# Fundamentals of Electrical Engineering

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# MODULE 1

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| **Contents:**<br>Basic terms in electricity - current,emf, resistance. Dc circuits- equivalent resistance - series, parallel, combination of series & parallel - simple problems.<br>Ohm's law- problems, Kirchhoff's laws –problems<br>Faraday's laws of electromagnetic induction, Lenz's law; Dynamically induced emf; Statically induced emf.<br>Generation of AC voltage- waveforms of emf - definitions-Cycle, Frequency, Period, Amplitude, Angular velocity, RMS value, Average value, Form Factor, Peak Factor.<br>Resistance- reactance-impedance, phase angle- power factor. |
| Three phase connections -star and delta - Relation between line and phase values (equations only)<br>Electric power-dc and ac powers-equations- unit-problems.<br>Electrical energy -equations - basic and commercial unit -problems. Calculation of monthly electricity bill. |

# BASIC TERMS OF ELECTRICITY

## Voltage (V)

- **The potential difference in charge between two points in an electrical field is called voltage.**
- **Unit of voltage is *' volt (V)'***

## Current (I)

- **The directed flow of free electrons is called *electric current.***
- **Unit of current is *ampere (A)***

**Electro Motive Force (E.M.F):**

It is the force which causes the flow of electrons in any closed circuit. The unit of electro motive force is volt. It is represented by letter E or V.

$$\text{EMF} = \frac{\text{Workdone}}{\text{Charge}}$$

$$\text{E or V} = \frac{\text{W}}{\text{Q}}$$

**Potential Difference (p.d):**

Whenever current flows through a resistor there will be a potential difference (p.d) developed across it. Essentially, emf causes current to flow; whilst a p.d. is the result of current flowing through a resistor. The unit of potential difference is volt (V).

## Resistance (R)

- **The opposition offered by a substance to the flow of electric current is called its *resistance*.**
- **Unit of resistance is *ohm (Ω)***

## Power

- **The rate at which work is done in an electric circuit is called its *Power.***
- **Unit of power is *watt (W)***

## Energy

- **The total work done in an electric circuit is called *Energy*.**
- **Unit of energy is kilowatt-hour (kWh)**

| S.No | E.M.F | Potential difference |
|---|---|---|
| 1 | It refers to source of electrical energy | It exists between any points in a circuit |
| 2 | It is measured in open circuit | It is measured in closed circuit |
| 3 | It is a cause for current flow | It is the effect of current flow |
| 4 | It is greater than the potential difference in the same circuit. | It is less than the E.M.F in the same circuit |

## Ohm's Law

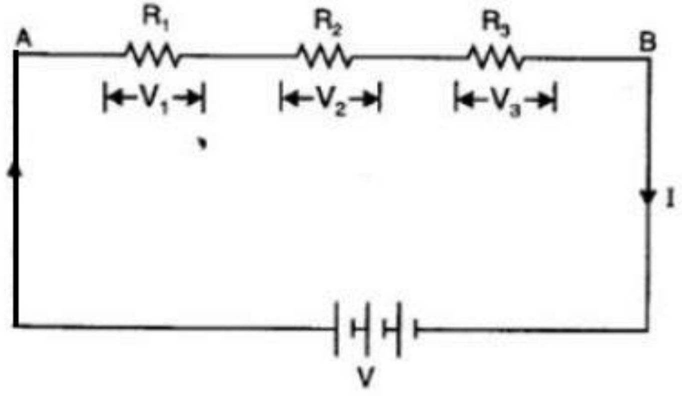
- At constant temperature, current through a conductor is directly proportional to the potential difference between two ends of the conductor.

$$V \propto I$$

$$\frac{V}{I} = \text{Constant} = R$$

**Series and parallel combination of resistors**

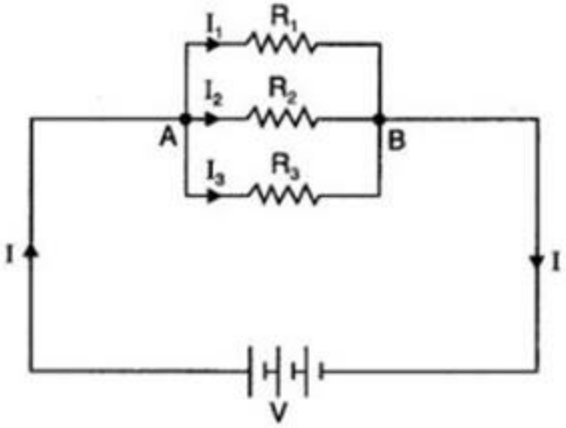
**Series**




$$V = V_1 + V_2 + V_3$$
$$= IR_1 + IR_2 + IR_3$$
$$= I\,(R_1 + R_2 + R_3)$$
$$\frac{V}{I} = R_1 + R_2 + R_3$$

$$\boxed{R_S = R_1 + R_2 + R_3}$$

**Parallel**




$$I = I_1 + I_2 + I_3$$
$$= \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$= V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

