SUBJECT: BASIC ELECTRICAL ENGNEERING (21ELE13/23)

MODULE-1

Syllabus: **D.C.Circuits:** Ohm's Law and Kirchhoff's Laws, Analysis of series, parallel and series- parallel circuits excited by independent voltage sources. Power and Energy. Maximum Power transfer theorem.

Single Phase AC circuits : Generation of sinusoidal voltage, frequency of generated voltage, definition and numerical values of average value, root mean square value, form factor and peak factors. Voltage and Current relationship with phasor diagram in R, L and C circuit.

Ohm's Law

German physicist Georg Ohm derived relationship between voltage, current and resistance in an electrical circuit called ohm's law.

It states that "The potential difference applied across the circuit, is directly proportional current flowing through the circuit provided the temperature remains Constant ".

$$V \alpha I$$

$$V = R I$$

R - Constant of proportionality called Resistance of a conductor in ohm's (Ω).

V – Potential difference across the circuit or voltage in volts (V).

I - Current in Amps (A).

Limitations of Ohm's law

- It is not applicable to non-metallic conductors like silicon carbide.
- It is not applicable to non-linear devices like diodes.
- It is not applicable to 'arc lamps', because arc produced exhibits non-linear characteristics.

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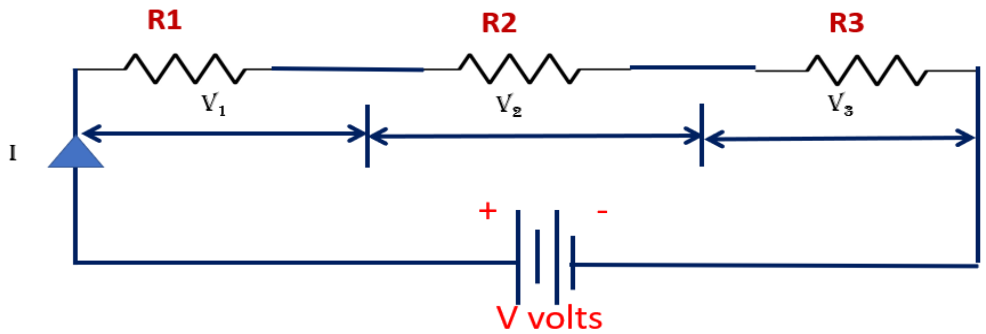
1.2 Analysis of Series and Parallel Circuits

I. Series Circuit

In a series circuit the finishing end of one resistor is connected to starting end of another resistor.
Consider three resistances connected series.



In series circuit the current flowing through all the resistances is same.

Let **'I'** be the current flowing through all the resistors.
Let **V_1, V_2,** and **V_3** be the voltages drops across the resistances **R1** ,**R2** and **R3** respectively

The supply voltage **'V'** is the sum of the voltage drops across the resistances.

I,e $V = V_1 + V_2 + V_3$
According to Ohm's law

$V_1 = IR_1$ $V_2 = IR_2$ $V_3 = IR_3$

Applying Ohm's law to the overall circuit $V = I R_T$

R_T - is the Total or equivalent resistance of the circuit

$$V = V_1 + V_2 + V_3$$
$$I R_T = IR_1 + IR_2 + IR_3$$
$$I R_T = I [R_1 + R_2 + R_3]$$

$$R_T = R_1 + R_2 + R_3$$

Thus the Total or Equivalent Resistance in a series Circuit is equal to the Sum of the resistances connected in series.

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Inference

- In Series circuit the same current is flowing through all resistances.
- The supply voltage **'V'** is the sum of the individual voltage drops across the each resistance.
- If **'N'** resistances connected in series then

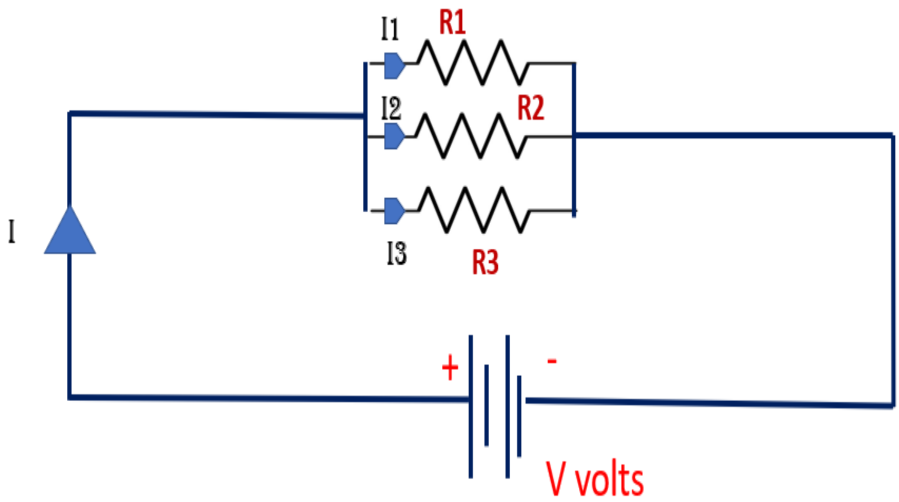
$$R_T = R1 + R2 + R3 + \text{---------------} + R_N$$

$$\text{and} \quad V = V1 + V2 + \text{-------------} + V_N$$

II. Parallel Circuit

In a Parallel circuit the starting end of all the resistor are connected to one point and finishing end of all the resistors are connected to another point.

Consider three resistances connected in parallel.



In parallel circuit the voltage applied across each resistance is equal to the supply voltage.

Let **'I'** be the current drawn from the supply.

Let I_1, I_2, and I_3 be the Current through the resistances **R1**, **R2** and **R3** respectively.

I,e

$$I = I_1 + I_2 + I_3$$

According to Ohm's law

$$I_1 = \frac{V}{R1} \qquad I_2 = \frac{V}{R2} \qquad I_3 = \frac{V}{R3}$$

Applying Ohm's law to the overall circuit $\quad I = \frac{V}{RT}$

R_{eq} - is the Total or equivalent resistance of the circuit

$$I = I_1 + I_2 + I_3$$

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

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

$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Thus the reciprocal of Total or Equivalent Resistance in a parallel Circuit is equal to the Sum of the reciprocal of individual resistances connected in parallel.

Inference

- In Parallel circuit the voltage across each resistance is equal to supply voltage.
- The total current **'I'** is the sum of the currents drawn by the each resistance.
- If **'N'** resistances connected in parallel then

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{-----------} + \frac{1}{R_N}$$

$$\textbf{and} \quad I = I_1 + I_2 + \text{-------------} + I_N$$

Note: When 2 Resistances are connected in parallel then the Total resistance is

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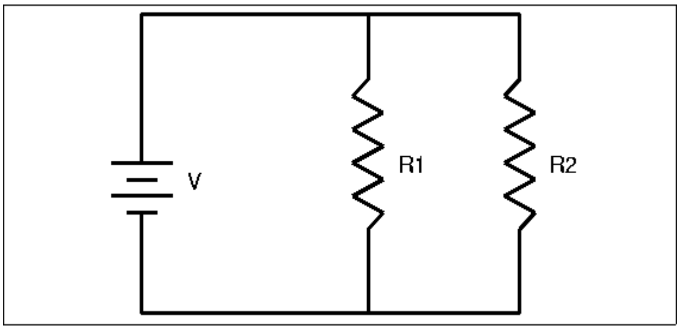


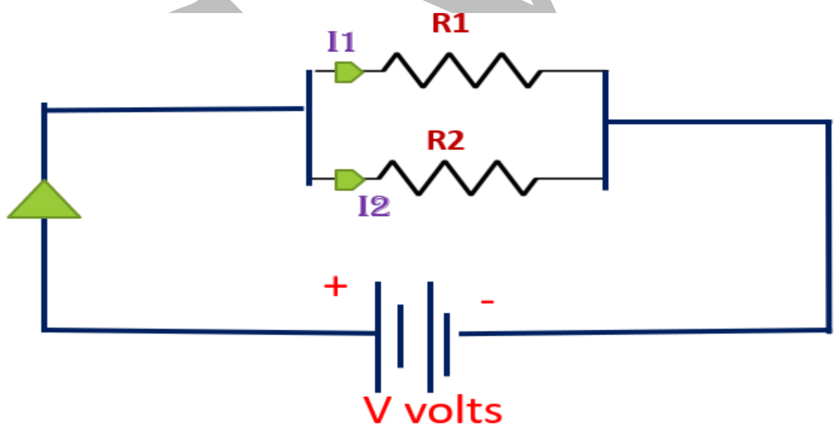
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_T} = \frac{R_1+R_2}{R_1R_2}$$

$$R_T = \frac{R_1+R_2}{R_1R_2}$$

III. Current Division in Parallel circuit of Resistors

Consider a parallel circuit of two resistors R_1 and R_2 connected across a supply Voltage of **'V'** Volts.



Let I_1 and I_2 be the Current through the resistances R1 and R2 respectively.

I,e $$I = I_1 + I_2 \quad \text{---------------------------1}$$

According to Ohm's law

$$I_1 = \frac{V}{R1} \quad \text{and} \quad I_2 = \frac{V}{R2}$$

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We know that in parallel circuit the voltage across each resistance is equal to supply voltage.

$$\text{I,e} \quad V = V_1 = V_2$$

Where V_1 and V_2 is the voltage across R_1 and R_2

wkt $V_1 = I_1 R_1$ and $V_2 = I_2 R_2$

Therefore $I_1 R_1 = I_2 R_2$

$$\boxed{I_1 = \frac{I_2 R_2}{R1}}$$

Substitute I_1 in equation 1 we get

$$I = I_1 + I_2$$

$$I = \frac{I_2 R_2}{R1} + I_2$$

$$I = I_2 \left[\frac{R_2}{R1} + 1 \right]$$

$$I = I_2 \left[\frac{R_2 + R1}{R1} \right]$$

Therefore $$\boxed{I_2 = \frac{I\, R1}{R_1 + R2}}$$

Similarly $$\boxed{I_1 = \frac{IR2}{R_1 + R2}}$$

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Comparison between Series and Parallel Combination of resistors

Series	Parallel
If finishing end of one resistor is connected to starting end of another resistor then the resistances are said to be connected is series.	If the starting end of all the resistor are connected to one point and finishing end of all the resistors are connected to another point then the resistances are said to be connected in Parallel.
In series circuit the current flowing through all the resistance is same.	In parallel circuit the Total current is equal to the current drawn by each resistance.
The supply voltage 'V' is the sum of the voltage drops across the resistances.	In parallel circuit the voltage applied across each resistance is equal to the supply voltage.
The equivalent resistance is equal to the sum of individual resistances	The reciprocal of equivalent resistance is equal to the sum of the reciprocal of the individual resistances.
If N resistances are connected in series then $R_T = R1 + R2 + R3 + \text{--------} + R_N$	If N resistances are connected in parallel then $1/R_T = 1/R1 + 1/R2 + 1/R3 + \text{-----} + 1/R_N$

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1.3 Kirchhoff's Law

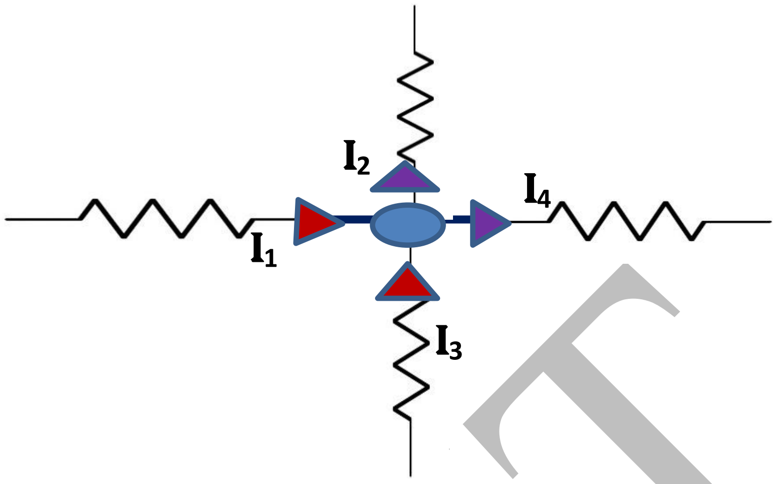
Kirchhoff's circuit laws are deals with the two parameters in the electric circuit - current and potential difference. They were first described in 1845 by German physicist Gustav Kirchhoff. He generalized the work of Georg Ohm.

i) Kirchhoff's Current Law (KCL)

Statement: It states that **"The Algebraic sum of the currents meeting at a junction in an electric circuit is equal to zero."**

$$\Sigma I = 0$$

Example: Consider a junction in an electrical network as shown in the fig.The currents I_1 and I_3 are taken as positive as they are entering the junction. While I_2 and I_4 are negative as leaving the junction.



Applying KCL to the above circuit

$$I_1 - I_2 + I_3 - I_4 = 0$$

$$\text{I,e} \quad I_1 + I_3 = I_2 + I_4$$

"The total current flowing towards a junction is equal to the total current leaving the junction."

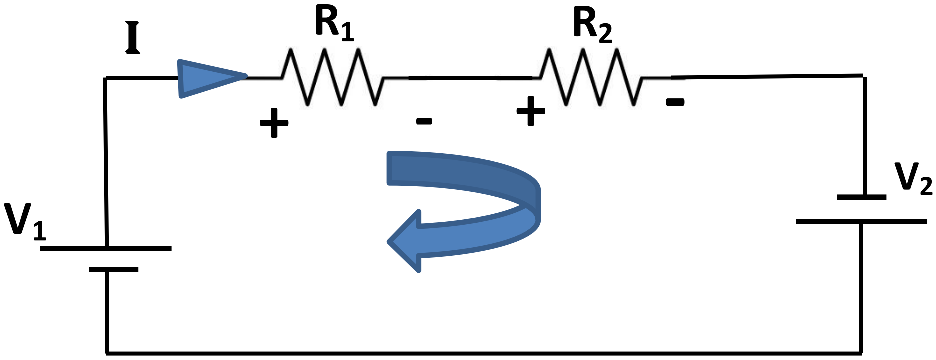
<u>Note:</u> Sign convention: The currents entering the junction taken as **positive** and the currents leaving the junction are taken as **negative**.

ii) Kirchhoff's Voltage law [KVL]

Statement: "**In any closed path, the algebraic sum of the Emf's and the voltage drops across the circuit elements is equal to zero**. "

$$\Sigma \text{ Emf} + \Sigma \text{ IR drops} = 0$$

Example: Consider an electrical network as shown in fig



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Applying KVL to the loop

$$-IR_1 - IR_2 + V_2 + V_1 = 0$$

$$V_1 + V_2 = IR_1 + IR_2$$

Note: Sign convention: while tracing the path across

i) If its moving from **'+' to '-'** then it is voltage drop therefore take as **negative.**

ii) If its moving from **'-' to '+'** then it is voltage rise therefore take as **Positive.**

1.5 Electrical Power

The rate at which electrical work is done in a circuit is called **Electrical Power**. Electrical power is denoted by P and measured in Watt (W).

$$P = V I$$

$$P = (IR)\, I = I^2 R \qquad [V = IR]$$

$$P = V \left(\frac{V}{R}\right) = \frac{V^2}{R} \qquad [I = V/R]$$

$$\mathbf{P = VI = I^2 R = \frac{V^2}{R} \text{ watts}}$$

1.6 Energy

Energy is defined as the amount of electrical work is done in a circuit in a specified time.

It is denoted as 'E' and measured in Joules (J).

$$\mathbf{E = VI\,t = I^2 R\,t = \frac{V^2 t}{R}} \text{ joules}$$

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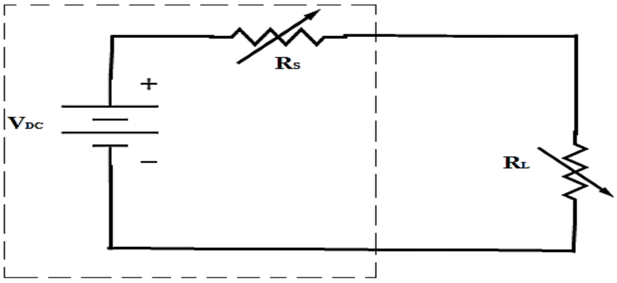
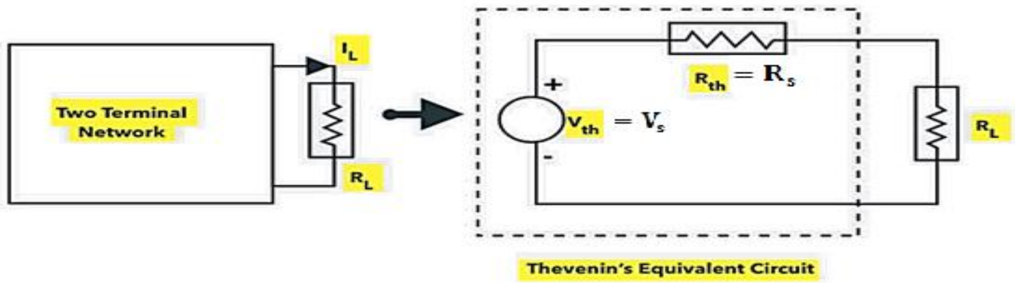
Maximum Power Transfer Theorem:

It states that "In any linear active network, maximum power is transferred from a source to a load when the value of load resistance is equal to the value of source resistance." This theorem finds its application when it is desired to obtain maximum power transfer from an active network to an external load resistor.



Proof of Maximum Power Transfer Theorem:

Consider the below DC two terminal network.



The original two terminal circuit is replaced with a Thevenin's equivalent circuit across the variable load resistance. The current through the load for any value of load resistance is

$$I_L = \frac{V_s}{R_s + R_L}$$

The Power absorbed by the load is

$$P_L = I_L^{\,2} \times R_L$$

$$= \left(\frac{V_s}{R_s + R_L}\right)^2 \times R_L$$

From the above expression, the power delivered depends on the values of RTH and RL, but mainly on the load resistance RL(as RTH is constant). To find the exact value of RL, we apply differentiation to PL with respect to RL and equating it to zero as shown below:

$$\frac{dP_L}{dR_L} = {V_s}^2 \left[\frac{(R_s + R_L)^2 - 2R_L \times (R_s + R_L)}{(R_s + R_L)^4}\right] = 0$$

$$(R_s + R_L) - 2R_L = 0$$

$$R_L = R_s$$

Therefore, this is the condition of matching the load where the maximum power transfer occurs when the load resistance is equal to the Thevenin's resistance of the circuit. By substituting the RTH = RL in the previous equation, we get: The maximum power delivered to the load is

or $P_{max} = I_L^2 \times (Rs + RL)$

but $R_L = R_s$ $\quad P_{max} = 2\, I_L^2\, R_L$ -----------(power input)

Therefore, the efficiency under the condition of maximum power transfer is:

Efficiency = PowerOutput /Power Input × 100

$= I_L^2 R_L / 2\, I_L^2 R_L \times 100$

= 50%

Module 1b. Single phase AC circuits

An Alternating Current is one in which the magnitude and direction of an electrical quantity changes with respect to time.

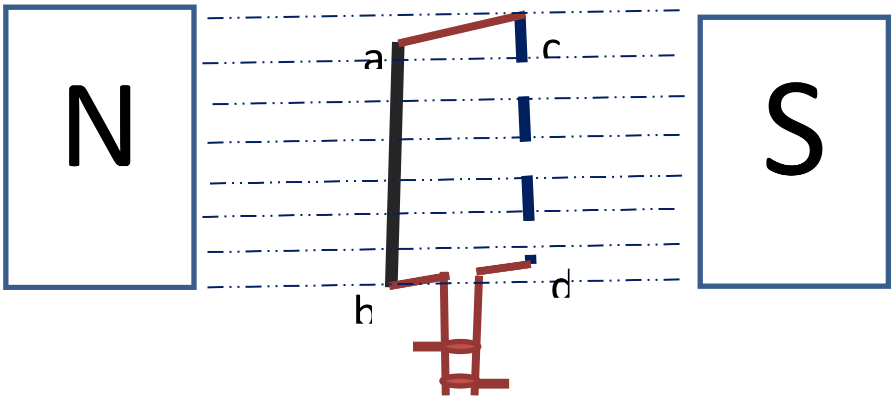
Faradays laws of Electromagnetic Induction

Whenever a conductor is placed in a varying magnetic field, an EMF is induced in a conductor.

Dynamically Induced Emf **$e = Blv\sin\theta$** volts

Generation of AC voltage

Consider a rectangular coil placed in a uniform magnetic field produced by two poles as shown in the figure.



Rotate the coil in the anticlockwise direction, while rotating the conductors will cut the magnetic flux due to which an emf is induced in the conductor. The magnitude of the Induced Emf is depends upon the position of the conductor in a magnetic Field.

We know that from the faraday's laws of electromagnetic Induction

The dynamically Induced Emf is given by

$$\mathbf{e = B\, l\, v\, Sin\theta} \quad \text{volts}$$

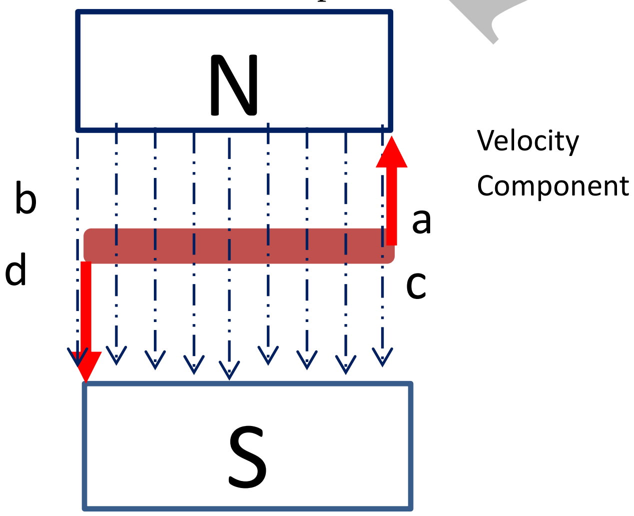
where B - Flux density of the magnetic field in wb/m^2

l - Length of the conductor in meter

v - Velocity of the conductor in m^2

θ - Angle between the relative velocity of the conductor and the plane of the flux.

