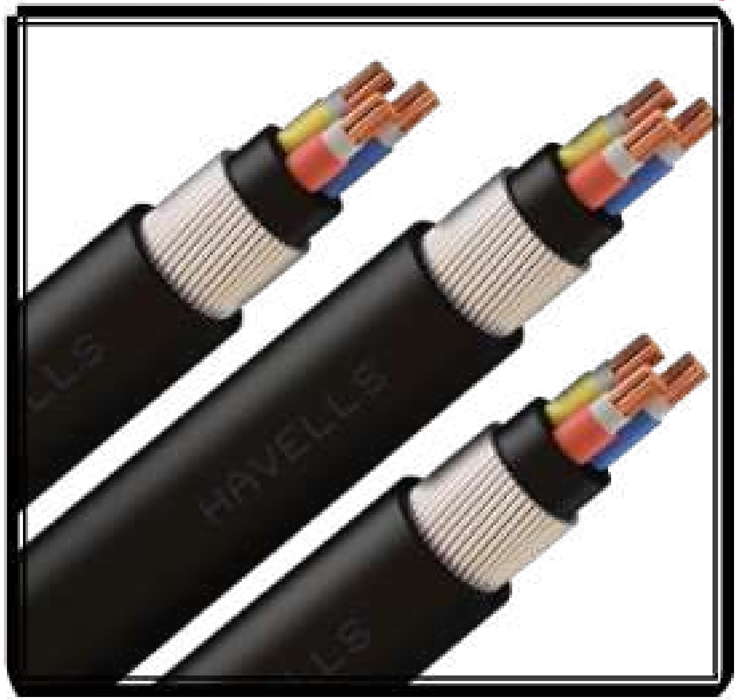
V. Based on Application:

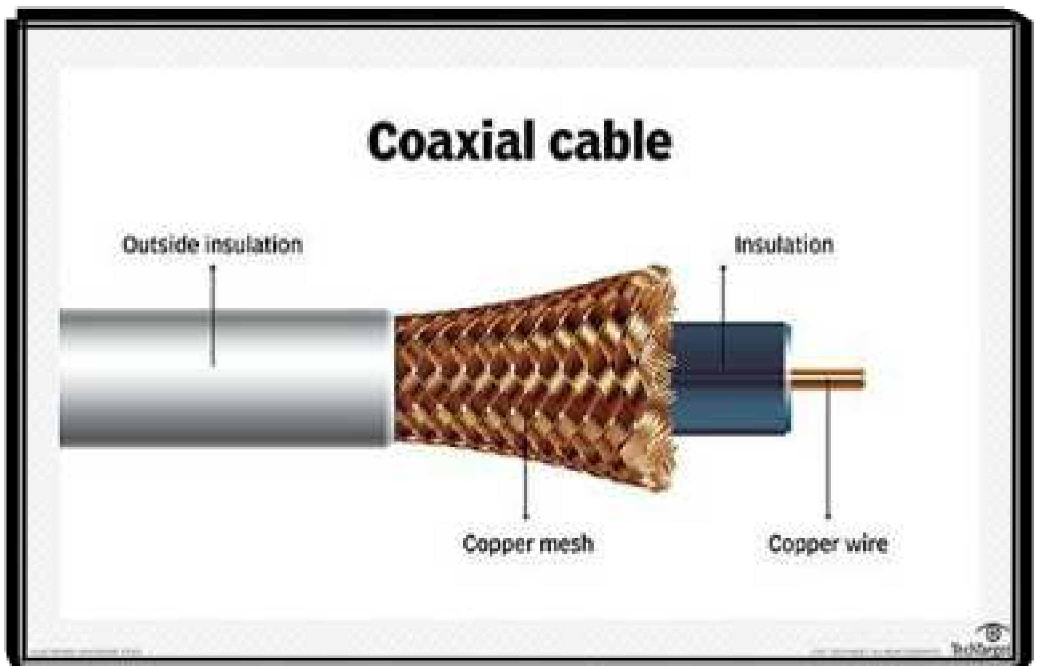
1. Automotive 2. battery cables 3. control & switch board 4. Power cables etc..