Let the Initial position of the coil be as shown in fig



(a) θ = 0

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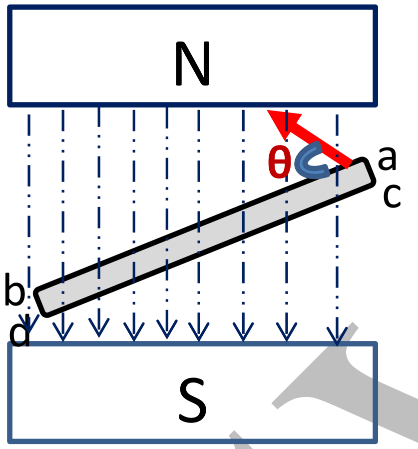
The plane of coil is perpendicular to the direction of the magnetic flux. The instantaneous component of velocity of conductors is parallel to the magnetic field .

Therefore, the angle between the magnetic flux and velocity component is zero I,e θ =0.

Hence the Emf Induced **e = B l v Sin0 =0 --- zero Emf**

When the coil is rotated in anticlockwise direction through some angle θ as shown in fig b.



(b) (0<θ<90)

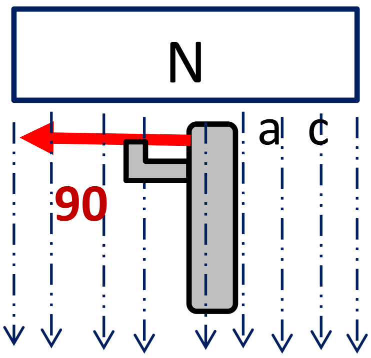
The instantaneous component of velocity of conductors is cutting the flux with an angle θ.

Hence the Emf Induced

$e = B\, l\, v\, \sin\theta$ ----- $(0<\theta<90)$

ex: If θ is 30 then e = 0.5 Blv

When the coil is further rotate in an anticlockwise direction, the instantaneous component of velocity acting perpendicular to the line of the flux as shown in fig c.



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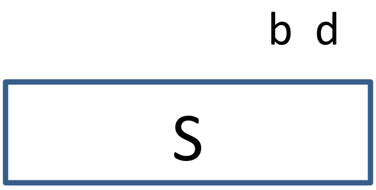


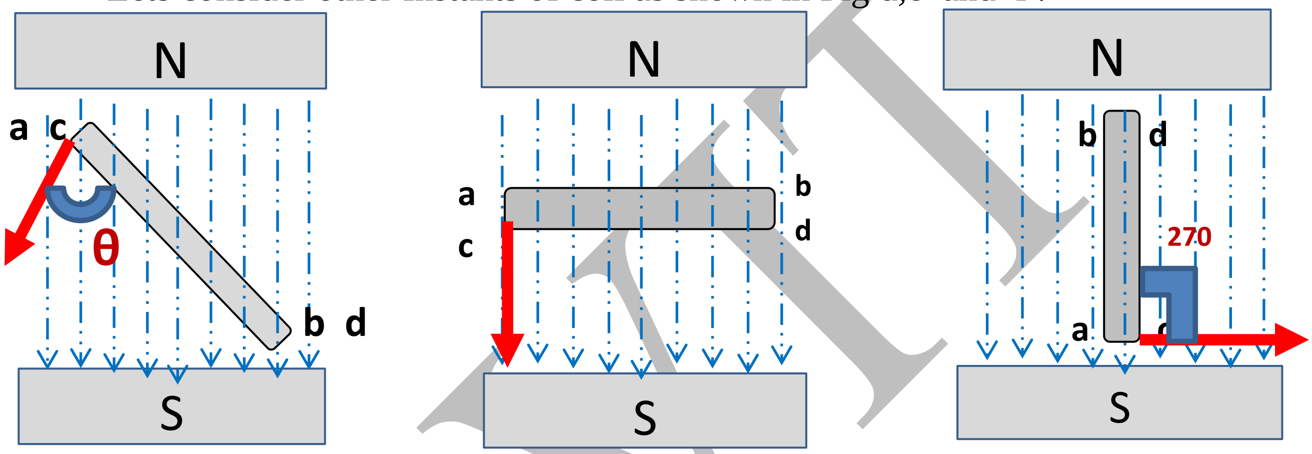
(c) (θ=90)

Therefore, the angle between the magnetic flux and velocity component is 90 I,e θ =90.

Hence the Emf Induced **e = B l v Sin90 = Blv**

So the Induced emf in this position is at its maximum Value.

Lets consider other Instants of coil as shown in Fig d,e and f .



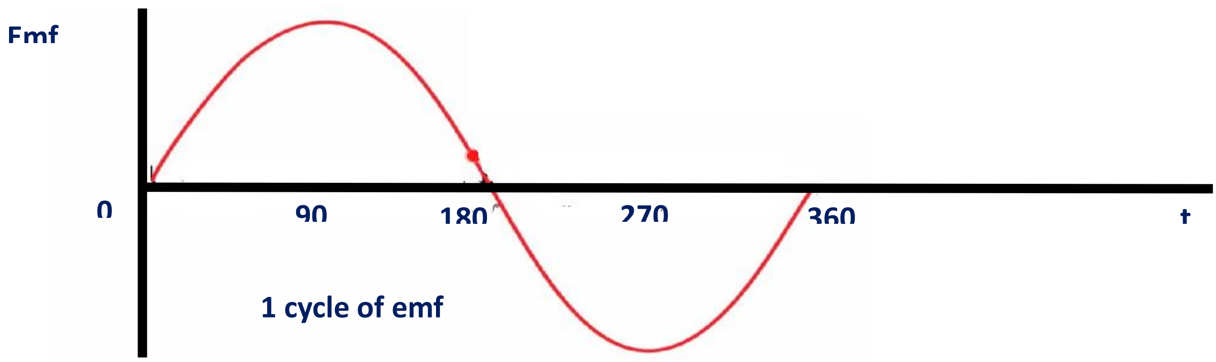
(d) (90<θ<180) **(e) θ=180** (f) θ=270

e = B l v Sinθ **e = 0** **e = -Blv**

Similarly when θ=360 the induced emf **e=0**

So, when θ varies from 0 to 360 the emf in an conductor varies in an alternating manner I,e from zero to maximum in one direction ,decreasing to zero, then achieving maximum in another direction and again decreasing to zero.

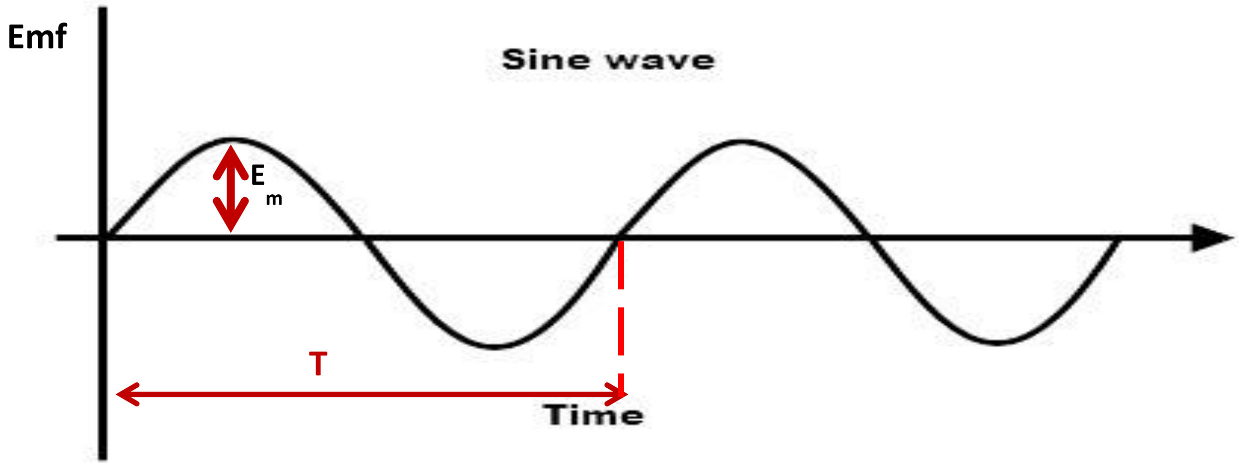
Therefore by rotating conductor from 0 to 360 we get one cycle of emf



Advantages of AC system over DC system

1. AC voltages can be efficiently stepped up/down using a device transformer.
2. By increasing the transmission voltage the losses can be reduced.
3. AC machines are simpler in construction than DC machines.
4. The cost and maintenance of Ac machines are less compare to Dc machines.

Important terms associated with an alternating quantity



1. **Amplitude (E_m or I_m) :** It is the maximum value attained by an alternating quantity. And also called as maximum or peak value.
2. **Time Period (T):** It is the Time Taken to complete one cycle of an alternating quantity.
3. **Instantaneous Value (e or i):** It is the value of the quantity at any instant.

   $e = Blv\sin\theta$ wkt $E_m = Blv$

   $e = E_m \sin\theta$ and $i = I_m \sin\theta$

4. **Frequency (f):** It is the number of cycles completed by alternating quantity in one second. The unit for frequency is **Hz or cycles/sec**.

   The relationship between frequency and time period can be derived as follows.

   Time taken to complete f cycles = 1 second

Time taken to complete 1 cycle is T= 1/f second

T =1/f ----sec

5. **Angular Frequency (ω):** Angular frequency is defined as the number of radians covered in one second.The unit of angular frequency is rad/sec.

$$\omega = 2\pi f \quad \text{------r/s}$$

6. **Average Value(E_{av} or I_{av}):** The arithmetic average of all the values of an alternating quantity over one cycle is called its average value.

$$\textbf{Average value} = \frac{\text{Area under curve for half cycle}}{\text{length of base over half cycle}}$$

For Symmetrical waveforms, the average value calculated over one cycle becomes equal to zero because the positive area cancels the negative area. Hence for symmetrical waveforms, the average value is calculated for half cycle.

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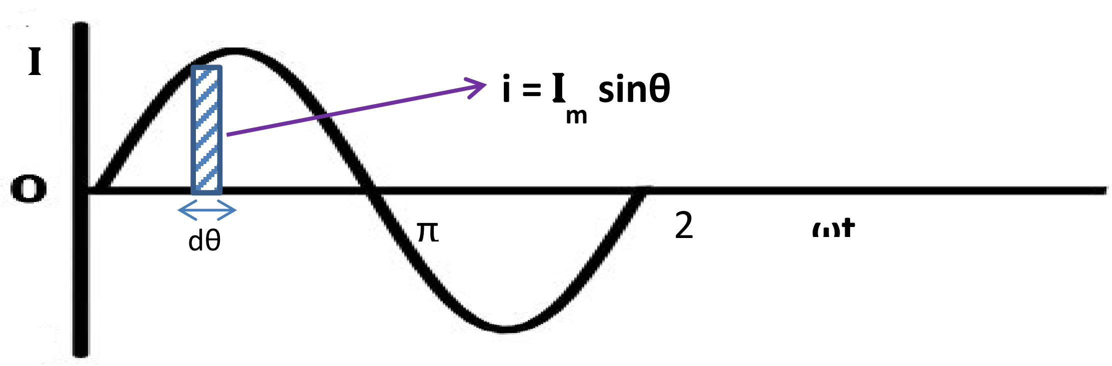
Average Value of an Alternating Quantity



Consider sinusoidal varying current

$$i = I_m \sin\theta$$

Consider an half cycle of alternating quantity and instant **'dθ'**

We know that

$$I_{av} = \frac{\textbf{Area under curve for half cycle}}{\textbf{length of base over half cycle}}$$

$$I_{av} = \frac{\int_0^{\pi} i\, d\theta}{\pi}$$

$$I_{av} = \frac{1}{\pi}\int_0^{\pi} i \quad = \frac{1}{\pi}\int_0^{\pi} I_m \sin\theta\, d\theta \qquad = \frac{Im}{\pi} \quad \int_0^{\pi} \sin\theta\, d\theta$$

$$= \frac{Im}{\pi}[-cos\theta]_0^{\pi} \qquad = \frac{Im}{\pi}\,[-(cos\pi - cos0)]$$

$$= \frac{Im}{\pi}\,[-((-1) - 1)] \qquad = \frac{Im}{\pi}\,[2]$$

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

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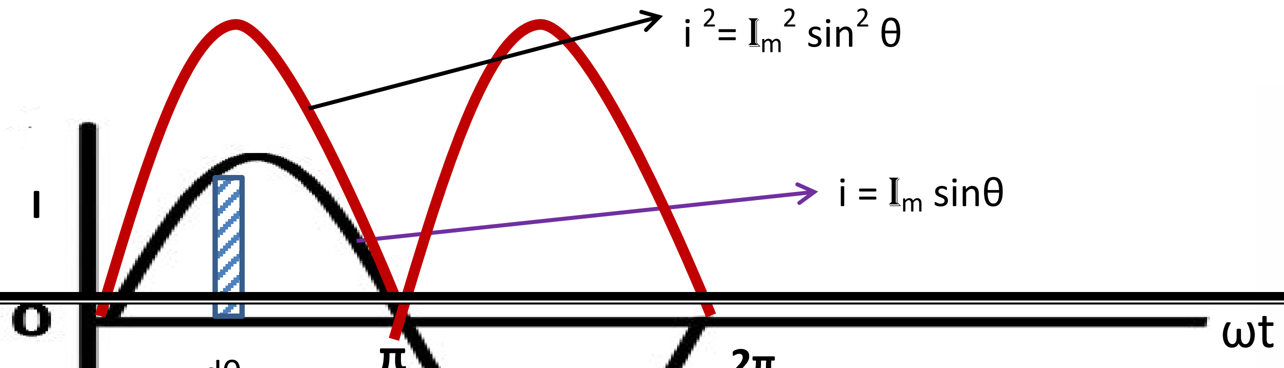
RMS(Root mean square) or Effective Value(E_{rms} or I_{rms})

Definition: The effective or RMS value of an alternating quantity is that steady current (dc) which when flowing through a given resistance for a given time produces the same amount of heat produced by the alternating current flowing through the same resistance for the same time

RMS Value of an Alternating Quantity



Consider sinusoidal varying current and square the current. Consider a half cycle of alternating quantity and instant **'dθ'**

Average value of square of the current over half cycle

$$\text{Average value} = \frac{\text{Area under curve for a cycle}}{\text{length of base over a cycle}}$$

$$= \frac{\int_0^{2\pi} i^2\, d\theta}{2\pi} = \frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\theta\, d\theta$$

$$= \frac{I_m^2}{2\pi}\int_0^{2\pi} \sin^2\theta\, d\theta = \frac{I_m^2}{2\pi}\int_0^{2\pi} \left[\frac{1-\cos 2\theta}{2}\right] d\theta$$

$$= \frac{I_m^2}{4\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{2\pi} = \frac{I_m^2}{4\pi}\left[(2\pi - 0) - \frac{1}{2}(\sin 2\pi - \sin 2x0)\right]$$

$$= \frac{I_m^2}{4\pi}\left[(2\pi) - \frac{1}{2}(0 - 0)\right] \quad = \frac{I_m^2}{4\pi}(2\pi)$$

Average square value= $\frac{I_m^2}{2}$

Root mean square value

$$I_{rms} = \sqrt{\text{mean or average square value}} = \sqrt{\frac{I_m^2}{2}}$$

$$\mathbf{I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 I_m}$$

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Form Factor (K_f): The Form factor of an alternating quantity is defined as the ratio of Rms value to the average value.

$$K_f = \frac{RMS\ value}{Average\ value}$$

The form factor of alternating current can be obtained as

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

Crest or Peak Factor (Kp): The peak factor of an alternating quantity is defined as the ratio of maximum value to the RMS value.

$$K_p = \frac{Maximum\ value}{RMS\ value}$$

The peak factor of alternating current can be obtained as

$$K_p = \frac{Im}{0.707Im} = 1.414$$

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MODULE 3A

Syllabus: **DC Machines:** (a) Principle of operation, constructional details, induced emf expression, types of generators, and the relation between induced emf and terminal voltage. (b) Principle of operation, back emf and torque equations, types of motors, characteristics (shunt and series only), and applications.

Single Phase Transformer: Necessity of transformer, the principle of operation, Types, and construction of single-phase transformers, emf equation, losses, variation of losses with respect to load, efficiency, and condition for maximum efficiency.

Introduction:

- An electrical machine, deals with energy transfer either from mechanical to electrical or electrical to mechanical is called **DC Machine.**
- The DC machines are classified into
- **i) DC Generator**
- **ii) DC Motor**
- **DC Generator:** The machine which converts mechanical energy into Electrical energy
- **DC motor:** The machine which converts Electrical energy into Mechanical energy

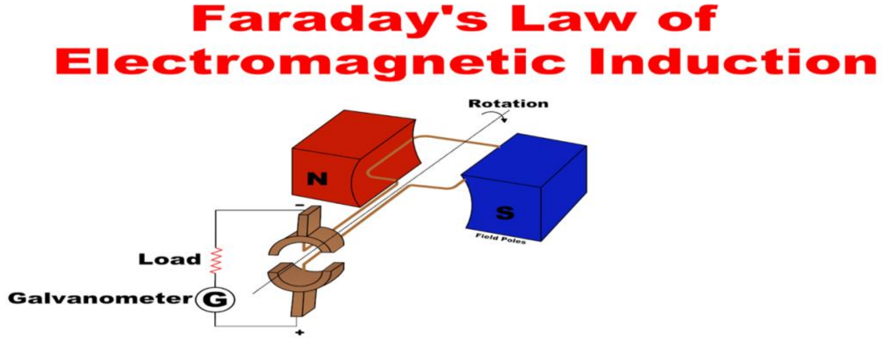
Working principle of D.C.Machine as a generator

Working principle of D.C.Machine as a generator:

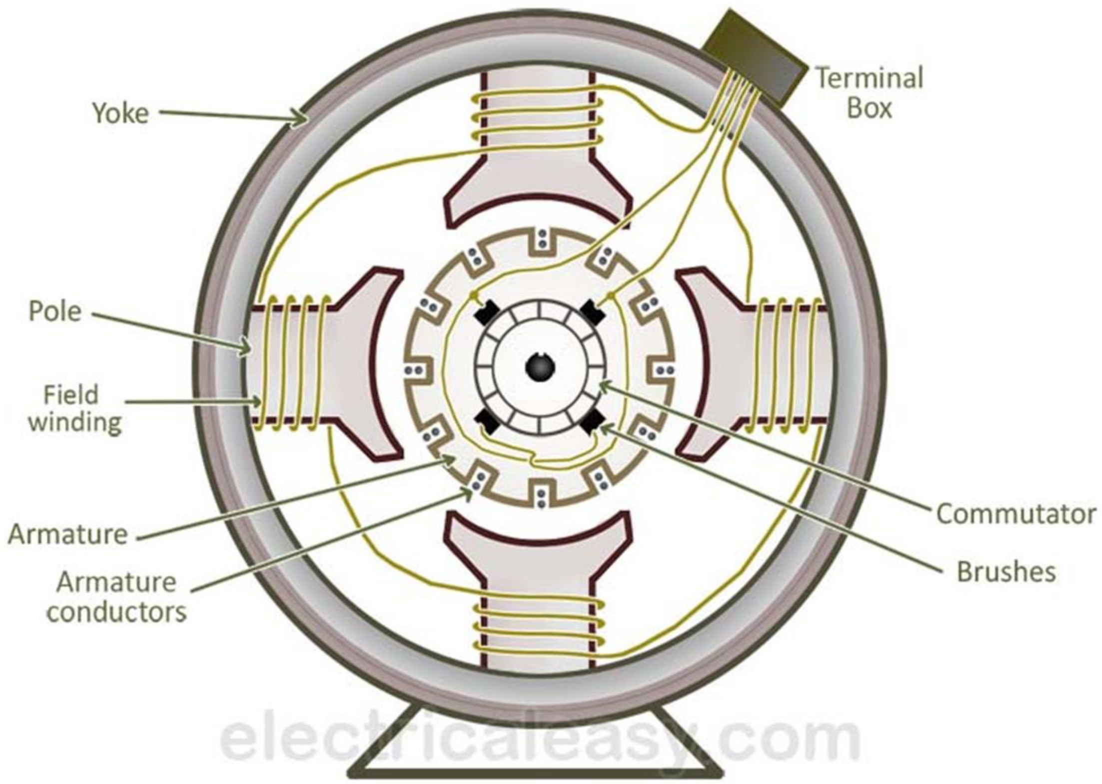
- It is based on the principle of **dynamically induced e.m.f .**
- Whenever a conductor cuts magnetic flux, dynamically induced e.m.f. is produced in the conductor according to the Faradays laws of Electromagnetic Induction. This e.m.f. causes a current to flow in the circuit, if the conductor circuit is closed.
- The emf is given by

  $$e = B * l * v * \sin\theta \text{ volts/coil side where,}$$

  Where B=the flux density in Tesla,
  l=the active length of the coil side in meters
  v=the velocity with which the coil is moved in meters/sec and
  θ is the angle between the direction of the flux and relative velocity.
- The direction of the induced voltage can be obtained by applying **Fleming's right hand rule.**



Construction of DC Machine



Salient parts of a D.C.Machine are:

(i)Yoke
ii) Field system (poles)
(iii) Armature
(iv) Commutator
(v)Brushes

Yoke:

It is made of **cast iron or silicon steel**

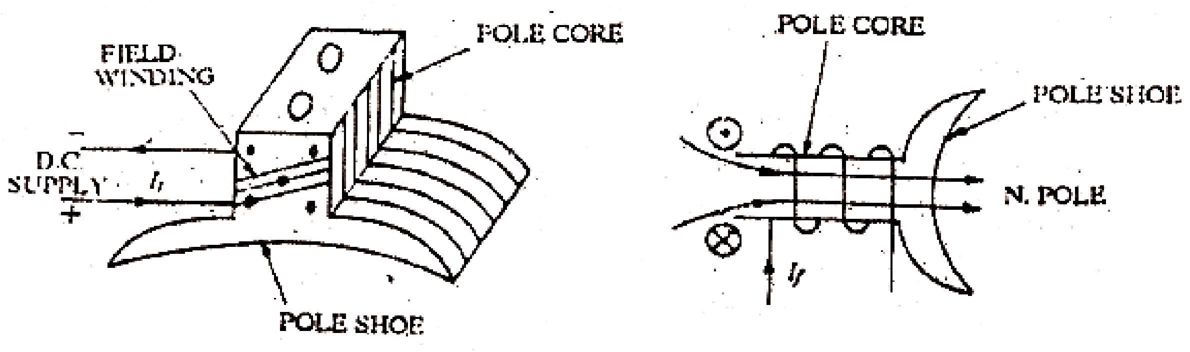
- It serves the purpose of **outermost cover** of the D.C. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO2, acidic fumes etc.
- It provides mechanical support to the poles, It forms a part of the magnetic circuit and it provides a path of low reluctance for magnetic flux.

Poles:

It is made cast iron or cast steel laminations which are stamped together.

Each pole is divided into two parts a) **pole core** and b) **pole shoe**

- Pole core basically carries a field winding which is necessary to produce the flux.
- It directs the flux produced through air gap to armature core and to the next pole.
- Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf. To achieve this, pole shoe has given a particular shape



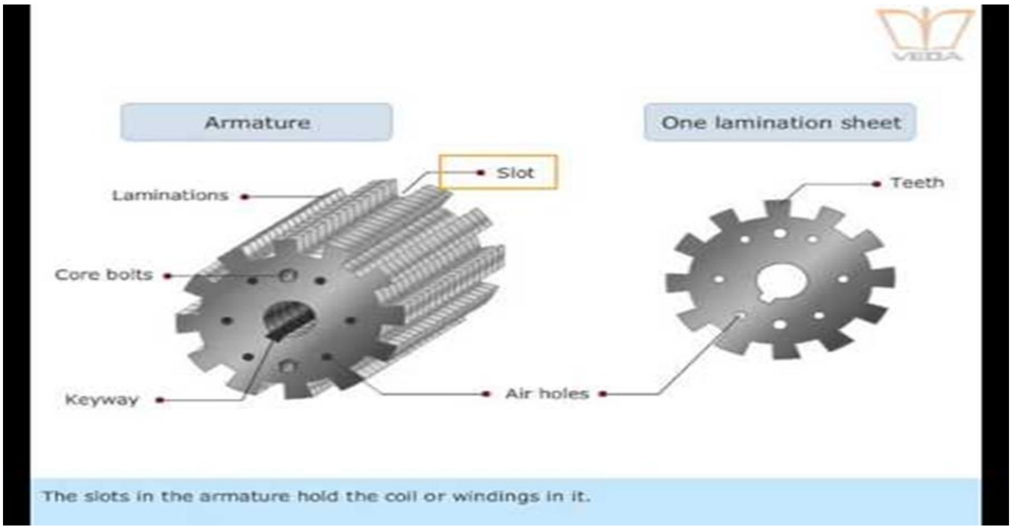
Field winding [F1-F2]:

It is made of conducting material like copper or Aluminum. The field winding is wound on the pole core with a definite direction.

- It carries current due to which the pole core behaves as an electromagnet and produces necessary flux. As it's exciting the pole as electromagnet hence it is also called Exciting winding.

Armature:

- It is further divided into two parts namely,
  - Armature core and
  - Armature winding
- Armature core is cylindrical in shape made up of iron and mounted on the shaft. It is provided with of slots on its outer periphery to place the conductor and the air ducts to permit the air flow through armature which serves cooling purpose.
- In order to collect the Emf generated in each conductor they are connected in certain pattern called armature winding.



Commutator:

- The basic nature of Emf induced in the armature conductors is alternating. This needs rectifications in case of D.C. generator which is possible by device called commutator.
- It is cylindrical in shape made of hard drawn copper segments. These segments are insulated from each other by a layer of mica.

Brushes and brush gear:

- Brushes collect current from commutator and make it available to the stationary external circuit.
- Ball bearings are usually used as they are more reliable.
- For heavy duty machines, roller bearings are preferred.

Types of D.C. Armature Windings

Lap Winding	Wave Winding
In this winding all the pole groups of the coils generating emf in the same direction at any instant of time are connected in parallel by the brushes.	In this winding all the coils carrying current in the same direction are connected in series and coils carrying current in opposite direction are connected in other series circuit.
2. Lap winding is also known as parallel windings.	2. Wave winding is also known as series winding.
3. The number of parallel path is equal to the number of poles i.e., A = P.	3. The number of parallel paths is always equal to 2 i.e., A = 2.
4. The number of brush required by this winding is always equal to the number of poles.	4. The number of brushes required by this winding is always equal to 2.
5. Lap windings are used for low voltage and high current machines.	6. Wave windings are used for high voltage and low current machines.

Emf Equation of DC Generator:

Let,

Φ = Flux produced by each pole in weber (Wb) and

P = number of poles in the DC generator.

N = speed of the armature conductor in rpm.

Consider a one revolution of the conductor

Total flux produced by all the poles $= \emptyset \times \mathbf{P}$

Time taken to complete one revolution $= \frac{\mathbf{60}}{\mathbf{N}}$

Now, according to Faraday's law of induction, the induced EMF of the conductor is equal to rate of change of flux.

$$e = \frac{d\phi}{dt} \quad and \; e = \frac{total\ flux}{time\ take}$$

Therefore,

Induced EMF of one conductor is

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

Let us suppose there are **Z** total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series.
Here, Z = total numbers of conductor A = number of parallel paths
Then, **Z/A = number of conductors connected in series**

Therefore,
Induced EMF of DC generator
E_g = EMF of one conductor × number of conductor connected in series.

Induced Emf of DC generator is

$$e = \phi P \frac{N}{60} X \frac{Z}{A}\ volts$$

$$\mathbf{e} = \frac{\emptyset PNZ}{60A}$$

Types of DC Generators

- Thw field winding is also called as exciting winding. Supplying current to the field winding is excitation.
- Depending upon the method of excitation used in the generators are classified into
  - i) Separately excited DC generator
  - ii) Self-excited DC generator.

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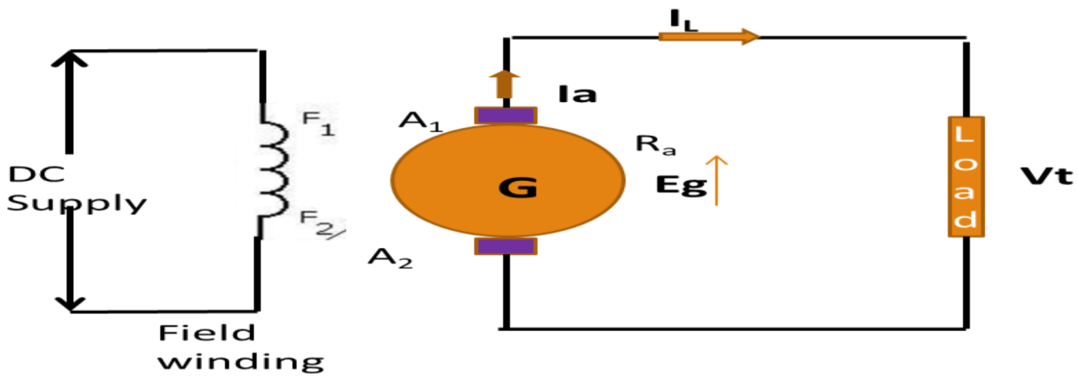
Separately Excited Generators:

In separately excited dc machines, the field winding is supplied from a **separate power source** as shown in below fig.



Eg- generated Emf in generator
Ia – Armature current
R_a - armature resistance
I_L - Load current
Vt- Terminal voltage
F1 and F2 – Terminals of field winding

Self-Excited Field Generators:

- The self-excited DC generator produces a magnetic field by itself without DC sources from an external. The electromotive force that produced by generator at armature winding is supply to a field winding instead of DC source from outside of the generator. Therefore, field winding is necessary connected to the armature winding.
- When generator started, due to residual flux, it develops a small amount of EMF which drives a small current in the field winding. This tends to increase the flux in the poles in turn increases the EMF.This cumulative process continues until generator produces a rated voltage.

They further classified into:

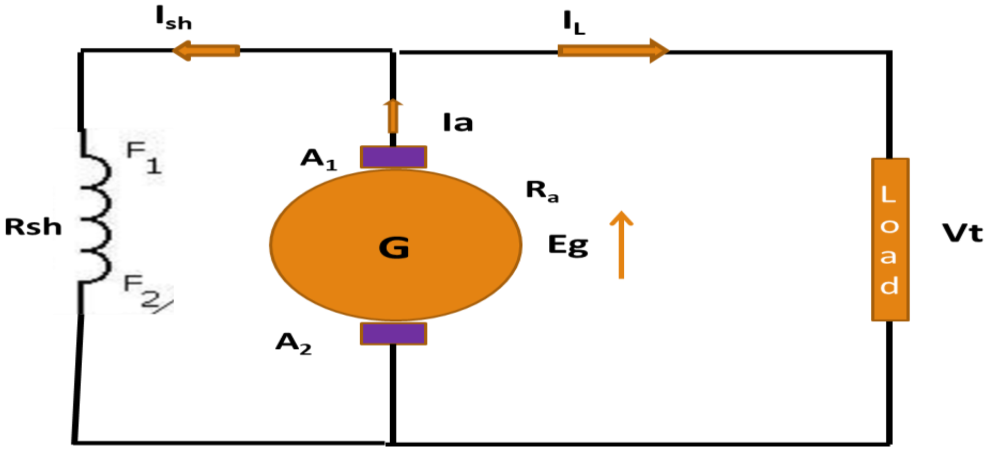
a) DC Shunt generator

b) DC Series generator

c) DC Compound generator.

a) **Shunt generator:**

- In shunt generator, the field winding is connected in **parallel** with the armature winding and combination across the load. As shown in the fig.



Ish- current through shunt field winding Rsh- Resistance of shunt field winding

From the fig

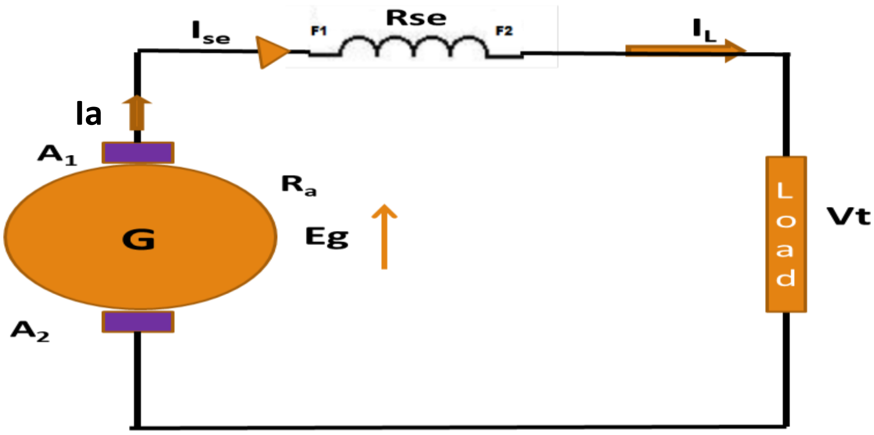
Armature current $I_a = I_L + I_{sh}$ and $I_{sh} = \frac{Vt}{Rsh}$

Induced EMF $E_g = V_t + I_aR_a + V_{brush}$

Terminal voltage $V_t = E_g - I_aR_a - V_{brush}$

b) **Series generator:**

- In series generator, the field winding is connected in **series** with the armature winding and to the load. As shown in the fig.



Ise- current through series field winding Rse- Resistance of series field winding

From the fig

Armature current $I_a = I_{se} = I_L$

Induced EMF $E_g = V_t + I_aR_a + I_{se}R_{se} + V_{brush}$

$$E_g = V_t + Ia(Ra + R_{se}) + V_{brush} \qquad [I_a = I_{se}]$$

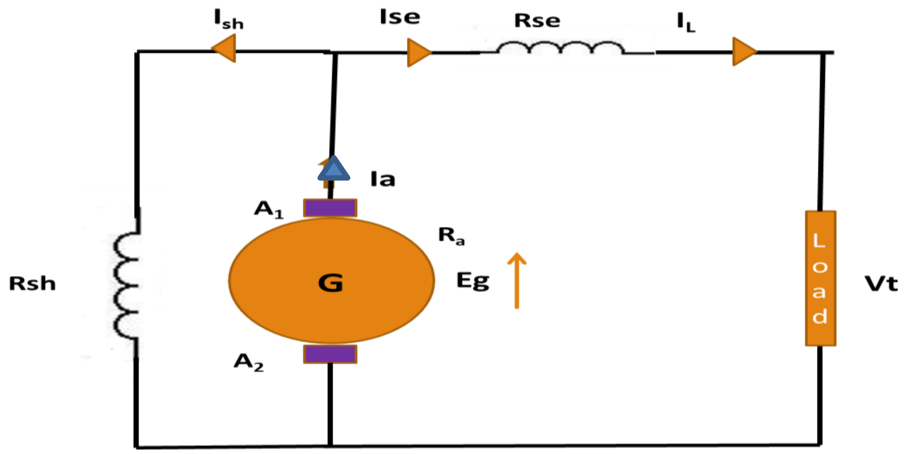
Terminal voltage $$V_t = E_g - Ia(Ra + R_{se}) - V_{brush}$$

Compound Generator:

- The compound generator has provided with magnetic field in combine with excitation of shunt and series field winding. The part of field winding is connected in parallel with armature called shunt field winding and part in series with armature winding called series field winding.
- There are two types of Compound generators such as
  (i) Long shunt Compound Generator
  (ii) Short Shunt Compound Generator

Short Shunt Compound Generator:

The shunt field winding is connected in parallel only with the armature. As shown in the fig.



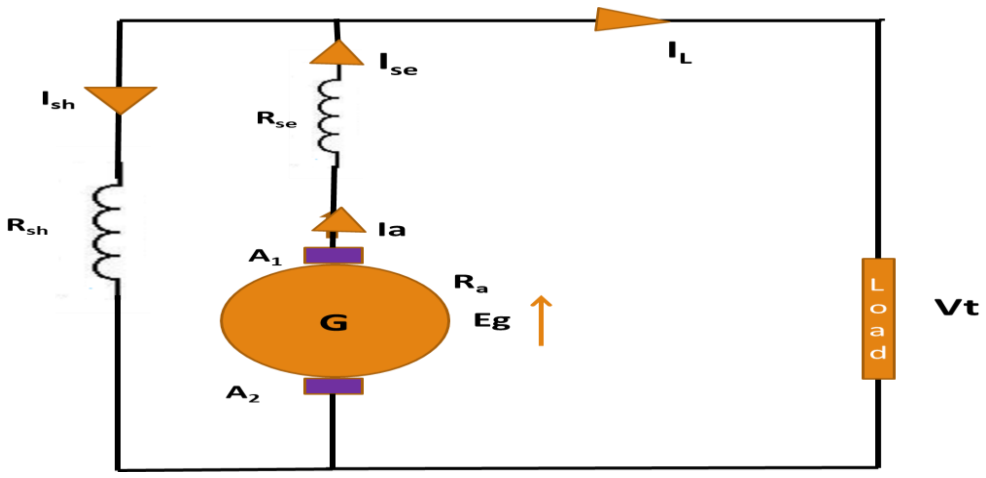
From the fig

Armature current $$I_a = I_{se} + I_{sh} \quad \text{and} \quad I_{se} = I_L$$

Induced EMF $$E_g = V_t + I_aR_a + I_{se}R_{se} + V_{brush}$$

Terminal voltage $$V_t = E_g - IaRa - I_{se} R_{se} - V_{brush}$$

Long Shunt Compound generator: The shunt field winding is connected in parallel with the series combination of armature and series field winding.



From the fig

Armature current $I_a = I_L + I_{sh}$, $I_a = I_{se}$ and $I_{sh} = \frac{Vt}{Rsh}$

Induced EMF $E_g = V_t + I_aR_a + I_{se}R_{se} + V_{brush}$

$E_g = V_t + Ia(Ra + R_{se}) + V_{brush}$ $[I_a = I_{se}]$

Terminal voltage $V_t = E_g - Ia(Ra + R_{se}) - V_{brush}$

DC Motors

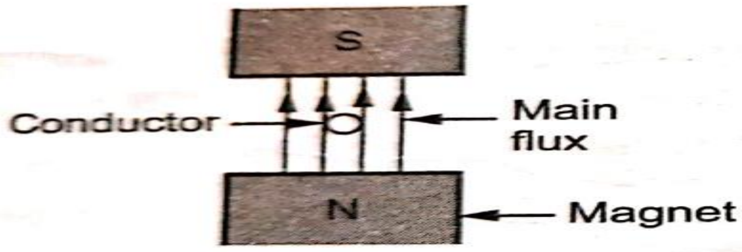
Operation of a DC motor:

- When a DC machine is loaded as a motor, the armature conductors carry current. These conductors lie in the magnetic field of the air gap. Thus, each conductor experiences a force. The conductors lie near the surface of the rotor at a common radius from its centre. Hence, a torque is produced around the circumference of the rotor, and the rotor starts rotating.

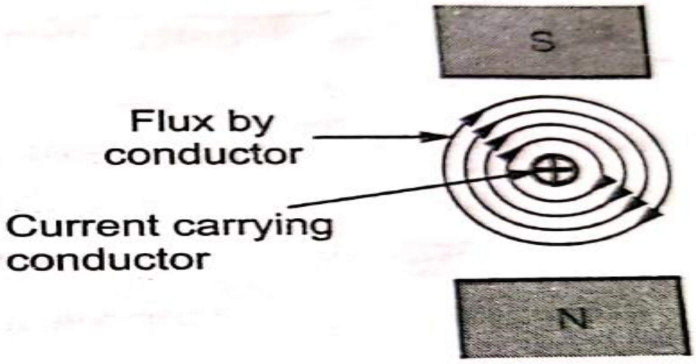
Working Principle of a DC motor

The principle of operation of the D C motor is" when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force".

Consider a single conductor place in a magnetic field as shown in the fig and the main flux produced by the poles.



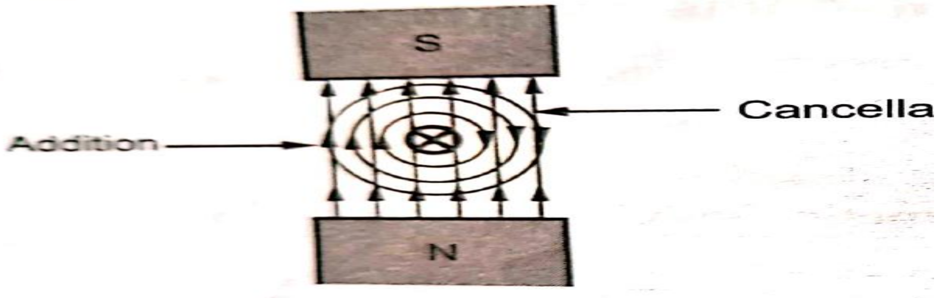
(a) Conductor in a magnetic field



When conductor excited by a separate supply it carries a current in a particular direction. Consider the conductor carries the current away from an observer as shown in the fig.

Any current carrying conductor produces its own magnetic field around it hence, this conductor also produces its own flux around it. The direction of this flux can be determined by right hand thumb rule. It is observed that the direction of flux is in clockwise direction.

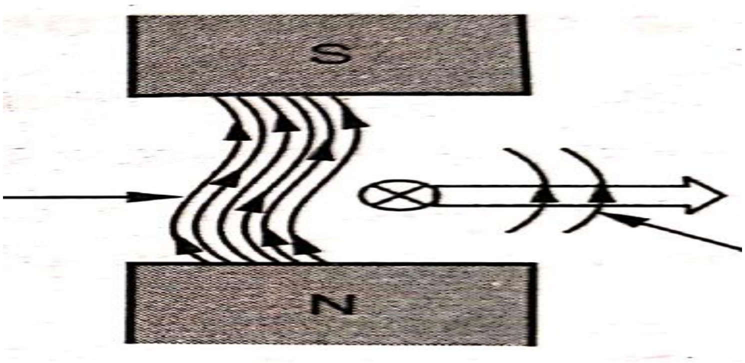
Now there are two fluxes present,
1. The flux produced by the poles called main flux.
2. The flux produced by the current carrying conductor.
These are shown in the fig



From this, it is clear that on one side (left side) of the conductor, both fluxes are in the same direction, there is gathering of the flux lines as two fluxes help each other.

As against this, on the right of the conductor, the two fluxes are in the opposite direction and hence try to cancel each other. Due to this, density of the flux line in this area gets weakened.

So on the left, there exists high flux density area while on the right of the conductor there exists low flux density as shown in the fig.



This flux distribution around the conductor acts like a stretched rubber band under tension. This exerts a mechanical force on the conductor which acts from high flux density area towards low flux density area, i.e. From left to right for the case considered as shown in the fig,

Due to this, overall armature experience a twisting force called torque and armature of the motor starts rotating.
The magnitude of the force experienced by the conductor in a motor is given by,

F=B l I Newtons(N)

B=Flux density due to the flux produced by the field winding.

l=Active length of the conductor.

I=Magnitude of the current passing through the conductor.

The direction of such force i.e. the direction of rotation of motor can be determined by **Fleming's right hand rule**.

Back Emf and its Significance:

- When the Armature of D C motor starts rotating and armature conductor cuts the magnetic flux, hence an EMF is induced in the Conductor called **Back EMF**.
- The induced emf acts in opposite direction to the applied voltage 'V'(Lenz's law) , hence it is called as back EMF. It is given by

$$E_b = \frac{\emptyset PNZ}{60\,A}$$

The Voltage equation of DC motor is **V = Eb + IaRa**

Therefore armature current $$I_a = \frac{V - E_b}{R_a}$$

Significance:

- The basic Principle of the Back EMF is that $E_b \alpha N$
- When the load suddenly put on the motor, motor tries to slow down. So speed of the motor reduces due to which the back EMF decreases. So the net Voltage $(V - E_b)$ increases and motor draws **more armature current**.
- When the load on the motor decreases, the speed of the motor increases due to which the back EMF increases. So the net Voltage $(V - E_b)$ decreases and motor draws **less armature current**
- Therefore due to the presence of back emf. The d.c. motor acts as a self-regulating machine. It regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement

Voltage equation of a Dc motor:

$$V = E_b + I_a R_a \quad \ldots\ldots..(1)$$

Multiplying the equation (1) by I_a we get

$$VI_a = E_b I_a + I_a^2 R_a \quad \ldots\ldots..(2)$$

Where,

$\mathbf{VI_a}$ is the electrical power input to the armature.