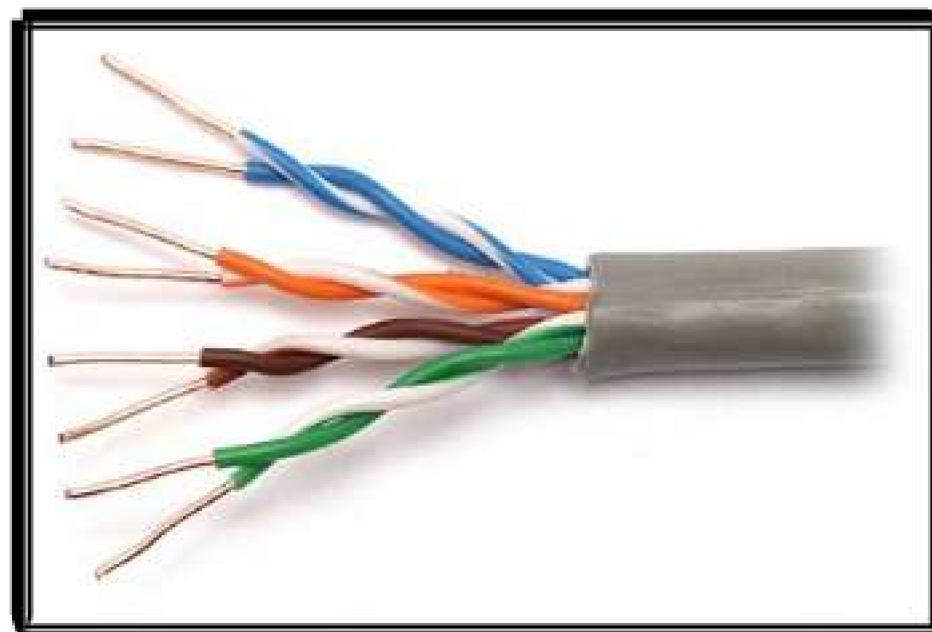
VI. In general:

1. Twisted pair 2. Coaxial 3. Multi conductor and
4. Fiber optic cables.

Types of Cables







EARTHING

- The process of transferring the **immediate discharge of the electrical energy directly to the earth by the help of the low resistance wire** is known as the electrical earthing.
- The electrical earthing is done by connecting the non-current carrying part of the equipment or neutral of supply system to the ground.
- **Earthing** is used to protect you from an electric shock. It does this by providing a path (a protective conductor) for a fault current to flow to earth. It also causes the protective device (either a circuit-breaker or fuse) to switch off the electric current to the circuit that has the fault.

Methods of Earthing

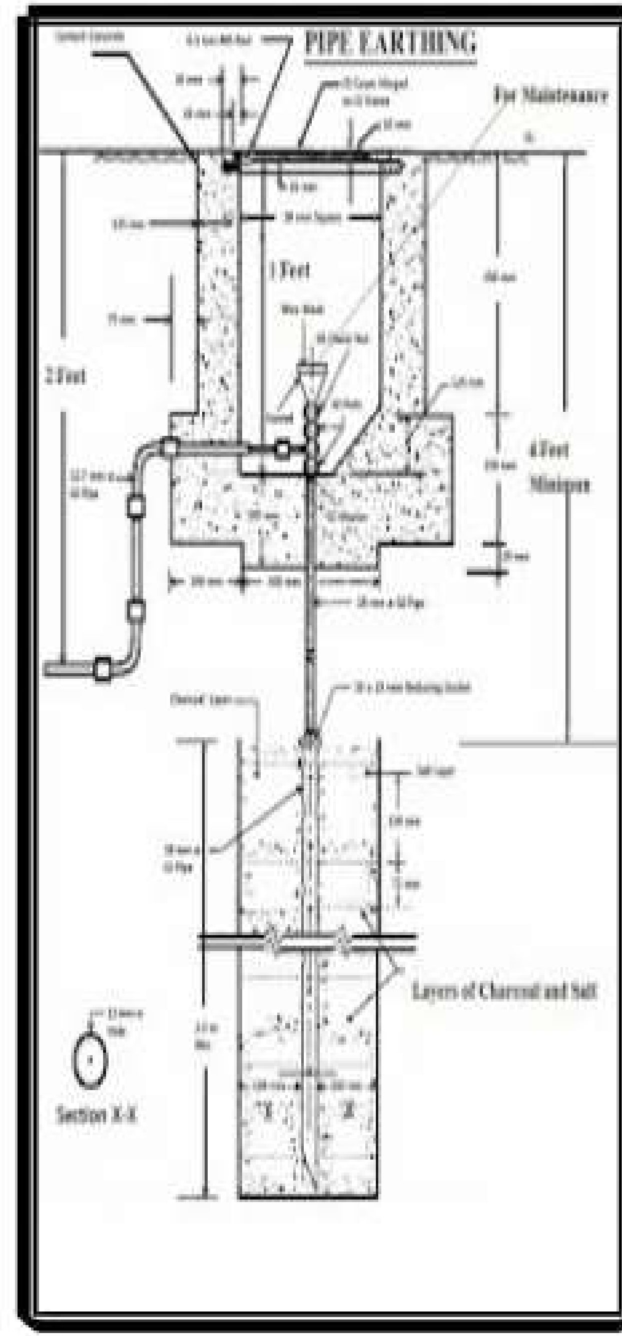
1. Pipe Earthing
2. Plate Earthing
3. Rod Earthing

1. Pipe earthing: This type of earthing is used most widely in Industries. In this system of earthing a GI pipe of 30-38 mm diameter and 2 Meters length is buried vertically in ground to work as earth electrode but the depth depend upon the soil conditions, there is no hard and fast rule for this.