$\mathbf{I^2_a R_a}$ is the copper loss in the armature.

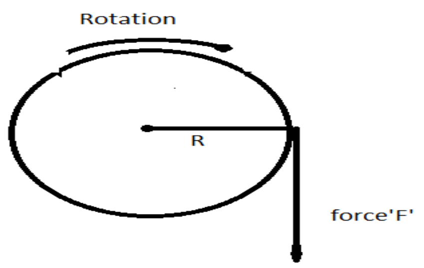
$\mathbf{E_b I_a}$ is the Mechanical power developed by the armature

The mechanical power developed by the armature is Pm.

$$\mathbf{P_m = E_b I_a}$$

Torque equation of a DC Motor:

The turning and twisting force about an axis is called **torque.**
Consider a wheel of radius 'R' meters acted upon the circumferential force 'F' netwons as shown in fig



The wheel is rotating with speed of 'N' rpm then its angular speed is,

$$\omega = \frac{2\pi N}{60} \text{ rad/sec} \qquad \text{--------1}$$

so work done in one revolution is

W= force X distance travelled in one revolution = **F X 2πR joules**

$$\textbf{Power} \quad P = \frac{workdone}{time\ for\ 1\ revolution} = \frac{F*2\pi R}{\frac{60}{N}} = F*R*\frac{2\pi N}{60}$$

$$P = T*\omega$$

Where T =Torque in Nm and ω= angular speed in rad/sec

Let 'T_a'is torque developed in the armature of the motor. It is also called as **armature torque**.

The gross mechanical power developed in the armature is 'E_bI_a'

Power in armature = armature torque *ω

$$E_bI_a = T_a*\frac{2\pi N}{60}$$

But,

$$E_b = \frac{\emptyset PNZ}{60\ A}$$

Therefore

$$\frac{\emptyset PNZ}{60\ A} * I_a = T_a * \frac{2\pi N}{60}$$

So, the torque equation is given as

$$T_a = \frac{1}{2\pi} X \frac{\varphi I_a PZ}{A}$$

Types of DC Motors:

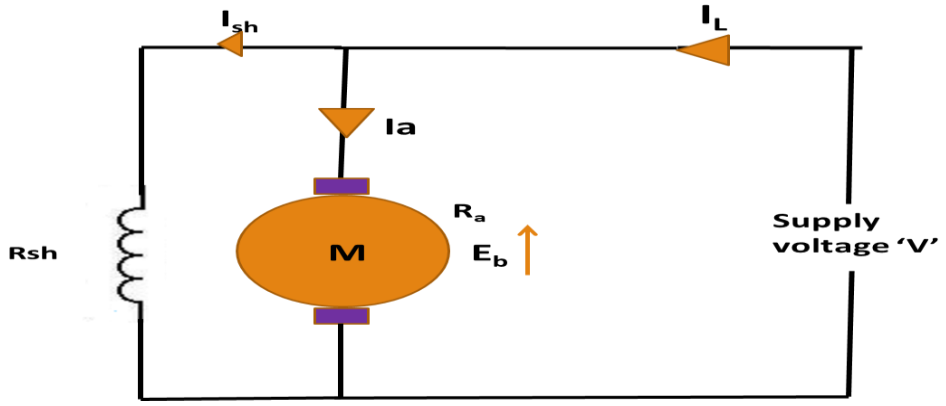
Motors are classified into 3 types: a) DC Shunt motor.

b) DC Series motor.

c) DC Compound motor.

a) DC Shunt motor:

- In shunt motor the field winding is connected in parallel with armature.
- The current through the shunt field winding is not the same as the armature current.



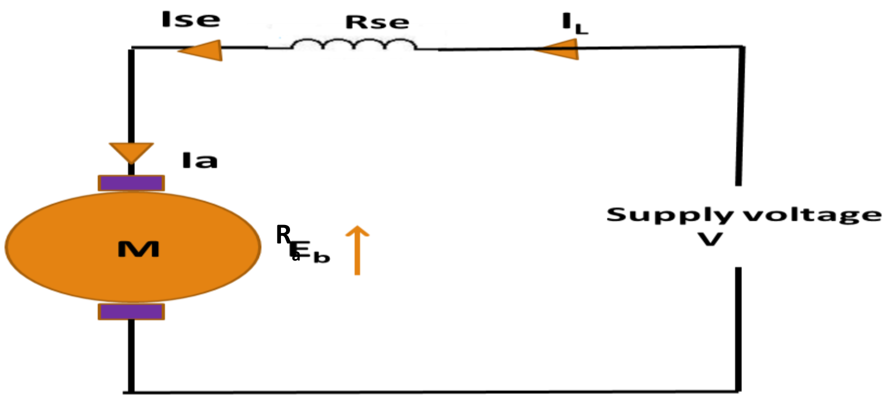
In above circuit

$$I_L = I_a + I_{sh} \quad \text{and} \quad I_{sh} = \frac{V}{Rsh}$$

$$V = E_b + I_a R_a + V_{brush}$$

b) DC Series motor:

- In series wound motor the field winding is connected in series with the armature.
- Therefore, series field winding carries the armature current.



In above circuit

$$I_L = I_a = I_{se}$$

$$V = E_b + I_a R_a + I_{se} R_{se} + V_{brush}$$

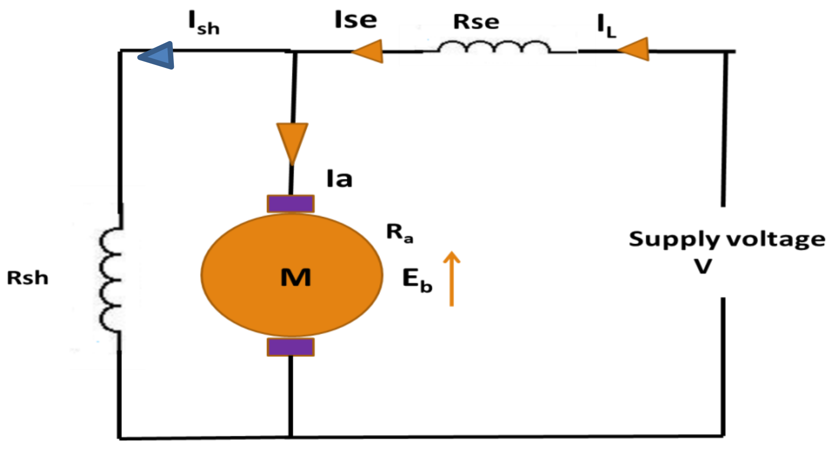
$$V = E_b + Ia(Ra + R_{se}) + V_{brush}$$

c) DC Compound motor:

- Compound wound motor has two field windings; one connected in parallel with the armature and the other in series with it.
- There are two types of compound motor connections :

1) Short-shunt connection Compound Motor

When the shunt field winding is connected in parallel with the armature winding it is called short-shunt connection.



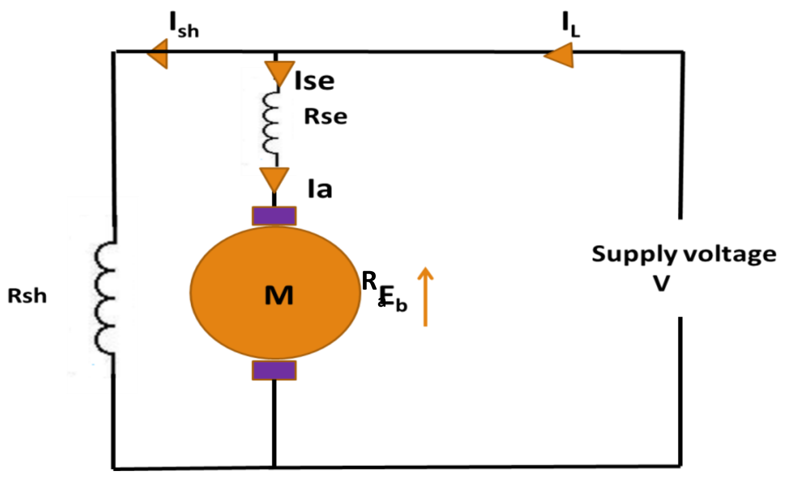
In above circuit

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

$$V = E_b + I_aR_a + I_{se}R_{se} + V_{brush}$$

Long shunt connection Compound Motor

When the shunt winding is so connected that in parallel with the series combination of armature and series field it is called long-shunt connection



In above circuit

$$I_L = I_{se} + I_{sh} \quad \text{and } I_{se} = I_a$$

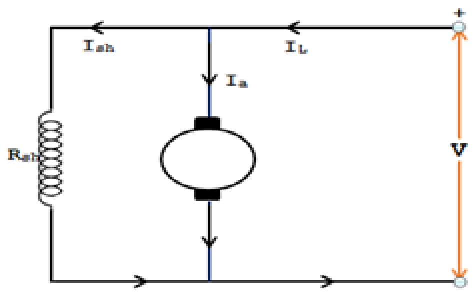
$$V = E_b + I_aR_a + IseR_{se} + V_{brush}$$

$$V = E_b + Ia(Ra + R_{se}) + V_{brush}$$

Characteristics of DC Motors:

The three important characteristic curves are

1. Torque V_s Armature current characteristic (T_a/I_a)
2. Speed V_s Armature current characteristic (N/I_a)
3. Speed V_s Torque characteristic (N/T_a)
DC Shunt Motor Characteristics:



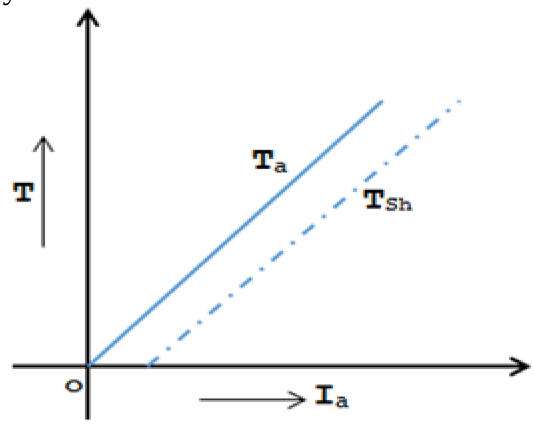
In DC shunt motor the field winding is connected in parallel with the source voltage, so the field current **Ish** and the **flux** are constant in a shunt motor .

Torque V_s Armature current characteristic (T_a/I_a):

We know that in a DC Motor **Ta α Φ Ia** by torque equation

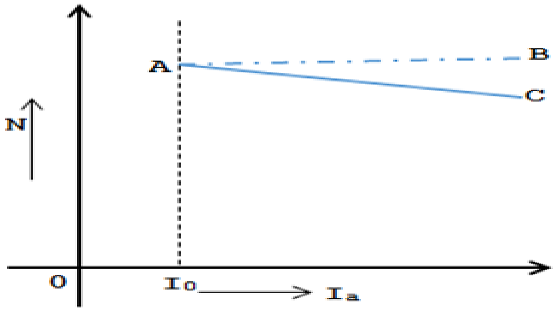
The flux Φ is constant in shunt motor, therefore **Ta α Ia**

The torque increases linearly with the armature current

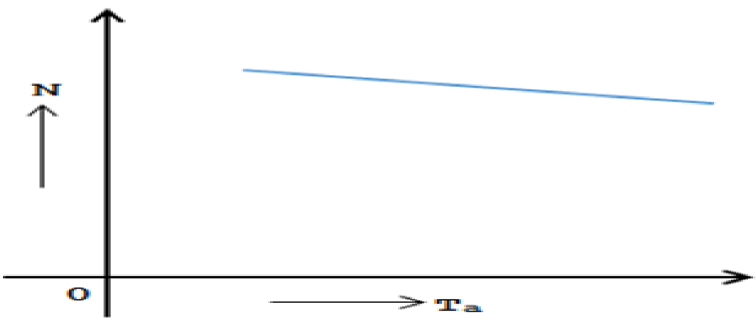


Speed V_s Armature current characteristic (N/I_a):

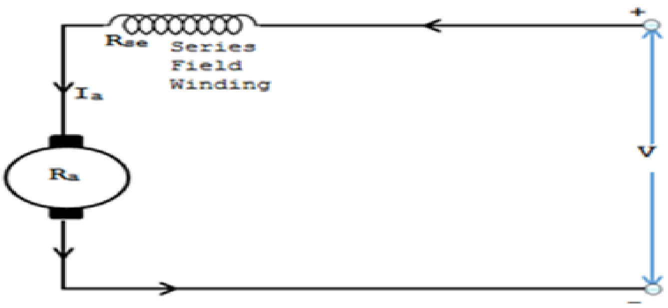
- **$N \alpha E_b$** **and Eb=V-IaRa**. As the flux is constant.
- When load increases , the armature current increases hence the drop I_aR_a increases therefore **V-IaRa** decreases hence speed decreases.



Speed V_s Torque characteristic (N/T_a): The speed reduces when the load torque increases.



DC Series Motor:

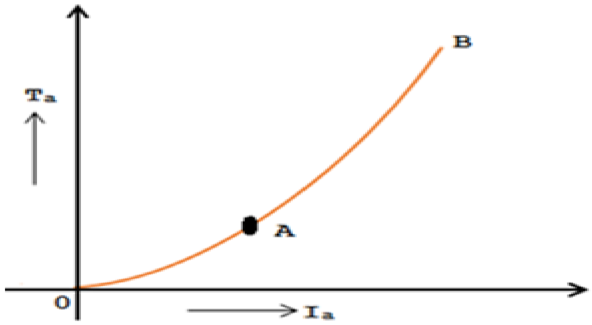


In DC series motor the field winding is connected in series with the source voltage, so the field current **Ise** and the **flux** are not constant.

Torque V_s Armature current characteristic (T_a/I_a):

We know that $T_a \propto \Phi I_a$

$$T_a \propto I_a^2$$



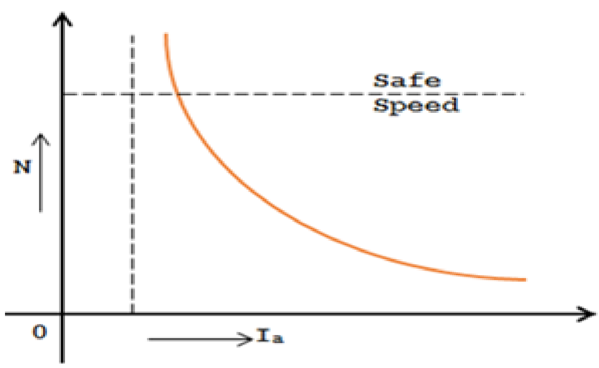
- The armature torque vs. armature current curve up to magnetic saturation is a parabola, which is shown in the characteristic curve OA.
- On the other hand once the magnetic saturation is reached, the Ta is directly proportional to the Ia.
- As a result the armature torque vs. armature current magnetic saturation characteristic is a straight line, which is shown in the curve AB.

Speed V_s Armature current characteristic (N/I_a):

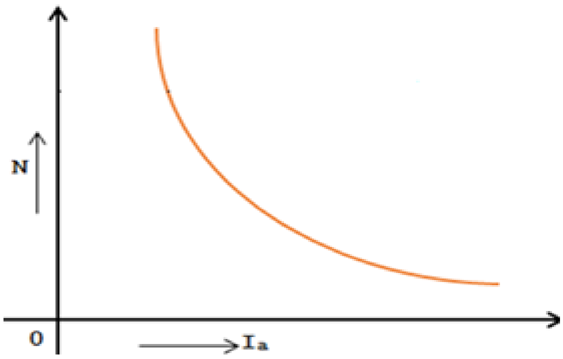
In Series Motor Speed -- $N \alpha (E_b/\Phi)$

$$N \alpha 1/ I_a \phi$$

$$N \alpha 1/ I_a^2$$



Speed V_s Torque characteristic (N/T_a): The speed reduces when the load torque increases.



Necessity of a Starter:

The starter is not required to start a DC. Motor but it enables us to start the motor in desired, safe way.

At the starting instant the speed of the motor is zero, (N = 0) and back emf $E_b = 0$

The voltage equation of a de motor is, $\mathbf{V = E_b + I_a R_a}$

At start $V = I_a R_a$ Therefore $\mathbf{I_a = V / R_a}$

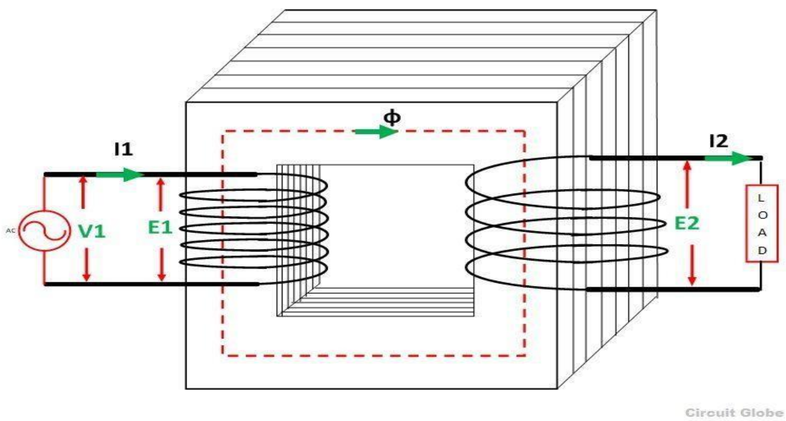
So at start, motor is showing a tendency to draw an armature current which may affect the performance of the motor and may burn out the winding

Module 3 (b): Single Phase Transformers

Introduction

- Transformer is a static device which transfer an electric power from one electrical circuit to another electrical circuit, with or without change of the voltage and without change of the frequency.

WORKING PRINCIPLE: - A transformer works on the principle of mutual induction betweentwo magnetically coupled coils.



Let N1-----> be the number of turns in coil 1 and
N_2 ------> be the number of turns in coil 2

When the supply Voltage 'V_1' is applied to the coil 1 the current 'I_1' starts flowing in the winding, which sets an alternating flux 'φ'. Hence an emf 'E_1' induced in the coil 1 due the Electromagnetic Induction .

I,e $E_1 = -N_1 \frac{d\emptyset}{dt}$ (self Induced Emf)

The part of flux 'φ' links the coil 2,which induces an Emf 'E_2' in coil 2 due to Mutual Induction. Hence current 'I_2' starts flowing coil 2.

i.e $E_2 = -N_2 \frac{d\emptyset}{dt}$ (mutually Induced Emf) .

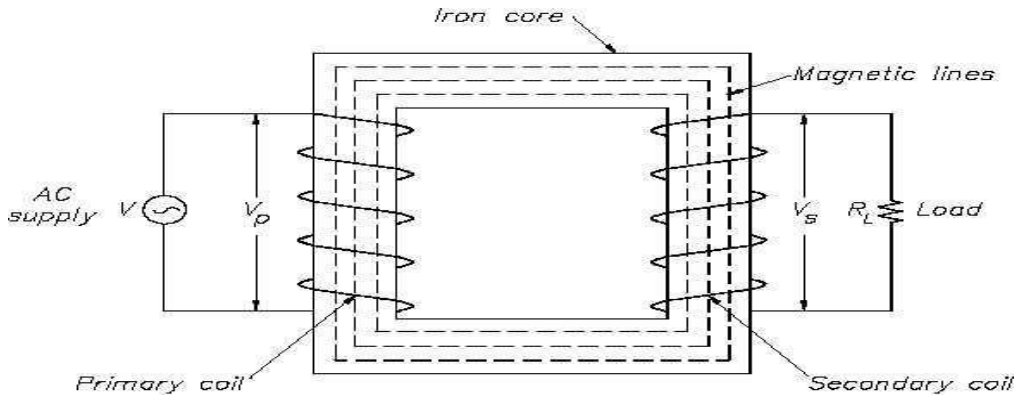
Therefore we will get output voltage 'V_2' across the coil 2.

CONSTRUCTION:

There are two basic parts of a transformer:

1) Magnetic core 2) winding

- The core of the transformer is either rectangular or square in size.
- The core is divided into i) Yoke ii)Limb
- Core is the Rectangular in shape which is made of thin sheets of silicon steel, which are laminated in order to reduce eddy current losses.
- The laminated sheets are overlapped so that to avoid air gap and they stamped together to form a core.
- The steel laminations are insulated from each other by using insulations like varnish
- The core provides low reluctance path for the flux provided by the winding
- The vertical portion on which the winding is wound is called Limb.
- The top and bottom horizontal portion is called Yoke.
- The core forms the magnetic circuit
- There are 2 windings i) Primary winding ii) Secondary winding which formsthe Electric circuit, made up of conducting material like copper.
- The winding which is connected to the supply is called primary winding andhaving 'N_1' number of turns.
- The winding which is connected to a load is secondary winding and having'N_2' number of turns.



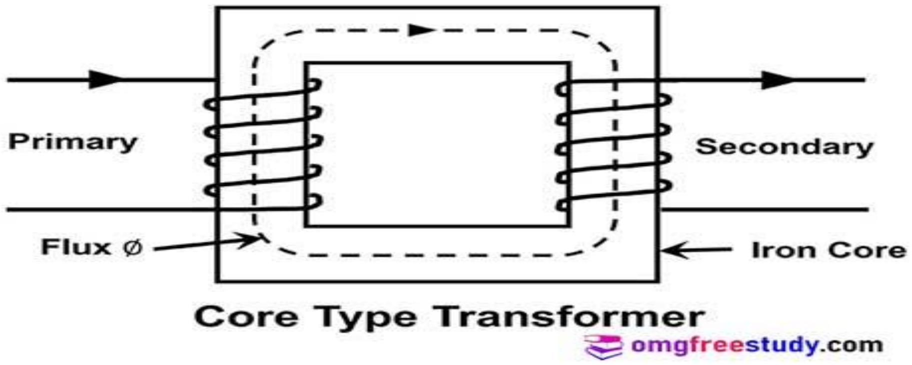
TYPES OF TRANSFORMER:

I) Based on Construction the transformer is divided into:

a) CORE TYPE b) SHELL TYPE.