1. Pipe earthing

- The earth wire are fastened to the top section of the pipe with nut and bolts.The pit area around the GI pipe filled with salt and coal mixture for reducing resistance. It can take heavy leakage current for the same electrode size in comparison to plate earthing.

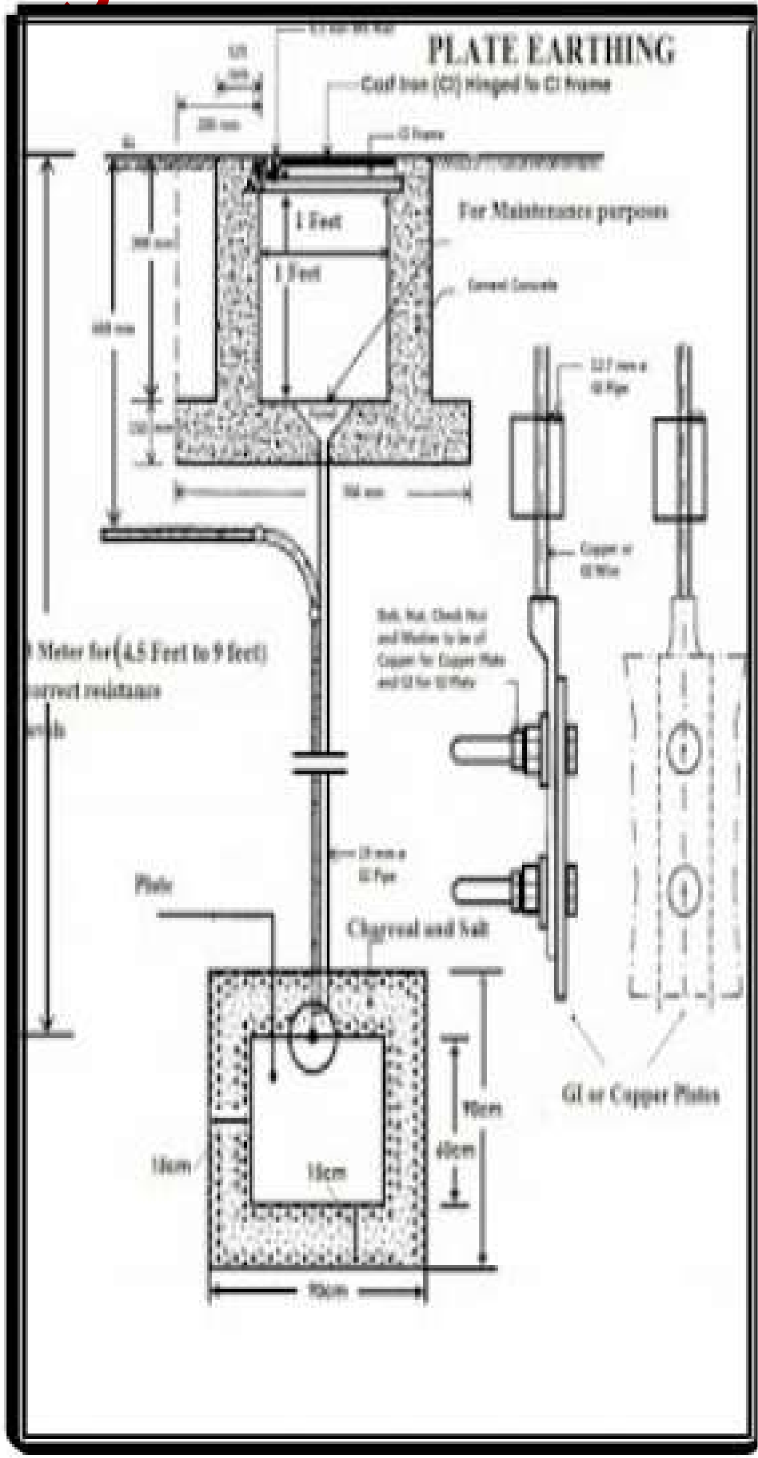
- Water is filled through pipe to Maintain the resistance of electrode. Pipe earthing is best form of earthing and it is also very cheap method of earthing.



2. Plate Earthing

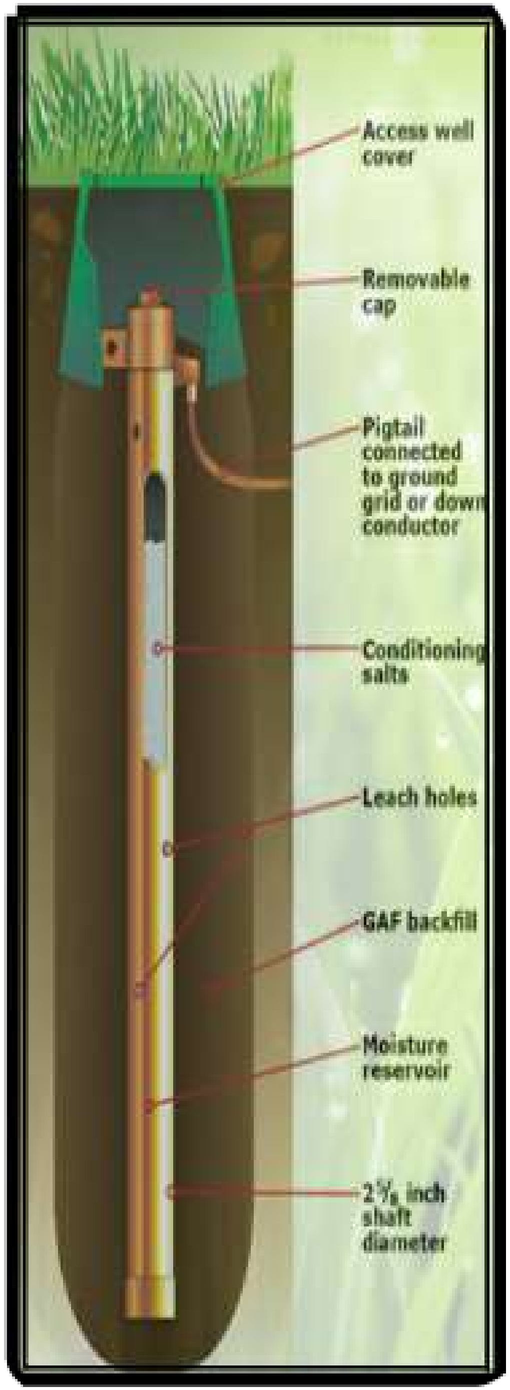
- In this type of earthing plate either of copper or of G.I. is buried into the ground at a depth of 3 Meter or greater than 3 Meters, Earthing plate should not be buried lesser than 3 Meters.
- Earthing plate is filled with layers of salt and coke not less than 1.5 feet so to provide lesser resistance.
- The earth is securely bolted to an earth plate with the help of bolt nut and washer made of copper, in case of copper plate earthing and of G.I. in case of G.I. plate earthing.

- For GI earthing Plate Size should be -- 600 mm X 600 mm X 8.30 mm
- For Copper earthing Plate Size should be-- 600 mm X 600 mm X 3.15 mm