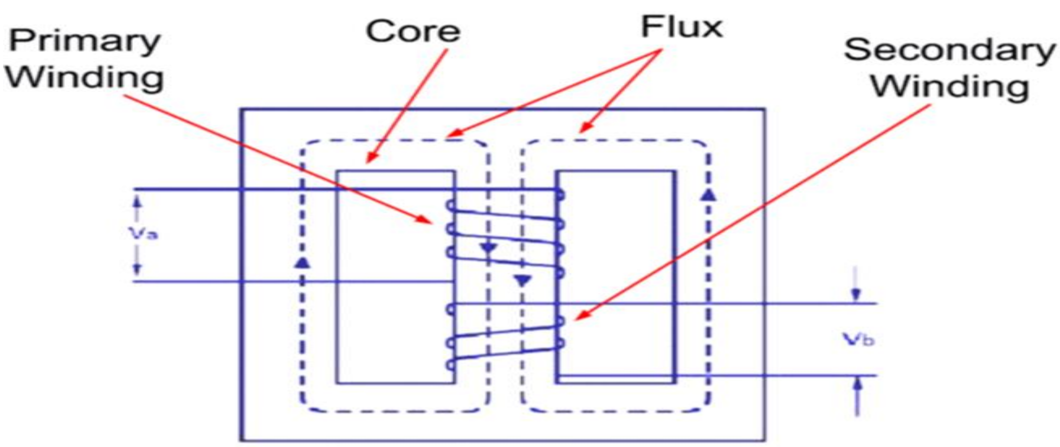
Core type transformer:

- It is rectangular in shape.
- It consists of 2 limbs on which the windings are wound.
- Since the windings are placed on the outer limbs of the core they can be easily removed for maintenance.
- The windings encircle the core.
- It has single magnetic circuit.
- It used for used for low voltage application.



Shell type transformer:

- It is rectangular in shape.
- It consists of 3 limbs and both the windings are wound on a central limb of the core.
- Since the windings are placed on the central limb of the core they cannot be easily removed for maintenance.
- The core encircles the winding.
- It has double magnetic circuit.
- It used for used for high voltage application



II) Based on of turns in primary and secondary winding the transformer is divided into:
a) STEP UP TRANSFORMER b) STEP DOWN TRANSFORMER c) ONE-ONE TRANSFORMER

Step up transformer

When N2 > N1 then (V2 > V1) the voltage is raised on the output side and is known as Step up transformer

Step down transformer

When N2 < N1 then (V2 < V1) the voltage level is lowered on the output side and is known as Step down transformer

(iii) 0ne-one transformer

When N2 = N1 then V2 =V1 the voltage is same on both side

Losses in a Transformer

The transformer has two types of losses

- Core or Iron losses [constant losses]
- Copper losses [cu losses]

Iron Losses (P_i)

Iron losses are caused by the alternating flux in the core of the transformer as this loss occurs in the core it is also known as Core loss. Iron loss is further divided into hysteresis and eddy current loss.
Once the core is manufactured the losses occurs in the core are constant. Hence the name constant losses

1. Hysteresis Loss

Due to the alternating flux setup in the core of the transformer, it undergoes a cycle of magnetization and demagnetization. Due to hysteresis effect there is a loss of energy in this process which is called hysteresis loss
The hysteresis loss can be minimized by using silicon steel material for the construction of core

2. Eddy Current Loss

The EMF induced in the winding sets up an eddy current in the core, the losses due to the eddy current is called eddy current losses.
The eddy current loss is minimized by making the core with thin laminations.

Copper losses (Pcu)

The copper losses are the power wasted in the form of I^2R loss due to the resistance of primary and secondary winding.
The copper loss depends on the magnitude of current flowing though the windings
When the load is connected across the transformer the current I_1 and I_2 starts flowing in the primary and secondary winding.
The losses can be minimized by designing the winding with low resistance conducting material
Thus total losses in the transformer = iron losses + copper losses
= Pi +Pcu

EMF equation of a single phase transformer

Let

N_1 - be the no. of turns of the primary winding

N_2 – be the no. of turns secondary winding

f – Frequency in Hz

Φ – flux in weber

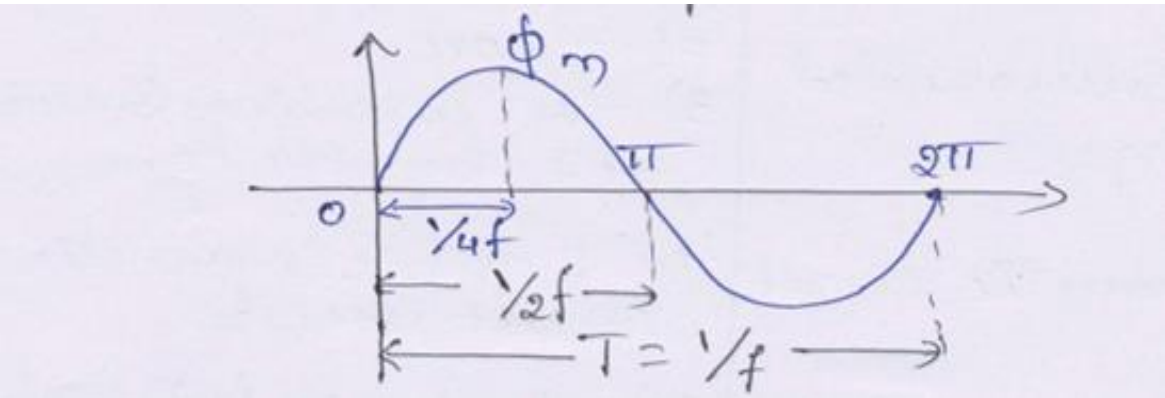
E_1- be the RMS value of emf induced in the primary

E_2 – be the RMS value of emf induced in the secondary

When the supply Voltage is applied to the primary winding which sets an alternating flux 'φ'. Hence an EMF 'E1' and 'E2' are induced in the primary and secondary winding respectively

$$e= \frac{d\emptyset}{dt} \quad \text{-------------- (i)}$$

Consider a one cycle of EMF



Let us consider 1/4th cycle of EMF

The change in flux in 1/4th cycle is

$$d\phi = \Phi_m - 0 = \Phi_m$$

The time taken to complete 1/4th of cycle is

$$dt = 1/4f$$

Substituting dϕ and dt in equation I we get

$$E_{avg} = \frac{d\emptyset}{dt} = \frac{\Phi m}{1/4f} = 4\ f\ \Phi m$$

we know that $E_{rms} = 1.11 \times E_{avg}$

Therefore $E_{rms} = 1.11 \times 4\ f\ \Phi m$

$E_{rms} = 4.44\ f\ \Phi m$ **induced per turn**

If N_1 be the number of turns in primary then $E_1 = 4.44\ f\ \Phi m\ N_1$ volts

If N_2 be the number of turns in secondary then $E_2 = 4.44\ f\ \Phi m\ N_2$ volts

Transformer ratio

Voltage Ratio

W.k.t $E_1 = 4.44\ f\ \varphi m\ N_1$

$E_2 = 4.44\ f\ \varphi m\ N_2$

Taking a ratio $\frac{E_2}{E_1} = \frac{4.44\ f\ \varphi m\ N_2}{4.44\ f\ \varphi m N_1} = \frac{N_2}{N_1}$

The transformer rating is done in VA(volt ampere)

(power)VA rating of a transformer= $V_1I_1 = V_2I_2$

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

Therefore $\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K$ (transformer ratio)

Efficiency

It is the ratio of the output power to the input power of a transformer

$$\eta = \frac{Power\ output}{Power\ Input}$$

Power input = Power output + losses

= Power output + P_{cu} + P_i

= $V_2I_2 \cos\varphi + P_{cu} + P_i$ wkt $P_{cu} = I^2R_2$

$$therfore\ \ \eta = \frac{V_2I_2\ \cos\emptyset}{V_2I_2\ \cos\emptyset + I_2^2 R_2 + Pi} \times 100$$

Condition for Maximum efficiency

The efficiency of a transformer is given by

$$\eta = \frac{Power\ output}{Power\ Input}$$

Power input = Power output + losses

= Power output + P_{cu} + P_i

= $V_2I_2 \cos\varphi + P_{cu} + P_i$ wkt $P_{cu} = I^2R$

$$therfore\ \ \eta = \frac{V_2I_2\ \cos\emptyset}{V_2I_2\ \cos\emptyset + I_2^2 R_2 + Pi} \times 100$$

Diff w.r.t I_2 and equating to zero

$$\frac{d\eta}{dI_2} = \frac{[V_2I_2\ \cos\emptyset + I_2^2 R_2 + Pi]\,[V_2 \cos\emptyset] - V_2I_2\ \cos\emptyset\,[V_2 \cos\emptyset + 2I_2^2 R_2]}{[V_2I_2\ \cos\emptyset + I_2^2 R_2 + Pi]^2} = 0$$

$$[V_2I_2\ \cos\emptyset + I_2^2 R_2 + Pi]\,\cancel{[V_2 \cos\emptyset]} = \cancel{V_2 \cos\emptyset}[I2[V_2 \cos\emptyset + 2I_2^2 R_2]$$

$$[V_2I_2\ \cos\emptyset + I_2^2 R_2 + Pi] = [V_2I_2 \cos\emptyset + 2I_2^2 R_2]$$

$$\cancel{V_2I_2 \cos\emptyset} + I_2^2 R_2 + Pi - \cancel{V_2I_2 \cos\emptyset} - 2I_2^2 R_2 = 0$$

$$P_i - I_2^2 R_2 = 0$$

Therefore $P_i = I_2^2 R_2$

$$\mathbf{Pi = Pcu}$$

SUBJECT: BASIC ELECTRICAL ENGNEERING

MODULE-4a

THREE PHASE SYNCHRONOUS GENERATORS (ALTERNATORS)

Syllabus: *Principle of operation, types and constructional features, advantages of rotating field type alternator, synchronous speed, frequency of generated voltage, EMF equation. Concept of winding factor (excluding the derivation of distribution & pitch factors).*

Principle of operation: Whenever a coil is rotated in a magnetic field an EMF will be induced in the coil.This is called the dynamically induced EMF (Faraday's law of electromagnetic induction.)

- Alternators are also called as Synchronous Generators due to the reason that undernormal conditions the generator is to be rotated at a definite speed called "SYNCHRONOUS SPEED", **Ns** R.P.M. in order to have a fixed frequency in the output.
- Ns is related with the frequency as Ns = 120f / P, where f is the frequency and P isthe total number of poles.

Introduction:

The two basic parts in of an alternator are: (i) Stator, (ii) Rotor.

- Stator is the stationary part and Rotor is the revolving part.
- There are two possibilities that (i) The armature can be the stator and the field systemcan be the rotor, and (ii) The armature can be the rotor and the field system is the stator.
- In practice large alternators are of the first type where in the stator is the armature and the rotor is the field system. And this type is called the "REVOLVING FIELDTYPE".

Advantages of Stationary armature over rotating armature

(i) More conductors can be easily accommodated in stationary armature and with this high voltage can be generated.
(ii) It is easy to collect the current from the stationary armature..
(iii) Insulation required for a stationary armature is less.
(iv) The rotating field makes the construction simple.
(v) The problem of sparking at the slip rings can be avoided.
(vi) Due to simple construction the cost is less.

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CONSTRUCTION:

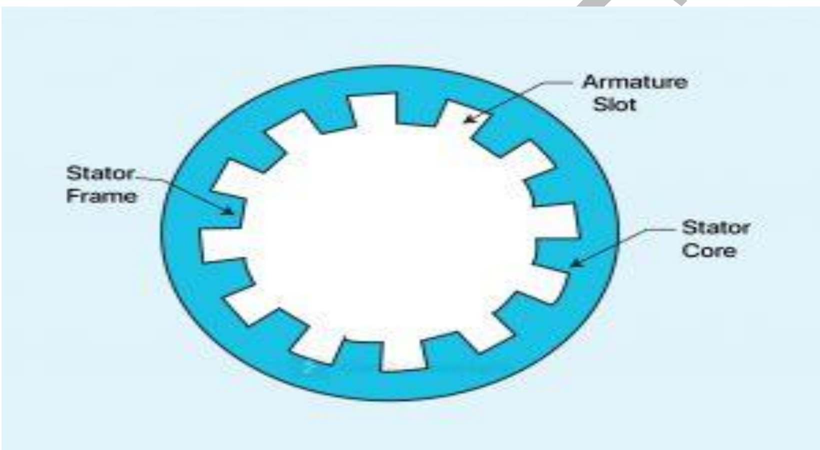
The two basic parts in of an alternator are: (i) Stator, (ii) Rotor.

- Stator is the stationary part and Rotor is the revolving part.

Stator

The stator of the synchronous generator is cylindrical in shape made up of silicon steel laminations. It consists of a stator frame and stator core. The stator frame is used for holding the armature stampings and windings in position. Ventilation is maintained with the help of holes cast in the frame itself, which assist in cooling the alternator.

The armature core is supported by the stator frame and is built up of laminations of steel alloys or magnetic iron. The core is laminated to minimize the loss. The laminations are insulated from each other. The stator is made up of a number of slots on its inner periphery, as shown in the below figure. The slots are used for holding the armature winding.

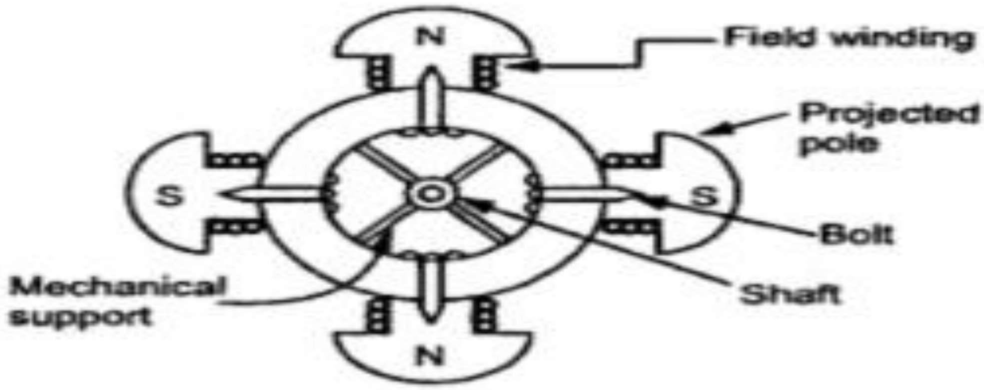


Rotor

There are two types of rotor, salient pole type and smooth cylindrical type.

Salient pole or Projected pole type alternator

The poles are made of thick steel laminations bolted together to a shaft. The poles are also laminated to minimize the eddy current losses. The salient pole type of rotors is characterized by their *large diameters* and relatively *short axial lengths*. All the poles are projected outside; since they are projected outside the mechanical strength is less. It is generally used for *low and medium-speed* operations, mainly employed in engine-driven alternators.

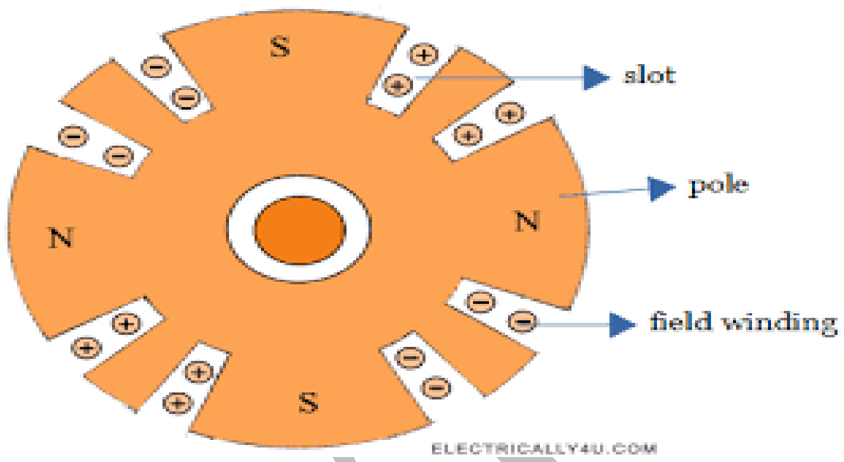


Smooth Cylindrical or Non salient type alternator

The rotor consists of a smooth solid steel cylinder, having a number of slots along its outer periphery to accommodate the field coils. They do not have projected poles, instead the slotted portion acts as pole. As shown in the figure below. Here, the rotor has 4 poles. The pole areas are surrounded by field windings placed in slots.

It has a very long axial length but small diameters. The construction of the rotor gives better balance and quieter operation.

This type of rotor is generally used for very high-speed operation and hence called turbo-generators, which are employed in alternators driven by a steam turbine.



Comparison between Salient pole and Non salient pole alternator

Salient pole alternator	Non Salient pole alternator
Poles are projected outside	Poles are not projected outside
Mechanically weak	Mechanically robust
Suitable for low speed machines	Suitable for high speed machine
Large diameter and small axial length	Small diameter and larger axial length
Air gap is not uniform	Air gap is uniform

Frequency of a Induced EMF

Let P- No of poles and N- speed of the rotor in RPM
f-frequency of the Induced EMF

One mechanical revolution of rotor = $\frac{P}{2}$ cycles of EMF electrically

Thus there are P/2 electrical cycles per revolution.

As speed is N r.p.m., in one second, rotor will complete (N/60) revolution.

But electrical cycles/sec = Frequency
f = (No. of electrical cycles per revolution) x (No. of revolutions per second)

$$f = \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120} \text{ Hz (cycles per sec).}$$

• So there exists a fixed relationship between three quantities, the number of poles P, the speed of the rotor N in r p.m. and f the frequency of an induced EMF in Hz (hertz).

Synchronous speed (N_s)

For a fixed number of poles, the alternator has to be rotated at constant speed in order to maintain the constant frequency of Induced EMF called Synchronous speed.

$$N_s = \frac{120f}{p} \text{ rpm}$$

Where f- frequency in Hz and P- No of poles

E.M.F. Equation of an Alternator

Let ϕ = Flux per pole, in Wb
P = Number of poles
N = Synchronous speed in r.p.m.
f = Frequency of induced e.m.f. in Hz
Z = Total number of conductors
Zph = Conductors per phase

For three phase Zph = $\frac{Z}{3}$

Tph – No of Turns per phase therefore Tph = $\frac{Zph}{2}$

Consider a single conductor which the cuts the flux ‘ϕ’ produced by each pole in one revolution.

The total flux **dϕ = ϕ x P**
Time taken to complete one revolution is **dt = 60/ N_s**
For one revolution of a conductor, according to faraday’s law of electromagnetic Induction

$$E_{avg} = \frac{d\varphi}{dt} = \frac{\varphi P}{60/N_s} = \frac{\varphi P N_s}{60} \quad \text{---------- (i)}$$

Wkt frequency $f = \frac{PN}{120} = \frac{PN}{2x60}$

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$$2f = \frac{PN}{60}$$

Substituting in equation (i) we get

$$E_{avg} = \phi \times 2f = 2\phi f$$

Therefore EMF induced per turn = 2 x (EMF per conductor) = **2 x (2 f ϕ)**

$$E_{avg} \text{ per turn} = 4 f \phi \text{ volts.}$$

Let T_{ph} be the total number of turns per phase connected in series then

$$E_{avg} = 4 f \phi \times T_{ph}$$
$$= 4 f \phi T_{ph}$$

R.M.S. value of EMF = K_f x Average value = 1.11 x 4 f ϕ T_{ph}

$$E_{ph} = 4.44 f \phi T_{ph} \text{ Volts}$$

If K_c – Pitch factor – the reduction in EMF due to short pitched winding
K_d – distribution factor – the reduction in EMF due to distributed winding

K_c and K_d are constants

Therefore the EMF induced in a Short pitched and distributed winding is

$$\boxed{E_{ph} = 4.44 f \phi T_{ph} K_c K_d}$$

K_c= 1 for full pitched winding and K_d = 1 for concentrated winding

For star connection winding line voltage $E_L = \sqrt{3}\ E_{ph} = \sqrt{3}\ 4.44 f \phi T_{ph} K_c K_d$
For delta connection winding line voltage $E_L = E_{ph} = 4.44 f \phi T_{ph} K_c K_d$

List of formulas

1. $f = \frac{PN}{120}$ ---Hz
2. $N_s = \frac{120f}{p}$ rpm
3. $Zph = \frac{Z}{3}$ and $Tph = \frac{Zph}{2}$
4. $E_{ph} = 4.44 f \phi T_{ph} K_c K_d$
5. For star connected winding $E_L = \sqrt{3}\ E_{ph}$ and for delta $E_L = E_{ph}$

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Problems on Alternators

1. A 3-ϕ, 4 Pole, 50 Hz star connected alternator has 36 slots with 30 conductors per slot. The useful flux per pole is 0.05 wb. Find the synchronous speed & line voltage on No-load. Assume winding factor of 0.96.
(June-July 2016, Dec 2016-Jan 2017)

Sol^n: Given:-
$\phi = 0.05$ wb
$P = 4$ Poles $f = 50$ Hz $N_s = ?$

No of conductors $Z = 36 \times 30 = 1080$ $E_L = ?$

$K_d = 0.96$ $K_c = 1$

No of conductors per phase $Z_{ph} = Z/3 = \frac{1080}{3}$

$Z_{ph} = 360$ per phase

Turns per phase $T_{ph} = \frac{Z_{ph}}{2} = \frac{360}{2} = 180$

$T_{ph} = 180$ conductors per phase

W.K.t

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

$N_s = 1500$ rpm

W.K.t for star connected

$$E_L = \sqrt{3}\, E_{ph} = \sqrt{3} \times 4.44 \times f \times \phi \times T_{ph} \times K_c \times K_d$$

$$= \sqrt{3} \times 4.44 \times 50 \times 0.05 \times 180 \times 1 \times 0.96$$

$E_L = 3322.2$ V

2) A 6 Pole, 3 Phase, Star connected alternator has an armature with 90 slots & 12 conductors per slot. It revolves at 1000 rpm, the flux per pole being 0.5 wb. Calculate the EMF generated, if the winding factor is 0.97 & all the conductors in each phase are in series. The coil is full pitched. (June/July 2016)

Sol:- Given:- $P = 6$

$Z = 90 \times 12 = 1080$ conductors

$Z_{ph} = Z/3 = \frac{1080}{3} = 360$ conductors per phase

$\phi = 0.5\,wb$ $\quad N = 1000\,rpm$ $\quad K_d = 0.97$

$K_c = 1$ $\quad E_{ph} = ?$ $\quad$ Star connected

$T_{ph} = \frac{Z_{ph}}{2} = \frac{360}{2} = 180$ turns per phase

$f = \frac{PN}{120} = \frac{6 \times 1000}{120} = 50\,Hz$

$E_{ph} = 4.44 f \phi T_{ph} K_c K_d$

$E_{ph} = 4.44 \times 50 \times 0.5 \times 180 \times 1 \times 0.97$

$E_{ph} = 19380.6\,V$

$\boxed{E_{ph} = 19.38\,KV}$

3) ★★★★★ A 6 Pole, 3 Phase, 50HZ alternator has 12 slots per pole & 4 conductors per slot. The winding is 5/6 full pitched. A flux of 25 mwb is sinusoidally distributed along the air gap. Determine the line Emf, if the alternator is star connected.