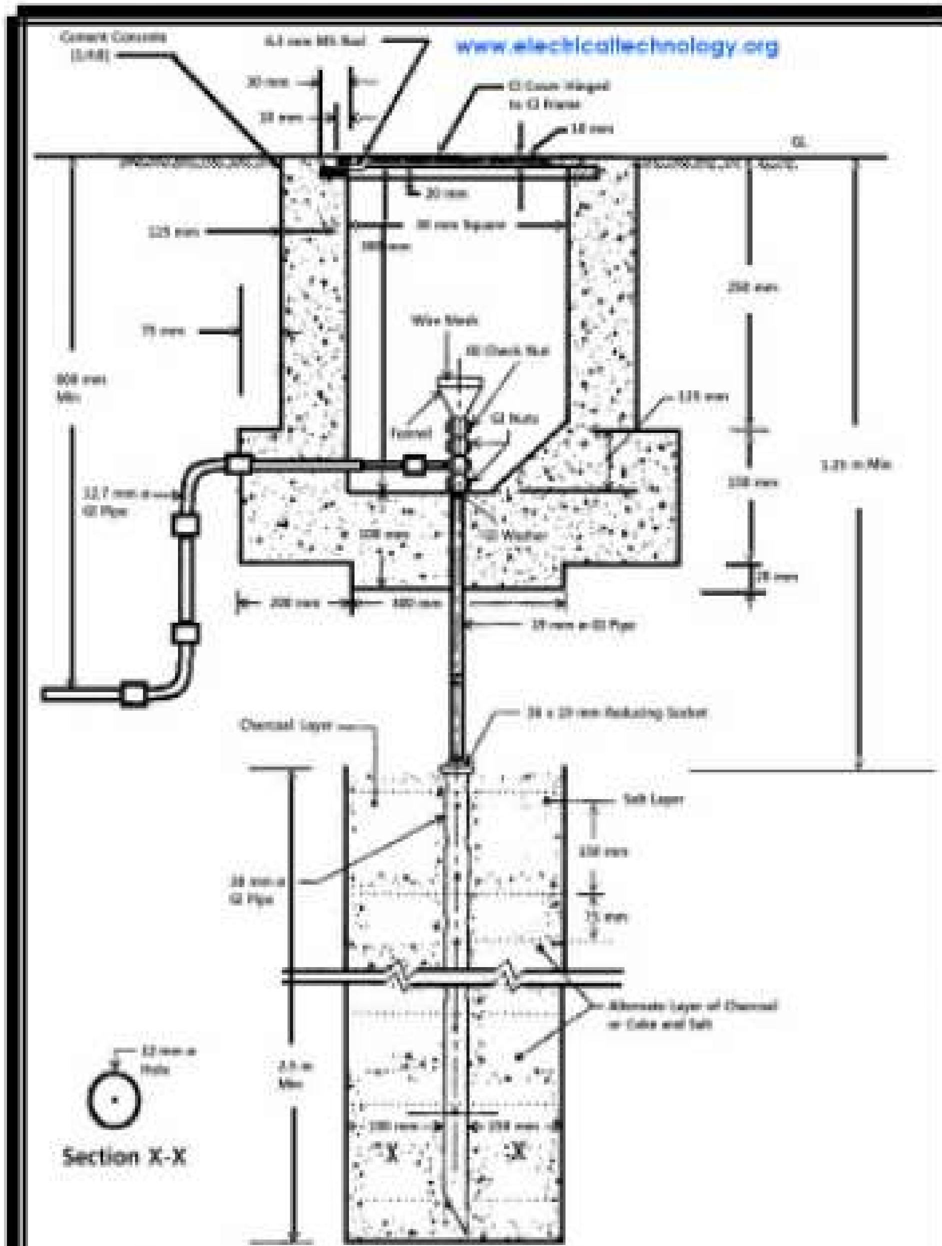


3. Rod Earthing

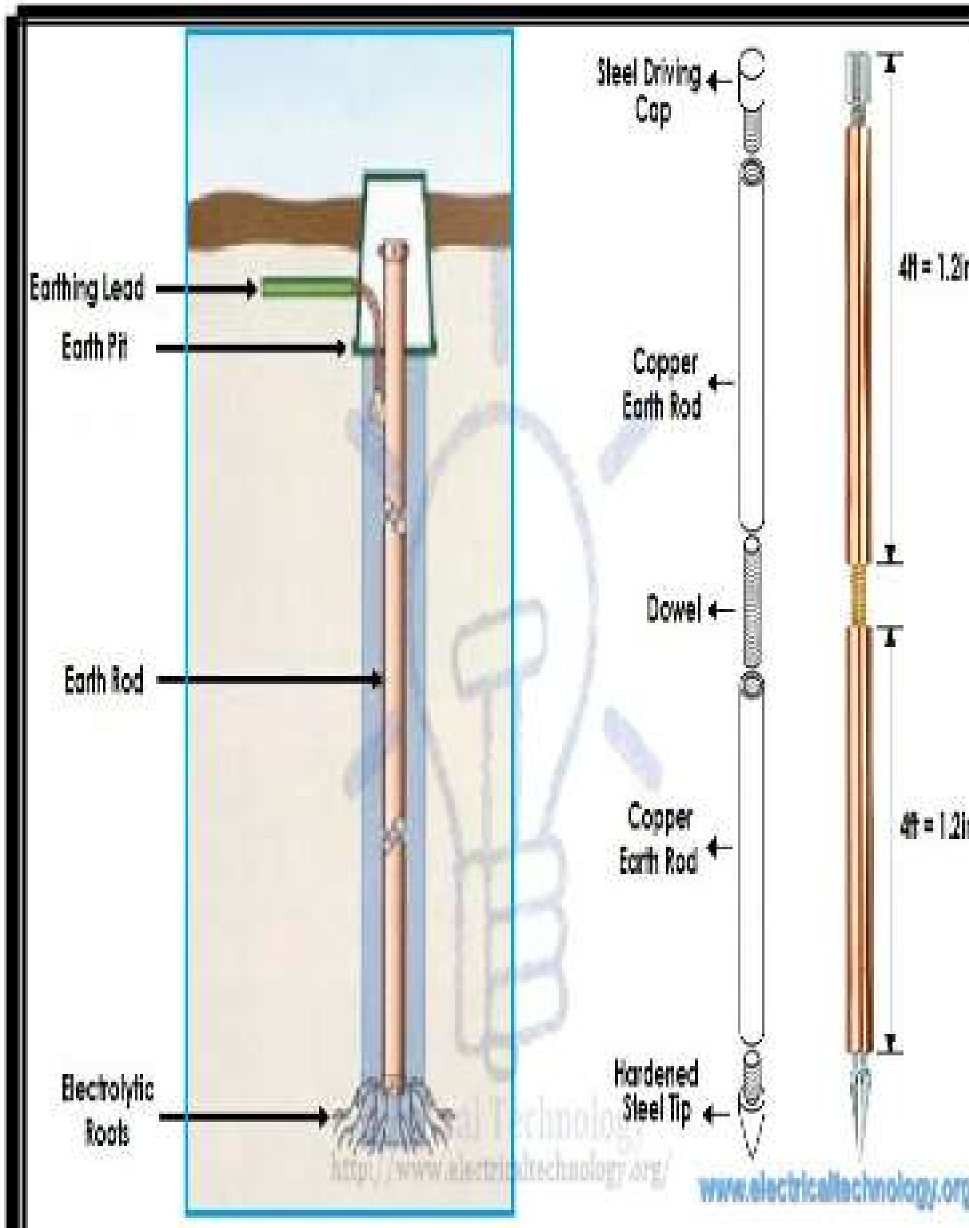
- This type of earthing is used in area where there is soil is sandy in nature and very lesser moistened. In this system of earthing 10-15 mm diameter solid rods of copper or 10-20 mm diameter solid rod of GI pipe is directly buried in earth not lesser then 3 meters. Rod is hammered into earth for reducing resistance of earthing electrode.
- This system of earthing is very cheap