Soln: Given:- $P = 6$, $f = 50HZ$

12 slots per pole → 4 conductor per slot

No of slots = $12 \times 6 = 72$

$Z = 72 \times 4 = 288$

$Z_{ph} = 288/3 = 96$ conductors per phase

$T_{ph} = Z_{ph}/2 = 96/2 = 48$ turns per phase

$K_c = 5/6$, $\phi = 25mwb = 25 \times 10^{-3}$, $K_d = 1$

$\therefore E_{ph} = 4.44 f \phi T_{ph} K_c K_d$

$E_L = \sqrt{3} E_{ph} = \sqrt{3} \times 4.44 \times 50 \times 25 \times 10^{-3} \times 48 \times \frac{5}{6} \times 1$

$E_L = 1545.75 V$

$\boxed{E_L = 1.545 KV}$

4) A 3ϕ, 16 pole alternator has a star connected winding with 144 slots & 10 conductors per slot. The flux per pole is 30 mwb. Find the phase & line voltages, if the speed is 375 rpm

Sol:-

$P = 16$ Poles Star connected

No of slots = 144

$Z = 144 \times 10 = 1440$ conductors

$Z_{ph} = Z/3 = \frac{1440}{3} = 480$ conductors per phase

$T_{ph} = Z_{ph}/2 = 240$ turns per phase

$\phi = 30 \times 10^{-3}$ wb $N = 375$ rpm

$E_L = ?$ $E_{ph} = ?$ $K_c = K_d = 1$

w.k.t

$$f = \frac{PN}{120} = \frac{16 \times 375}{120} = 50 \text{HZ}$$

$E_{ph} = 4.44 f \phi T_{ph} K_c K_d$

$= 4.44 \times 50 \times 30 \times 10^{-3} \times 240 \times 1 \times 1$

$E_{ph} = 1598.4$ Volts

$E_L = \sqrt{3} E_{ph}$ for star connected

$E_L = 2768.5$ Volts

5) A 2 Pole 3-ϕ Alternator running at 3000rpm has 42 slots with 2 conductors per slot. Calculate flux per pole, required to generated a line voltage of 2300V. Assume Kd = 0.952 & Kp = 0.956. The armature is star connected.

Sol^n: Given:- P = 2 Pole N = 3000rpm

No of Slots = 42 → with 2 conductor per slot

$Z = 42 \times 2 = 84$ conductors

$Z_p = 84/3 = 28$ conductors per phase

$T_{ph} = Z_{ph}/2 = 14$ turns per phase

$E_L = 2300V$ star connected ϕ

$K_d = 0.952$ $K_p = 0.956 = K_c$

$\phi = ?$

w.k.t $f = \frac{PN}{120} = \frac{2 \times 3000}{120} = 50 Hz$

w.k.t for star connected

$E_L = \sqrt{3} E_{ph} = \sqrt{3}\, 4.44 f \phi T_{ph} K_c K_d$

$2300 = \sqrt{3} \times 4.44 \times 50 \times \phi \times 14 \times 0.952 \times 0.956$

$\phi = \frac{2300}{\sqrt{3} \times 4.44 \times 50 \times 14 \times 0.952 \times 0.956} = 0.46 wb$

MODULE-4b
Induction Motors

Syllabus: *concept of rotating magnetic field, Principle of operation, construction of motor, types – squirrel cage and phase wound rotor, slip and problems on slip, significance of the slip.*

Introduction:

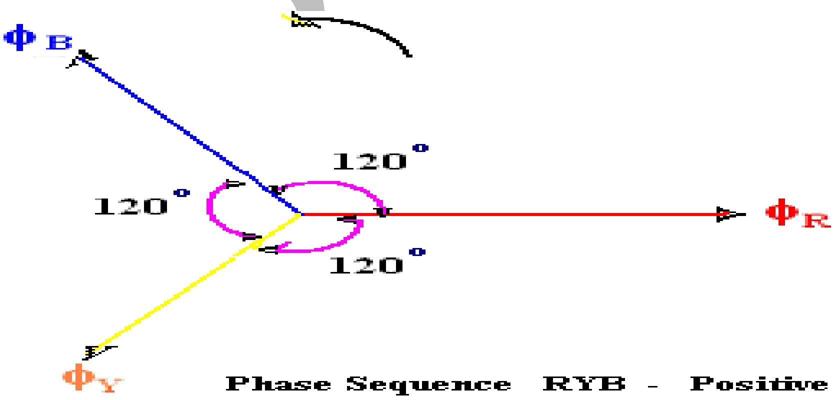
- The induction motors are most widely used ac motors in industry.
- They convert electrical energy in AC form into mechanical energy.
- They work on the principle of electromagnetic induction.
- They are simple and rugged in construction, quite economical with good operating characteristics and efficiency, requiring minimum maintenance, but have a low starting torque.
- They run at practically constant speed from no load to full load condition.
- The important advantages of three phase induction motors over other types are self-starting property, no need of starting device, higher power factor, good speed regulation and robust construction.

ROTATING MAGNETIC FIELD (RMF)

The stator of a three phase induction motor carries a three phase star or delta connected winding, to which three phase a.c. supply is given

The three phase currents flow simultaneously through the windings and are displaced by 120° from each other.

If the phase sequence is RYB, the three phase currents produce the three fluxes ϕ_R, ϕ_Y and ϕ_B which are equal in magnitude but displaced by 120° from each other, as shown in a fig



Let the magnitude of each flux is ϕ_m

From the phasor diagram with 'ϕ_R' as reference.

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The equations of the three fluxes are,

$$\Phi_R = \Phi_m \sin\omega t = \Phi_m \sin\theta$$

$$\Phi_Y = \Phi_m \sin(\omega t - 120°)$$

$$\Phi_B = \Phi_m \sin(\omega t - 240°) = \Phi_m \sin(\omega t + 120°)$$

The resultant flux or total flux 'φ_T 'at any instant is given by the vector sum of the flux in each of the phases.

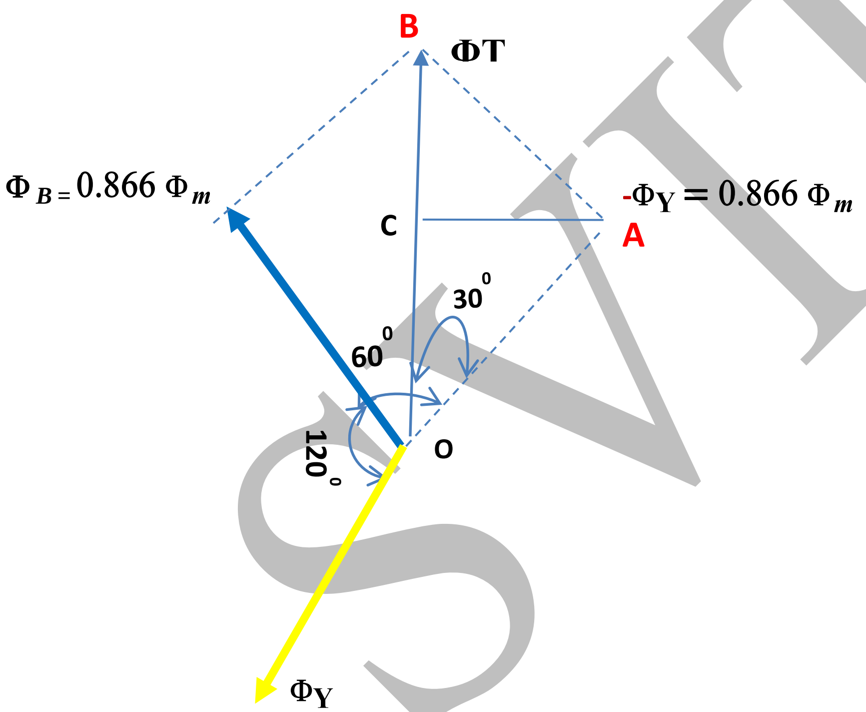
Let us consider at different instants

i) When **ωt =0,** Then

$$\Phi_R = \Phi_m \sin 0 = 0$$

$$\Phi_Y = \Phi_m \sin(0 - 120°) = -0.866\,\Phi_m$$

$$\Phi_B = \Phi_m \sin(0 + 120°) = 0.866\,\Phi_m$$



Draw AC perpendicular to OB such that it bisects OB/2

Consider a triangle OAC

$$\text{Cos } 30 = \frac{OC}{OA} = \frac{OB/2}{OA} = \frac{\varphi T/2}{0.866\varphi m}$$

$$\frac{\sqrt{3}}{2} = \frac{\varphi T/2}{0.866\varphi m}$$

$$\Phi_T = 1.5\,\Phi_m$$

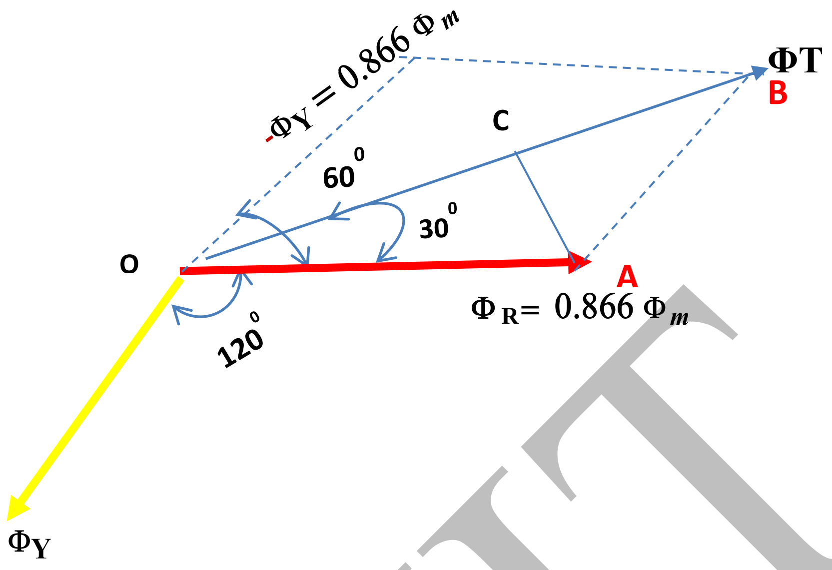
Thus the total flux Φ_T is 1.5 times of Φm in magnitude and its position is vertically upwards at ωt = 0.

ii) When **ωt =60,** Then

$$\Phi_R = \Phi_m \sin 60 = 0.866\ \Phi_m$$

$$\Phi_Y = \Phi_m \sin(60 - 120^\circ) = -0.866\ \Phi_m$$

$$\Phi_B = \Phi_m \sin(60 + 120^\circ) = 0$$



Consider a triangle OAC

$$\text{Cos } 30 = \frac{OC}{OA} = \frac{OB/2}{OA} = \frac{\varphi T/2}{\mathbf{0.866\varphi m}}$$

$$\frac{\sqrt{3}}{2} = \frac{\varphi T/2}{\mathbf{0.866\varphi m}}$$

$$\mathbf{\Phi_T = 1.5\ \Phi_m}$$

Thus magnitude of total flux Φ_T is same but it is rotated through 60° in space clockwise direction.at ωt = 60

Similarly if phasor diagram is drawn for various values of ωt, it can be seen magnitude is always **1.5 Φ_m** but it rotates in space. Such a magnetic field is called **Rotating magnetic field (RMF)**.

Thus though supply is stationary, windings are stationary; the resultant flux produced rotating in space with constant magnitude and speed.

I,e it rotates with synchronous speed **N_s =120f / P**

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Construction Of Induction Motor

A three-phase **Induction motor** mainly consists of two parts

1. **Stator**
2. **Rotor**.

The stator is the stationary part of the induction motor, and the rotor is the rotating part. The construction of the induction motor is explained below in detail

1. Stator

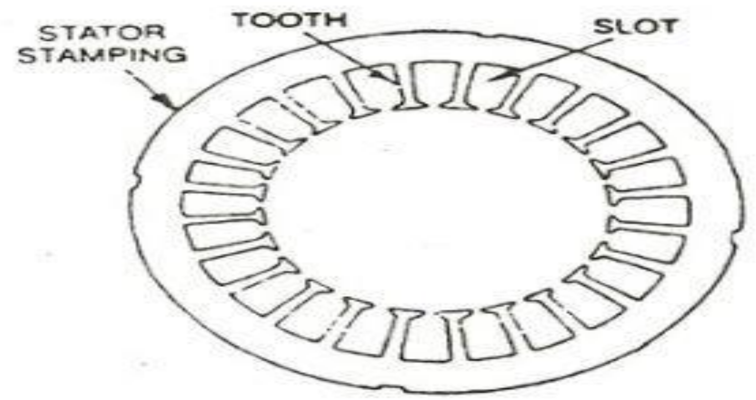
The stator is built up of high-grade alloy steel laminations to reduce eddy current losses. It has three main parts, namely the outer frame, the stator core, and a stator winding.

Outer frame

It is the outer body of the motor. Its main function is to support the stator core and to protect the inner parts of the machine.

Stator Core

The stator core is built of high-grade silicon steel stampings. The stampings are fixed to the stator frame. Each stamping is insulated from the other with a thin varnish layer. Slots are punched on the inner side of the stampings to carry the stator winding as shown in the figure below:



Stator windings

The core of the stator carries three-phase windings which are usually supplied from a three-phase supply system. These windings are either connected in star or delta.The six terminals of the windings are connected in the terminal box of the machine.

2. Rotor

Construction of Rotor

The rotor is also built of thin laminations of the same material as the stator. The laminated cylindrical core is mounted directly on the shaft. These laminations are slotted on the outer side to receive the conductors. There are two types of rotors.

i) Squirrel Cage Rotor

ii) Slip ring or phase wound rotor

i) Squirrel Cage Rotor

A squirrel cage rotor consists of a laminated cylindrical core. The circular slots at the outer periphery are semi-closed. Each slot contains an uninsulated bar conductor of aluminum or copper. At the end of the rotor the conductors are short-circuited by a heavy ring of copper or aluminum called end rings.
The diagram of the cage rotor is shown below:

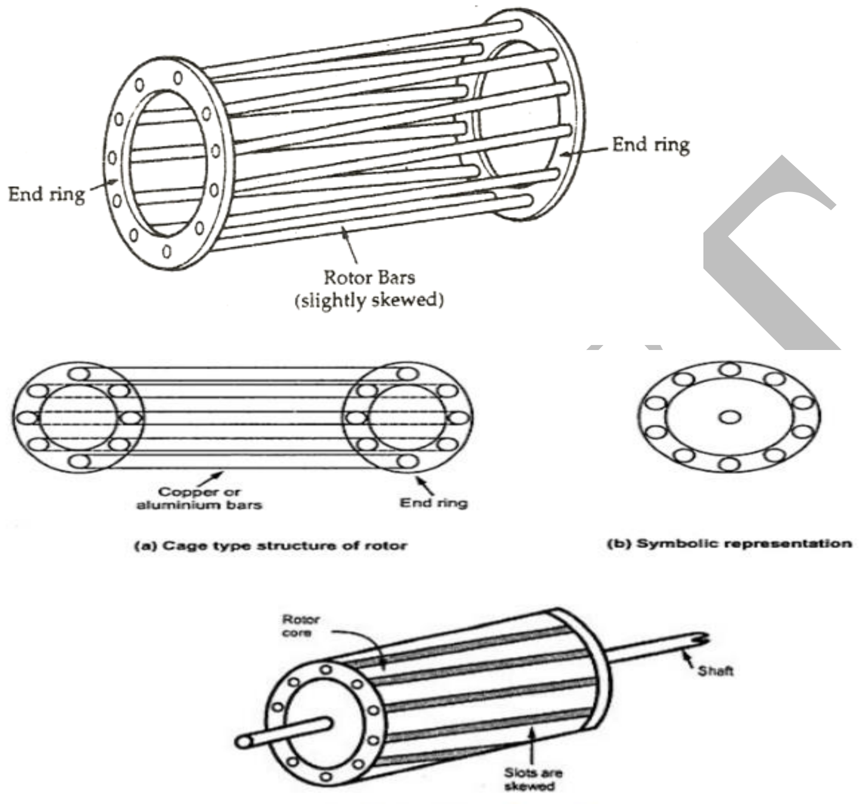
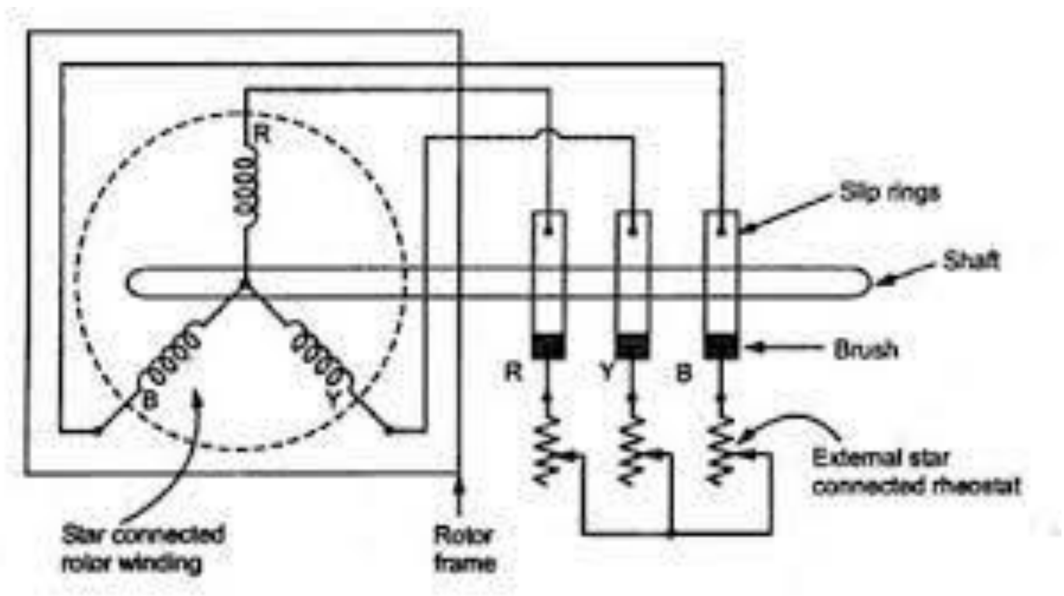


Fig 2.22 Squirrel Cage Rotor

ii) Slip Ring or Phase Wound Rotor

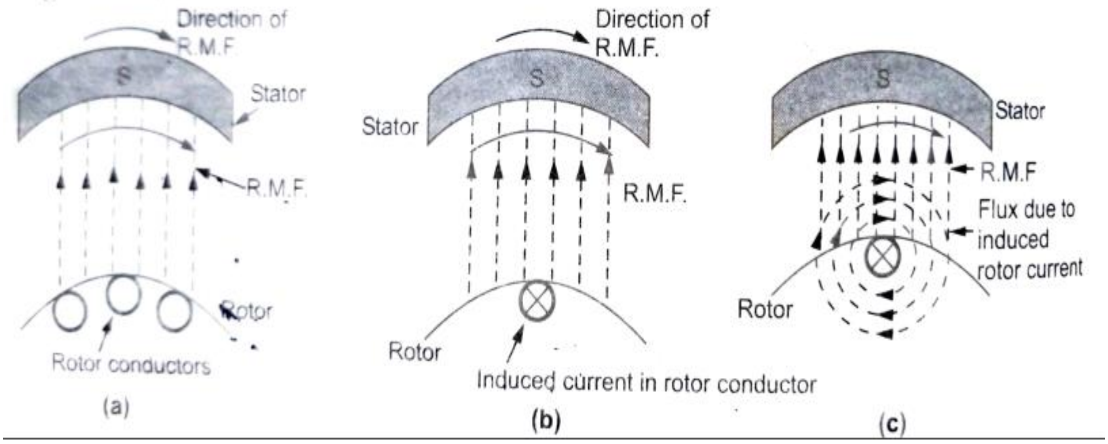
The phase wound rotor is also called a Slip Ring Rotor. It consists of a cylindrical core that is laminated. The outer periphery of the rotor has a semi-closed slot that carries 3 phase insulated rotor windings. The three ends of 3-φ winding, available after connecting the winding in star or delta , are permanently connected to slip rings.

With the help of slip rings the external resistances can be added in series with each phase of rotor winding to control the rotor resistance per phase .Which helps to control starting torque speed of motor etc.



WORKING PRINCIPLE:

- When a 3-Φ supply is given to the stator winding a magnetic field of constant magnitude 1.5Φm and rotating with the synchronous speed Ns is produced.
- This rotating field produces an effect of rotating poles around a rotor. Let direction of rotation of this rotating magnetic field is clockwise as shown in fig (a)
- This rotating speed sweeps across the conductors and hence an EMF is induced in rotor conductors.
- According to lenz's law, the direction of the induced EMF is such as to oppose the very cause producing it.
- As rotor forms closed circuit, induced EMF circulates current through rotor called rotor current as shown in the Fig. (b). Let direction of this current is going into the paper denoted by a cross as shown in the R.M.F
- Any current carrying conductor produces its own flux. So rotor produces its flux called rotor flux. For assumed direction of rotor current, the direction of rotor flux is clockwise as shown in the Fig. (c).



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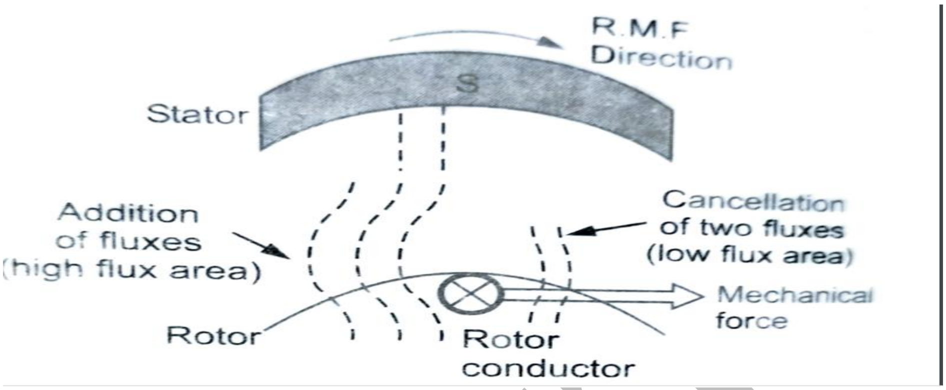
- Both the fluxes. Interact with each other .At left side of the conductor both fluxes are in same direction, therefore addition of fluxes (high flux area) and on right Cancellation of two fluxes (low flux area).
- As flux lines act as stretched rubber band, high flux density area exerts a push to rotor conductor towards low flux density area. So rotor conductor experiences a force from left to right in this case, as shown in the Fig. (d), due to interaction of the two fluxes.



- As all the rotor conductors experience a force, the overall rotor experiences a torque and starts rotating. So interaction of the two fluxes is very essential for a motoring action. But as the speed of the rotor is in the same direction of rotating magnetic field, the relative speed decreases.
- The speed of the rotor gradually increases and tries to catch up the speed of rotating magnetic field. But if it catches up the speed, then the relative speed becomes zero and hence, no emf will be induced in the rotor conductors hence the torque becomes zero hence motor stops. Thus rotor will not be able to catch the speed of the magnetic field, but rotates at a speed slightly lesser than the synchronous speed.

CONCEPT OF SLIP (S)

- According to Lenz's law, the direction of rotor current will be such that they tend to oppose the cause producing it.
- The cause producing the rotor current is the relative speed between the rotating field and the stationary rotor.
- Hence, to reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch it.
- In practice the rotor can never reach the speed of the rotating magnetic field produced by the stator.
- This is because if rotor speed equals the synchronous speed, then there is no relative speed between the rotating magnetic field and the rotor.
- This makes the rotor current zero and hence no torque is produced and the rotor will tend to remain stationary.
- In practice, windage and friction losses cause the rotor to slow down. Hence, the **rotor speed (N) is always less than the stator field speed (NS).**
- Thus the induction motor cannot run with ZERO SLIP.

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Slip Speed: The difference between the synchronous speed (N_S) of the rotating stator field and the actual rotor speed (N) is called the slip speed.

$$\textbf{Slip speed} = N_S - N$$

This speed the magnitude of the induced EMF decides and the rotor current, which in turn decides the torque produced.

Slip of Induction Motor

Slip of the induction motor is defined as the difference between the synchronous speed (Ns) and actual speed of rotor i.e. motor (N) expressed as a fraction of the synchronous speed (N.). This is also called absolute slip or fractional slip and is denoted as's'.

$$S = \frac{Ns - N}{Ns}$$

The percentage slip is expressed as,

$$\%S = \frac{Ns - N}{Ns} x100$$

In terms of slip, the actual speed of motor (N) can be expressed as,

$$N = N_s (1-S)$$

Effect of Slip on the Rotor Frequency or Expression for Rotor frequency (f_r)

In case of induction motor, the speed of rotating magnetic field in stator is,

$$N_s = \frac{120f}{P} \text{ ------------- } (1)$$

Wkt the slip of Induction motor $S = \frac{Ns - N}{Ns}$ where **N** – is the speed of Rotor in rpm

At **start** of motor , when **N = 0,** the slip **s = 1** and stationary rotor has maximum relative motion with respect to rotating magnetic field. Hence maximum EMF gets induced in the rotor at start.

The frequency of this induced EMF at start is same as motor actually it rotates with speed **N** , the relative speed of rotor with respect R.M.F decreases and becomes equal to slip speed of $N_s - N$.

The induced EMF in rotor depends on rate of cutting flux i.e. relative speed **Ns- N**. Hence in running condition magnitude of induced EMF decreases so as its frequency.

If ' f_r' is the frequency of rotor induced EMF and rotor currents,
In running condition at slip speed Ns - N then there exists a fixed relation between (Ns- N), f_r , and P.
So we can write for rotor in running condition,

$$N_s - N = \frac{120fr}{P} \text{ -------- } (2)$$ where rotor poles = stator poles =P

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Divide the equation 2 by equation 1 we get

$$\frac{Ns - N}{Ns} = \frac{120fr/P}{120f/p}$$

$$S = \frac{fr}{f}$$

Therefore the rotor frequency $\mathbf{f_r = sf}$

.

List of Formulas

1. The rotating magnetic field rotate with the speed of

   $N_s = \frac{120f}{P}$ where f – is the supply frequency in HZ

2. Slip speed = $N_S - N$

3. Slip of Induction motor $S = \frac{Ns - N}{Ns}$

   $$\%S = \frac{Ns - N}{Ns} x100$$

4. Rotor speed or actual speed of motor $N = N_s(1-S)$

5. Rotor frequency $f_r = sf$

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List of formulas

1) $N_s = \frac{120f}{P}$

2) $S = \frac{N_s - N}{N_s} \Rightarrow \%S = \frac{N_s - N}{N_s} \times 100$

3) $N = N_s(1-S)$

4) $f_r = Sf$

Problems

1) what is the slip speed, slip & at what sp[eed] rotor runs if the frequency of the emf in the stator of a 4 pole, 3 ϕ Induction mo[tor] is 50 HZ & in the rotor is 1.5 HZ?

Sol:- $P = 4$ $f = 50\,HZ$ $f_r = 1.5\,HZ$

$N_s - N = ?$ $S = ?$ $N = ?$

w.k.t $f_r = Sf$ $S = f_r/f = \frac{1.5}{50} = 0.03$

$S = 0.03$

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

$N_s = 1500\,rpm$

iii) $N = N_s(1-S)$

$N = 1500(1-0.03)$

$N = 1455$ rpm

iv) Slip speed $N_s - N = 1500 - 1455$

$= 45$ rpm

2) A 3 ϕ 4-pole 400V, 50HZ induction motor runs with a slip of 4%. Find rotor speed & frequency

Sol:- $P = 4$, $f = 50$ $S = 4\% = 0.04$

$N = ?$; $f_r = ?$

w.k.t i) $f_r = Sf$ ∴ $f_r = 0.04 \times 50$

$f_r = 2$ HZ

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

$N_s = 1500$ rpm

ii) $N = N_s(1-S)$

$= 1500(1-0.04)$

$N = 1440$ rpm

3) A 10 pole induction motor supplied by a 6 pole alternator, which is driven at 1200 rpm. If the motor runs at slip of 3% what is its speed?

Sol:- Given:- $P = 10$ → Induction motor

$P = 6$ → alternator → (rotating) $N_g = 1200\,rpm$

$S = 3\% = 0.03$ $N = ?$

w.k.t $N_s = \frac{120f}{P}$

$1200 = \frac{120 \times f}{6}$

$f = 60\,Hz$

∴ The Synchronous speed of Induction motor is $N_s = \frac{120f}{P} = \frac{120 \times 60}{10}$

$N_s = 720\,rpm$

w.k.t $N = N_s(1 - S)$

$= 720(1 - 0.03$

$N = 698.4\,rpm$

4) If a 6 Pole induction motor supplied from a 3-ϕ 50HZ supply has a rotor frequency of 2.3HZ calculate i) the percentage slip. ii) The speed of the motor

Sol:- $P = 6$ $f = 50HZ$ $f_r = 2.3HZ$

$\%S = ?$ $N = ?$

w.k.t $N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000rpm$

$N_s = 1000rpm$

$f_r = Sf$

i) $S = f_r/f = 0.046$

$S = 4.6\%$

ii) $N = N_s(1-S)$

$= 1000(1-0.046)$

$N = 954 rpm$

5) A 3-ϕ 6 Pole 50HZ induction motor has a slip of 1% at no load & 3% at full load Determine i) Synchrouns speed ii) No load speed iii) Full load speed iv) Frequency of rotor current at stand still v) Frequency of rotor at full load

Sol:- $P = 6$ $f = 50\,Hz$ Slip at No load $\boxed{S_0 = 1\%}$

$S_0 = 0.01$

Slip at full load $S_f = 3\% = 0.03$

i) Synchronous speed $N_s = ?$

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000\ rpm$$

$$\boxed{N_s = 1000\ rpm}$$

ii) No load speed $N_0 = ?$

$$N_0 = N_s(1 - S_0)$$
$$= 1000(1 - 0.01)$$
$$\boxed{N_0 = 990\ rpm}$$

iii) Full load speed $N_f = ?$

$$N_f = N_s(1 - S_f)$$
$$= 1000(1 - 0.03)$$
$$\boxed{N_f = 970\ rpm}$$

iv) f_r at stand still i.e No load $\rightarrow S_0 = 0.01$

$$f_{r0} = Sf = 0.01 \times 50$$
$$\boxed{f_{r0} = 0.5\ Hz}$$

v) f_r at full load $\rightarrow S_f = 0.03$

$$f_{rf} = Sf = 0.03 \times 50$$
$$\boxed{f_{rf} = 1.5\ Hz}$$

MODULE-5

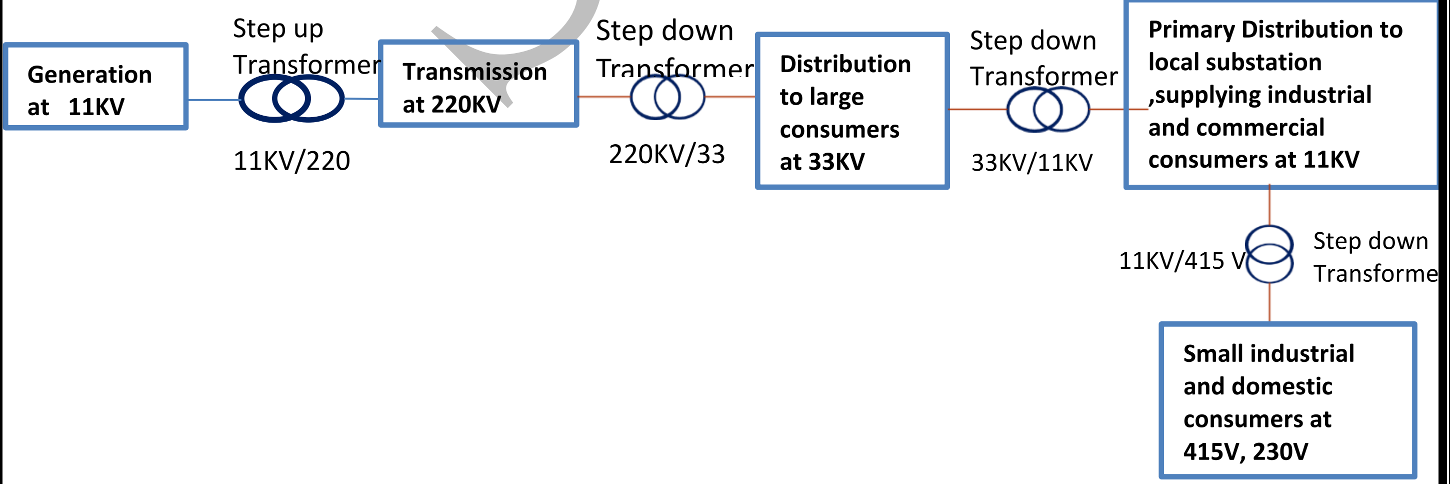
Syllabus: ***Power transmission and distribution:*** *Concept of power transmission and power distribution. Low voltage distribution system (400 V and 230 V) for domestic, commercial, and small-scale industry through block diagrams only.*
Equipment Safety measures: *Working principle of Fuse and Miniature circuit breaker (MCB), merits and demerits.*
Personal safety measures*: Electric Shock, Earthing and its types, Safety Precautions to avoid shock, and Residual Current Circuit Breaker (RCCB)*
Electricity bill: *Power rating of household appliances including air conditioners, PCs, laptops, printers,etc. Definition of "unit" used for consumption of electrical energy, two-part electricity tariff, calculation of electricity bill for domestic consumers.*

Power Transmission and Distribution

Electrical energy is generated at generating stations which are usually situated far away from the consumers. Hence an extensive network of conductors between generating stations and consumers is required. These networks of conductors are divided into two main components, called transmission and distribution system.
The generation, transmission and distribution system of electrical power is called **Electrical power supply system.**

The electrical power supply system consists of 3 divisions:
1. Generation
2. Transmission
3. Distribution

The power is generated in generating station. The transmission system is to deliver bulk power from generating station to load centers and to large industrial consumers. The distribution system is to deliver from load centers to various consumers.
The block diagram is as shown below



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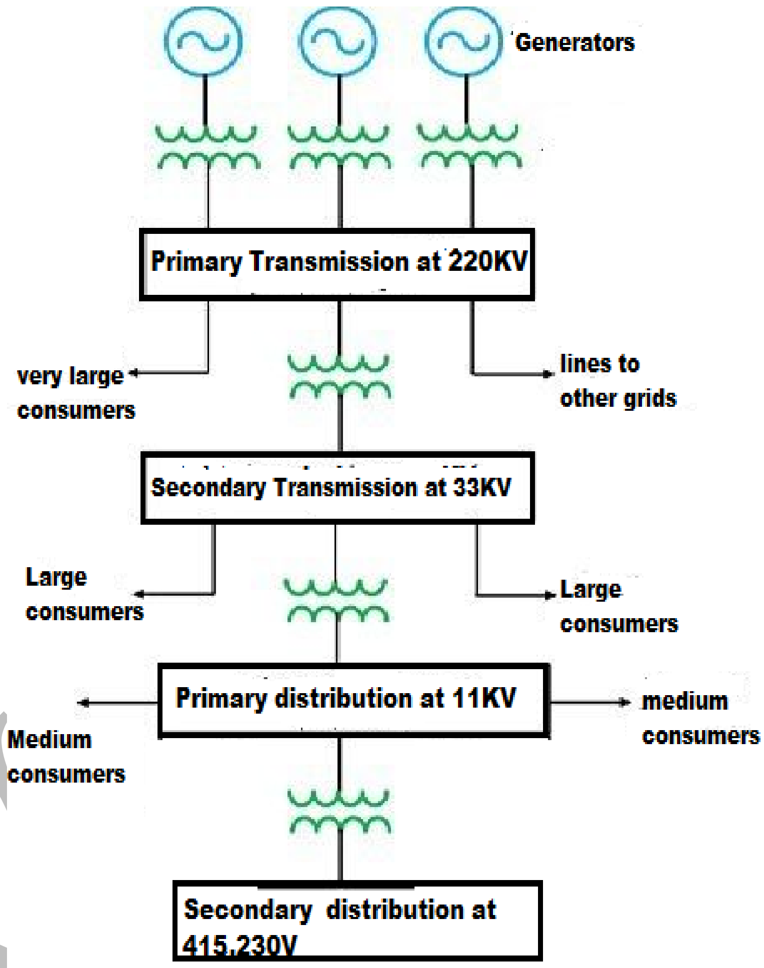
Single line diagram

- The block diagram and single line diagram is as shown in fig.
- The electrical power generated by 3-phase alternators in generating stations.
- Usually the generated voltage is 11KV in certain cases 33KV also.
- In order to reduce the copper loss and for economy reasons the voltage is stepped up from 11KV to 220KV using step up transformers.
- The Primary transmission lines transmit the power from generating station to primary substations.
- At this primary substation the voltage is step down to 33KV by using step down transformer.
- Then the secondary transmission lines transmit the power to various substations and to large Industries.
- In primary distribution station the voltage is step down to 33KV to 11KV using step down Transformer.
- These substations transmit the power to various areas and to the medium scale industries.
- In each area using step down transformer the voltage is step down to 11KV to 415V
- The most of domestic, commercial and small scale industries are supplied power at low voltage i,e 415V to 3-Phase load and 230V to single phase loads.



Single line diagram of Electrical power

Low voltage distribution system (400 V and 230 V) for domestic, commercial and small-scale industry

The power is generated in generating station. The transmission system will deliver bulk power from generating station to distribution centers. Then distribution centers will distribute the power to various consumers. The block diagram for low voltage distribution system for domestic, commercial and small scale industries is as shown below.

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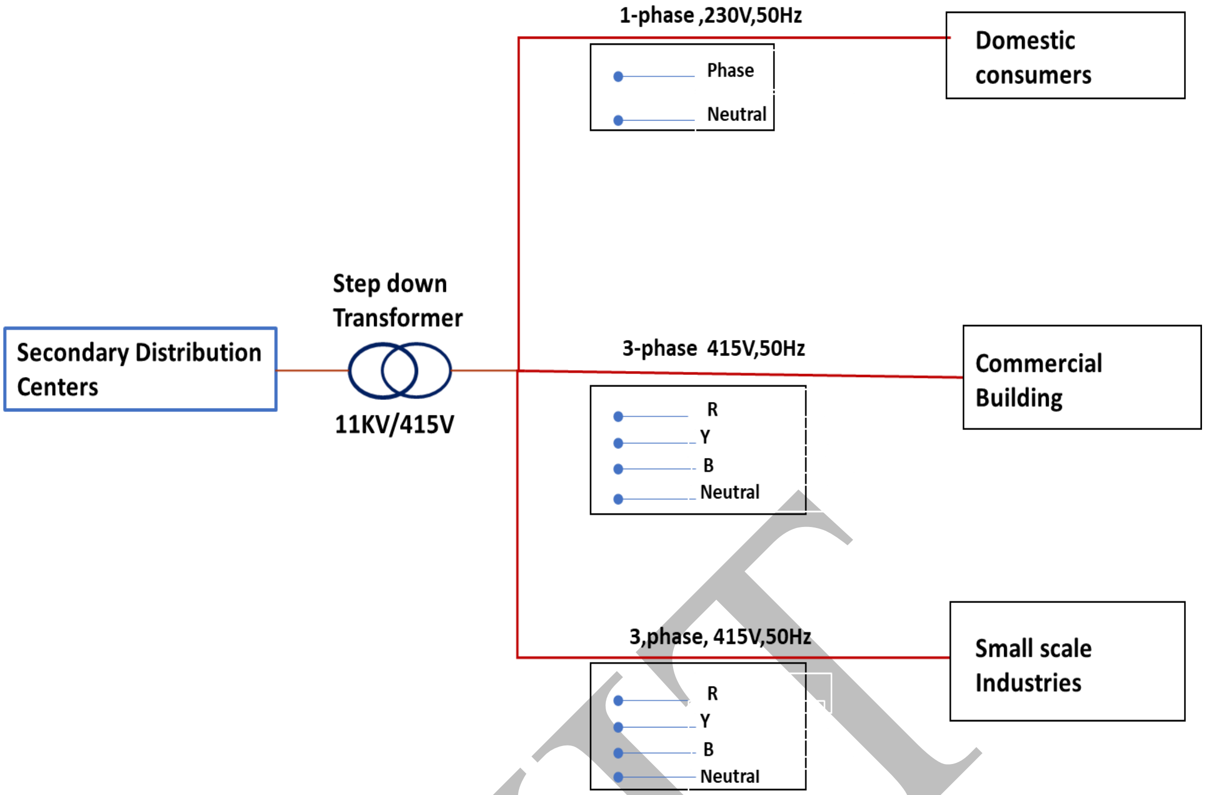

The electric power from primary distribution line (11KV) is delivered to secondary substations. The secondary substations located near the consumer localities step down the voltage from 11KV to 415V using step down transformer. The 415V, 3phase- 4wire (R, Y, B, N) distribution is done for 3 phase loads like commercial buildings and small scale industries. Single phase voltage of 230V is supplied for domestic consumers through one phase and the neutral.

Equipment Safety measures
Protective Devices

Protection for electrical installation must be provided in the event of faults such as short circuit, overload and earth faults. The protective device must be fast acting and isolate the faulty part of the circuit immediately. It also helps in isolating only required part of the circuit without affecting the remaining circuit during maintenance. The following devices are usually used to provide the necessary protection:

- Fuses
- Relays
- Miniature circuit breakers (MCB)
- Earth leakage circuit breakers (ELCB)

Fuse

An Electric Fuse is a protective device which interrupts the flow of excessive current in an Electric circuit. This works on the principle of heating effect of the Electric Current

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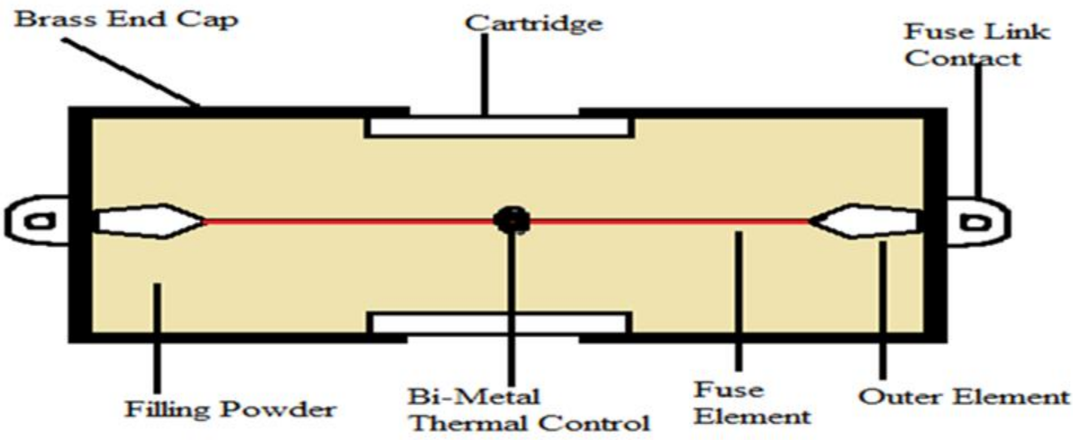

A Fuse consists of conducting wire, which has high resistivity and low melting point. The thickness of the Fuse wire is determined based on the amount of current flow in the circuit. If a fault causes a flow of excess Current then a Conductor break the Circuit by melting or separating it, the thin Conductor used is known as an Electric Fuse. The wire inside the Fuse melts if there is an occurrence of high Current due to a short Circuit or an overloaded Circuit. As a result of which the Current stops flowing since the wire has broken. In order to stop the flow of Electricity. Once a Fuse melts, it can be changed or replaced with a new Fuse. A Fuse is normally made up of elements like zinc, copper, aluminum and silver.