Types of Earthings



Pipe Earthing



Copper Rod Electrode Earthing System

BATTERIES

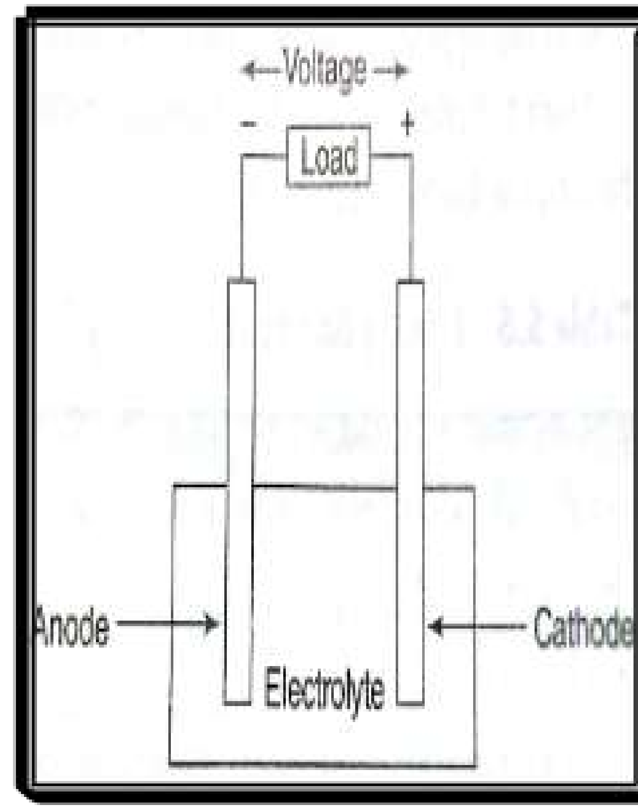
- A device that converts the stored chemical energy in to electrical energy using chemical action is called battery.
- The chemical action that takes place in the battery is the movement of electrons from one terminal to another.
- Cell: it is a device that consists of two electrodes and an electrolyte.
- Battery: it is a single unit which comprises of two or more cells which are connected together electrically.
- In day-to-day activities , battery is used as an energy source in many residential and industrial applications.

Construction

- It consists of three parts mainly

Those are

1. Anode : the electrode that oxidizes and releases electrons.
2. Cathode: the electrode that acquires electrons during electro chemical reaction.
3. Electrolyte: the medium through which electrons get transferred from anode to cathode is called electrolyte.



Classification of batteries

- The two main categories

1. Primary Batteries: it is also called single-use or throw-away battery, as it cannot be recharged to reuse.

Ex: alkaline batteries, mercury batteries, silver-oxide batteries and zinc carbon batteries.

2. Secondary Batteries: the battery that can be electrically recharged again are called secondary batteries.

Ex: Nickel Cadmium, Lead-Acid batteries and Lithium-Ion batteries.