Miniature circuit breaker (MCB) :

An MCB - miniature circuit breaker is an electromagnetic device that embodies complete enclosure in a molded insulating material.

The main function of an MCB is to open the circuit automatically when the current passing through MCB exceeds the value for which it is set. It can be manually switched ON and OFF as similar to normal switch if necessary. An MCB is a simple, easily operable device and is maintenance-free too. It can be easily replaced.

The trip unit is the key part of the MCB on which the unit operates. The bi-metal present in the MCB circuit protects against overload current and the electromagnet in the circuit protects against short-circuit current.

Working

When the overflow of current takes place through MCB , the bimetallic strip gets heated and it deflects by bending. The deflection of the bi-metallic strip or trip bar releases a latch. The latch causes the MCB to turn off by stopping the flow of the current in the circuit. This process helps to safeguard the appliances or devices from the hazards happening due to overload or overcurrent. To restart the flow of current, MCB must be turned ON manually.

In the case of short circuit conditions, the current rises suddenly in an unpredictable way, leading to the electromechanical displacement of the plunger associated with a solenoid. The plunger hits the trip lever, it causes the automatic release of the latch mechanism by opening the circuit breaker contacts.

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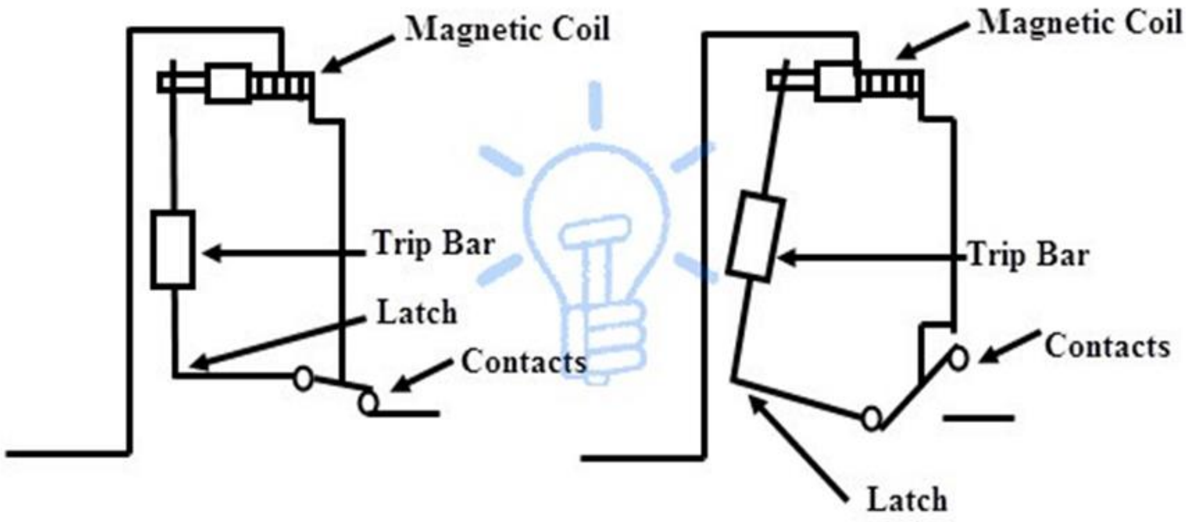

Comparison between Electric Fuse and MCB

ELECTRIC FUSE	MINIATURE CIRCUIT BREAKER – MCB
Whenever excessive current flows through the fuse, the conducting material inside it melts down thereby interrupting the current flow.	An electromagnetic mechanism present inside the MCB helps it to instantaneously interrupt the current flow during faults.
Fuses other than rewireable fuses cannot be reused.	Miniature circuit breakers can be reused after the clearance of faults.
Fuses acts faster than MCB. Typical tripping time 2ms.	Tripping time for MCB is 20ms.
Can protect against short circuit and overloads.	Can protect against short circuit and overloads.
Cheaper than MCB.	MCB costlier than fuses.
Fuse cannot be used as as an ON/OFF switch.	The Circuit breaker is used as an ON/OFF switches.

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Personal safety measures:

Electric shock and precautions

An electric shock is the sudden discharge of electricity through a part of the body when a person comes in contact with electrical equipment.

The factors affecting the severity of shock are

1. Magnitude of the current through the body
2. Path of the current through the body
3. Time for which current is passed through the body
4. Frequency of the current
5. Physical and physiological condition of the person

Precautions against Electric shock

- Avoid water at all times when working with electricity. Never touch or try repairing any electrical equipment or circuits with wet hands. It increases the conductivity of the electric current.
- Never use equipment with damaged insulation. The insulation of conductors must be proper and in good condition.
- Earth connection should be maintained in proper condition
- Use of the fuses and cables of proper rating.
- Use the rubber soled shoes while working.
- Megger tests should be done to check the insulation.
- Never touch two different terminals at the same time.
- Never remove the plug by pulling wire.
- The sockets should be placed at a proper height
- Switch off supply and remove the fuses before starting the work with any installation.
- Always use insulated screw drivers, and line testers.

Earthing :

Connection of the body of electric equipment to the general mass of the earth by wire of negligible resistance is called **Earthing**. It brings the body of the equipment to the zero potential during electric shock.

Necessity of Earthing

1. To protect the human beings from danger of shock in case they come in contact with the charged frame due to defective insulation.
2. It guarantees the safety of electrical appliances and devices from the excessive amount of electric current.
3. It protects the appliances from high voltage surges and lightning discharge.
4. It provides an alternative path for leakage of current hence protects the equipment.
5. It keeps the voltage constant in the healthy phase
6. It protects the Electric system and buildings from lightning.
7. It avoids the risk of fire in the electrical installation system.
8. To maintain the line voltage constant under unbalanced load condition.

Types of Earthing

They are two types of earthing

1. Plate earthing
2. Pipe earthing

- **Plate Earthing :**

In this method a copper plate or GI plate of 60cmX60cmX3.18cm is placed vertically down inside the ground at a depth of 3m. The plate is surrounded by the alternate layers of salt and coal with a minimum thickness of about 15cm. The earth wires drawn through the GI pipe are bolted through the earth plate. The GI pipe is fitted with the funnel on a top in order to have an effective earthing by pouring the salt water periodically. The schematic arrangement is as shown below.

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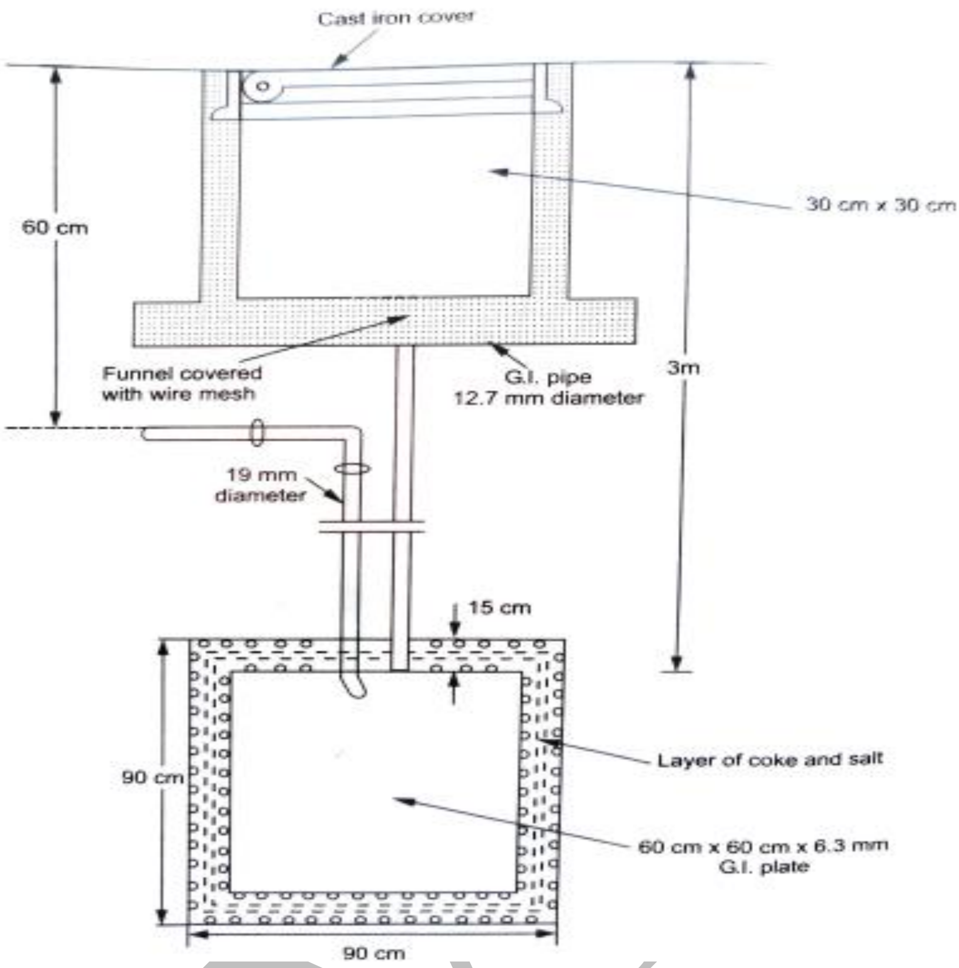
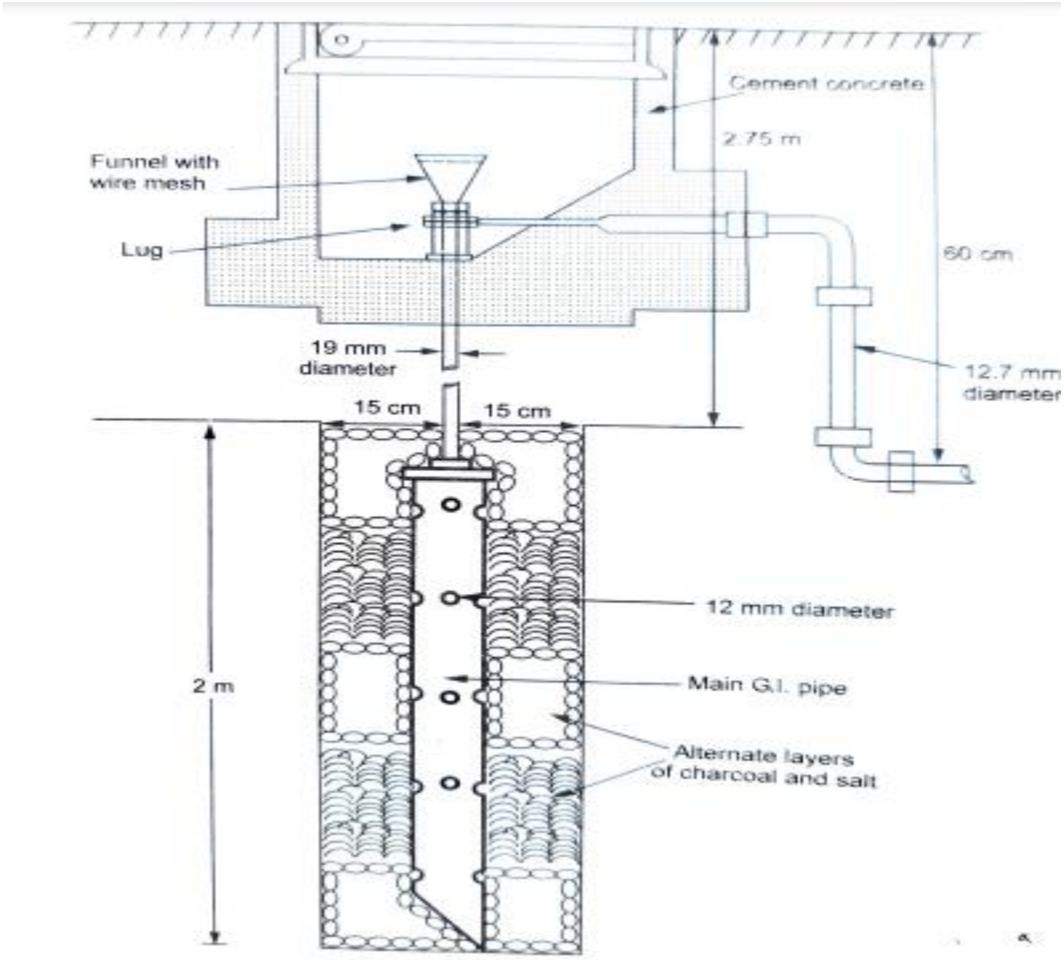


The earthing efficiency increases with the increase of the plate area and depth of the pit. The depth of the pit depends upon the resistivity of the soil.
The only disadvantage of this method is that discontinuity of earth wires from the earthing plate which is placed below the ground as it cannot be observed physically this may cause miss leading and result into heavy losses under fault condition

- **Pipe Earthing :**

In this method a Galvanized iron pipe of 38 mm diameter and length of 2 meters with 12 mm holes is placed vertically into the ground at a depth of 4.75m.This pipe acts as an earth electrode. The depth depends upon the condition of the soil
The pit area around the pipe is filled with the alternate layers of salt and coal for improving the condition of the soil and earthing efficiency. The earth wires are connected to the top section of the pipe above the ground level with nut and bolts. The funnel is provided to pour the salt water. The schematic arrangement is as shown below.



The contact surface of GI pipe with the soil is more as compare to the plate. Hence it can handle large leakage current for the same electrode size. The earth wires connected to the GI pipe above the ground level can be physically inspected time to time.
The only disadvantage of pipe earthing is that, the pipe length has to be increased sufficiently in case of soil of high specific resistivity. This increases excavation work and hence increased in cost .

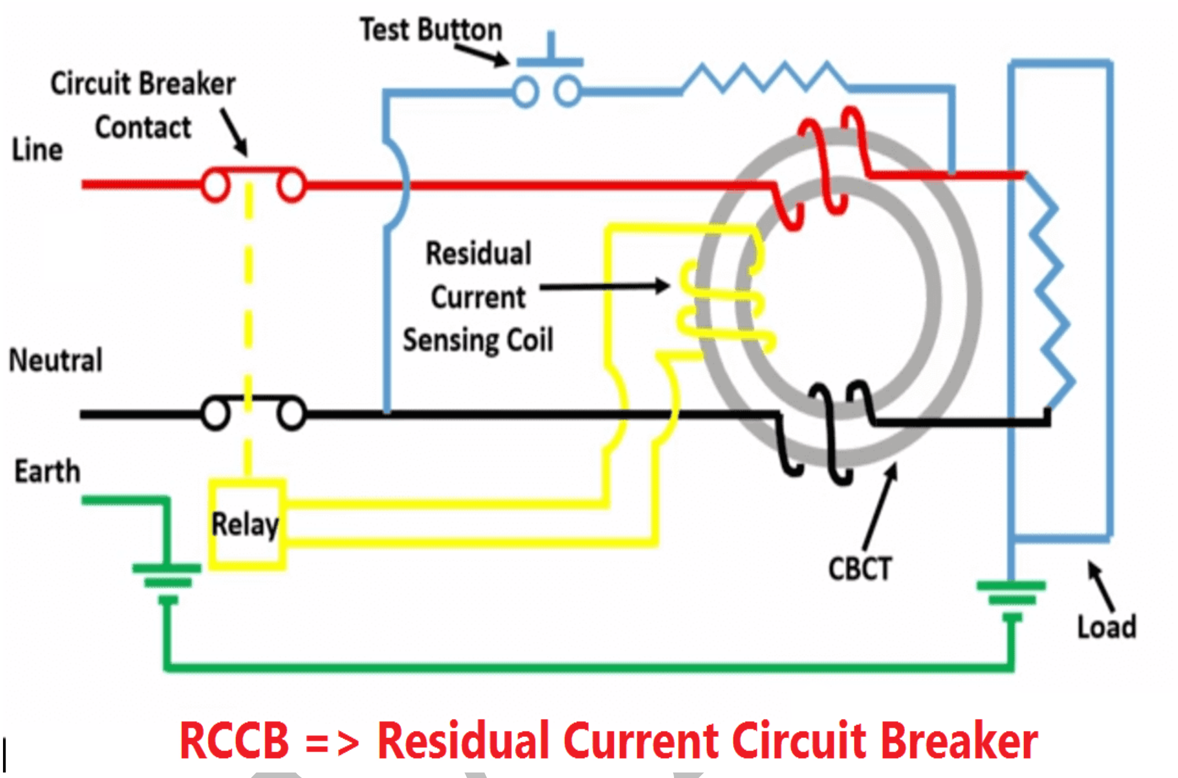
Earth leakage circuit breaker (ELCB)

In certain situations the leakage currents flows through the metal bodies of the appliances, thus the person touching to such appliances may get a shock. There is a risk of fire due to such leakage current flowing to the earth. The MCB and Fuse cannot provide protection against earth leakage current. Hence there is a need of advice which can directly detect the earth leakage currents and cut the supply, if such current exceeds the preset value such device is called earth leakage circuit breaker.

- There are two types of ELCB which are
    1. Voltage operated generally called ELCB
    2. Current operated generally called residual current circuit breaker(RCCB).

Residual current circuit breaker (RCCB)

RCCB is nothing but current operated ELCB. The schematic of RCCB shown in a fig.



RCCB consist of a small current transformer surrounding live and neutral wire.The sensing coil on the current transformer is connected to a trip coil of a circuit breaker.

Under a normal condition the current in a line conductor(I_L) is same as the current in Neutral conductor (I_N). Hence I_L- I_N is Zero, therefore two fluxes produced by I_L and I_N cancel each other and sensing coil does not sense any imbalance.

If there is fault the fault current I_F flows through the earth conductor hence there is difference between the current I_L and I_N. The difference I_L –I_N is called residual Current .The fluxes produced by I_L and I_N are no longer same under a fault condition ,producing flux in the core. Due to the residual flux EMF get induced in the sensing coil, which circulates the current through the tripping coil of the circuit breaker. This operates the circuit breaker and disconnects the supply from the device.As the action of the trip coil depends on the residual current the device is called residual current circuit breaker.

Power rating of household appliances

The Rating of an electrical appliance indicates the voltage at which the appliance is designed to work and the current consumption at that voltage. The Power rating of the appliance is related the power it consumes. Every electrical appliance has a power rating which indicates the amount of electricity required to do work. . This is usually given in watts (W) **or kilowatts (kW).**

The Energy consumption of a device is calculated by multiplying the wattage of a device and operational hours

Energy consumption = Wattage X operational hours .

UNIT: The unit of electrical energy consumed is kWh. One kilowatt-hour is the electrical energy consumed by an electrical appliance of power 1 kW when it is used for one hour. Therefore 1kwh =1 unit.

Calculation of Power consumption of electrical home appliances.

Let us consider different home appliances to calculate approximate total energy consumption of house per month.

Sl NO	Appliances	Watts	NO	Total no of watts	No of operational hours per day	Total Energy consumed= No of watts x No of operation hours	Energy consumed in kwh(units) per day= energy consumed / 1000
1	Tube light	60 W	10	600	5	3000	3
2	Fan	75 W	4	300	8	2400	2.4
3	Refrigerator	200W	1	200	24	4800	4.8
4	AC	1000W	1	1000	5	5000	5
5	Laptop	50W	1	50	2	100	0.1
6	Television	50W	1	50	3	150	0.15
7	Grinders	1000W	1	1000	½	500	0.5
8	Printers	50W	1	50	½	25	0.025
9	Washing machine	2000W	1	2000	1	2000	2
10	Micro wave	1000W	1	1000	1	1000	1
			Total no of units consumed per day				**18.9=19units**

Therefore per day 19 units of energy is consumed

For 1 month = 19 x 30 = **570 units per month**

Tariff

The electrical energy generated in generating station is delivered to a large number of consumers at reasonable rates.

Definition of tariff: The rate at which the electrical energy is supplied to a consumer is known as tariff.

The tariff should include:

1. Recovery of cost of generating electrical energy in power stations
2. Recovery of cost of capital investment in transmission and distribution.
3. Recovery of operation and maintenance of supply of electrical energy.
4. A suitable profit on capital investment.

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There different types tariff. The consumers who have appreciable maximum demand for them two part tariff method is employed.

Two Part Tariff

When the rate of electricity energy is charged on the maximum demand of the consumer and the units consumed is called two part tariff.

In this tariff scheme, the total costs charged to the consumers consist of two components: fixed charges and variable charges (running charges). It can be expressed as:

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

Where, Fixed charges - A = charge per kW of max demand

Variable charges - B = charge per kWh of energy consumed .It is obtained by multiplying no of units consumed and rate per unit.

The fixed charges will depend upon maximum demand of the consumer and the running charge will depend upon the energy (units) consumed. The fixed charges are due to generation, transmission and maintenance.

Advantages

If a consumer does not consume any energy in a particular month, the supplier will get the return equal to the fixed charges.

Disadvantages

If a consumer does not use any electricity, he has to pay the fixed charges regularly.

The maximum demand of the consumer is not determined. Hence, there is error of assessment of max demand.

Electricity Bill

Calculation of electricity bill for low tension domestic consumer is as follows.

The electricity bill consists of two components: fixed charges and variable charges (running charges). It can be expressed as:

Total Electricity Bill = [A (kW) + B (kWh)] + Tax

Where, Fixed charges - A = charge per kW of max demand

A= Total kW X charge per kW

Example: if the sanctioned load is 3KW then A= [1x85 + 2x95] = 275rs

(Note: For 1kw it is 85 rs and above 1kw it 95 rs per kw)

Where Variable charges - B = charge per kwh of energy consumed.

B = No of units consumed x rate per unit

Example: If the no of units consumed is 120 units then

B = [50 x4.1 + 50 x 5.55+ 20 x 7.1] = 624 rs

(Note: For 0- 50 units – 4.1 rs per unit, 50- 100 units – 5.55 rs , 100- 200 units – 7.1rs)

Therefore Total Electricity bill for given example is

= 275 +624+ Tax.

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