1. Lead-Acid Battery

- Lead acid battery is the most commonly used secondary battery,
- A single lead acid battery capable of producing 2.1V.
- Anode material: Lead (Pb) or sponge lead
- Cathode material: Lead peroxide (PbO_2)
- Electrolyte: H_2SO_4(Dilute sulphuric Acid)

During Discharging:

- At Anode: $Pb+SO_4$ -------> $PbSO_4$
- At Cathode: $PbO_2+2H+H_2SO_4$------> $PbSO_4+2H_2$

During Charging:

- At Anode: $PbSO_4+2H$ -------> $Pb+H_2SO_4$
- At Cathode: $PbSO_4+SO_4+2H_2O$-------> $PbO_2+2H_2SO_4$

2. Nickel Cadmium Battery

- A single Nickel cadmium battery capable of producing 1.2V.
- Anode material: Cdmium (Cd)
- Cathode material: Nickel hydroxide(NiOH2)
- Electrolyte: alkaline potassium hydroxide (KOH)

During Discharging:

- At Anode: Cd+2OH---------> Cd(OH)2
- At Cathode: NiO(OH)+H2O------> Ni(OH)2+OH

During Charging:

- At Anode: Cd(OH)2+2K-------> Cd+2KOH
- At Cathode: Ni(OH)2+OH--------> NiO(OH) + H2O

3. Lithium Ion(Li-ion) Battery

- The secondary battery that plays a major role in electric vehicles is Lithium-ion battery or Li-ion battery.
- Li-ion battery is that possess higher charge and discharge efficiency, and its energy density is high.
- A single Lithium ion battery capable of producing 3.6V.
- Anode: Lithiated carbon
- Cathode: Lithium metal oxide, $LiMO_x$ where M is any metal.
- Electrolyte: Ethylene carbonate or Diethyl carbonate.

Based on the metal , the Li-ion battery is classified as:

1. Lithium Cobalt oxide battery
2. Lithium Manganese oxide battery
3. Lithium Nickel Manganese battery
4. Lithium Iron Phosphate battery
5. Lithium Nickel Cobalt Aluminium Oxide battery
6. Lithium Titanate battery.

IMPORTANT CHARACTERISTICS FOR BATTERY

- The different battery characteristics which are to be considered in selecting a battery for specific applications are:

1. Type 2. Voltage 3. Discharge curve 4. Capacity

5. Energy density 6. power density 7. temperature dependence 8. service life

9. Physical requirement 10. charge/discharge cycle

11. Cost 12. ability to deep discharge

13. Application requirement.

Types of batteries

ENERGY CONSUMPTION

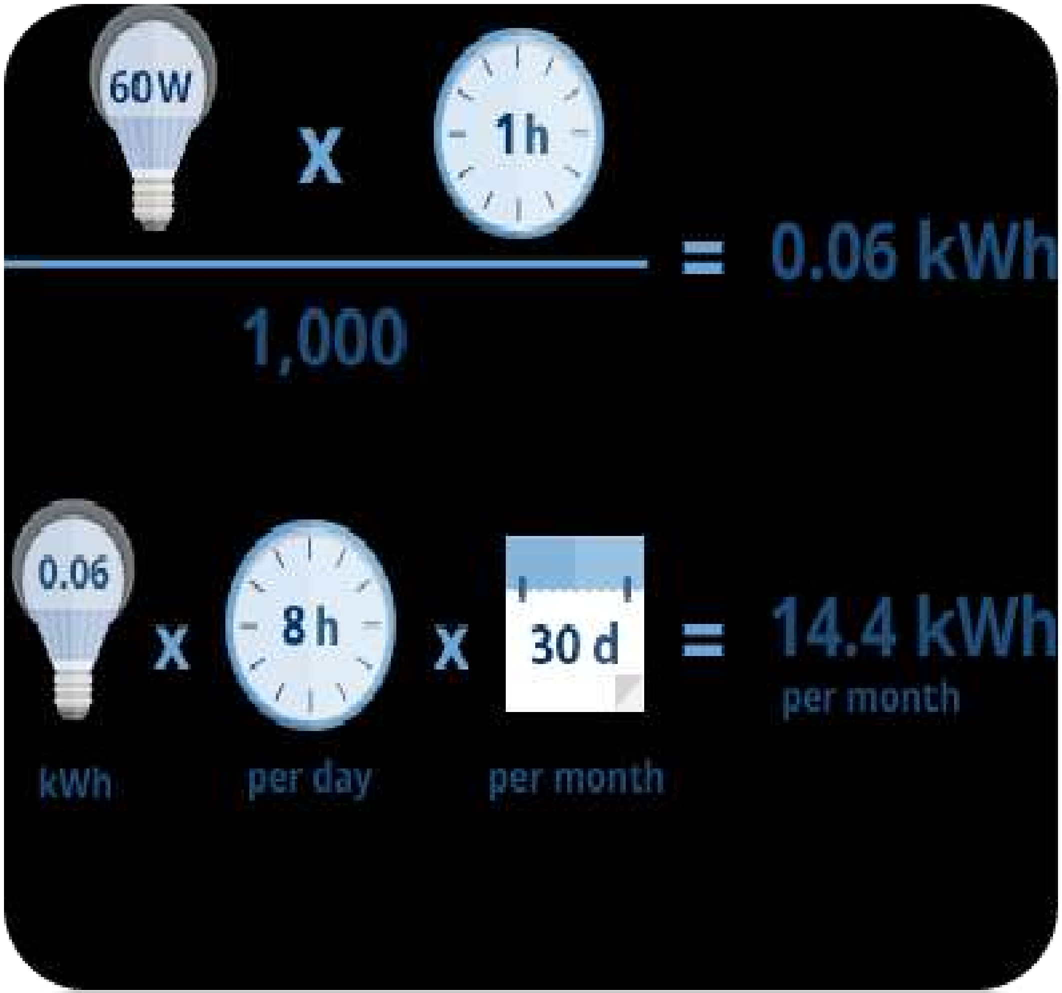
Elementary Calculations for energy consumption

How to calculate consumption of electrical energy?

(Wattage × Hours Used Per Day) ÷ 1000 = Daily Kilowatt-hour (kWh)

1 kWh=1 UNIT

1 kilowatt (kW) = 1000 Watts



POWERFACTOR IMROVEMENT

BATTERY BACKUP

- Battery backup is defined as the provision provided to have a continuous power supply to the electronic equipment even when the main grid fails due to some technical faults.
- The battery backup device which is commonly used in residential applications is more powerful with compact size.
- Types of battery backup device:

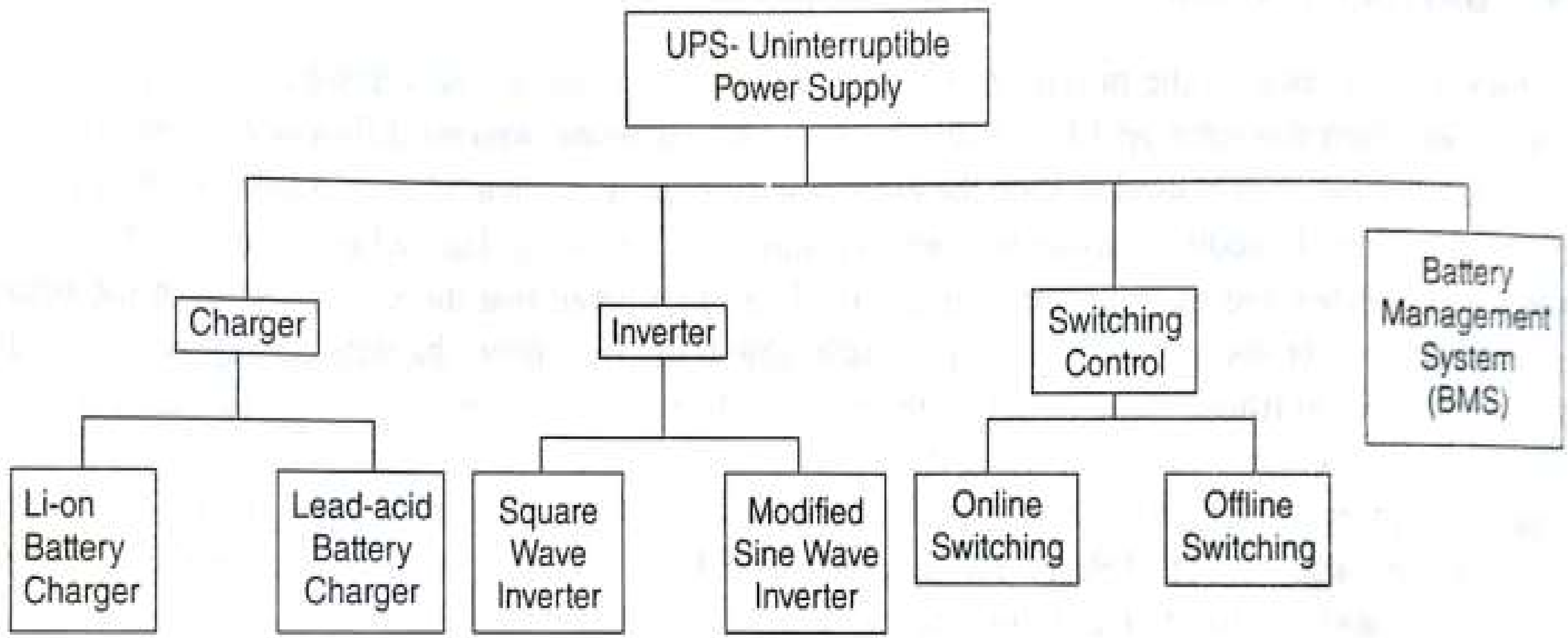
1. Off-line device
2. Line-interactive device
3. On-line device.

Block diagram of the battery backup device

- The four major blocks

1. Charger 2. inverter 3. switching control

4. Battery Management System (BMS)



Block diagram of Battery backup device

THANK YOU