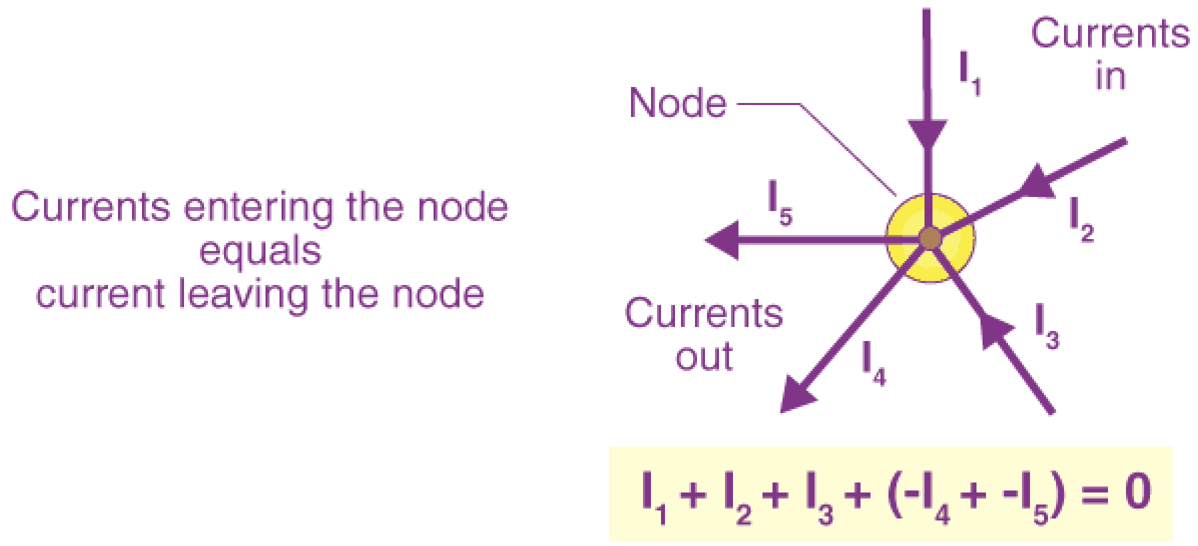
$$\frac{I}{V} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

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

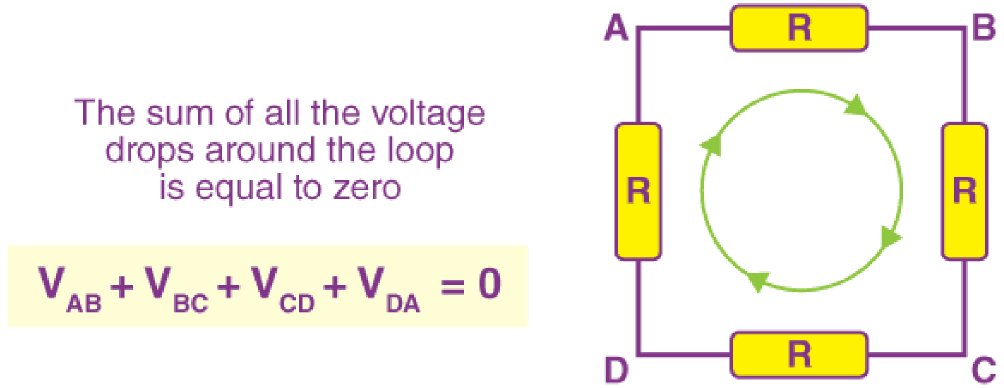
# Kirchhoff’s First Law or Kirchhoff’s Current Law

- According to Kirchhoff’s Current Law,
- The total current entering a junction or a node is equal to the charge leaving the node as no charge is lost.
- This property of Kirchhoff law is commonly called **Conservation of charge**




# Kirchhoff’s Second Law or Kirchhoff’s Voltage Law

- According to Kirchhoff’s Voltage Law,
- The voltage around a loop equals the sum of every voltage drop in the same loop for any closed network and equals zero.
- the algebraic sum of every voltage in the loop has to be equal to zero and this property of Kirchhoff’s law is called **conservation of energy.**



| S.NO | Series circuit | Parallel circuit |
|---|---|---|
| 1 | There are only one path for the current to flow | There are as many paths as the resistance are connected in parallel |
| 2 | Same current through all the resistor | Potential is same across all the resistor |
| 3 | The voltage drop across each resistor is different | The current in each resistor is different |
| 4 | The sum of voltage drop is equal to the applied voltage. | The sum of branch current is equal to the total current applied |
| 5 | The total resistance is equal to the sum of all resistors<br>$R = R_1+R_2+R_3+......................R_n$ | The reciprocal of the total resistance is equal to the sum of the reciprocals of all resistors<br>$1/R = 1/R_1+1/R_2+1/R_3+..........+1/R_n$ |
| 6 | The total resistance is always greater than the greatest resistance in the circuit | The total resistance is always less than the smallest resistance in the circuit. |
| 7. | Dissimilar ends of resistors are connected together to form a closed circuit | similar ends of resistors are connected together to form a closed circuit |
| 8 | **Uses:** To operate low voltage devices with high voltage source<br>Ex. Decorative lamps(serial set) | All lamps, fans, motors etc.,are connected in parallel across the supply in house wiring |

# FARADAYS LAW

## Faraday's laws of electromagnetic induction

- ***First law***

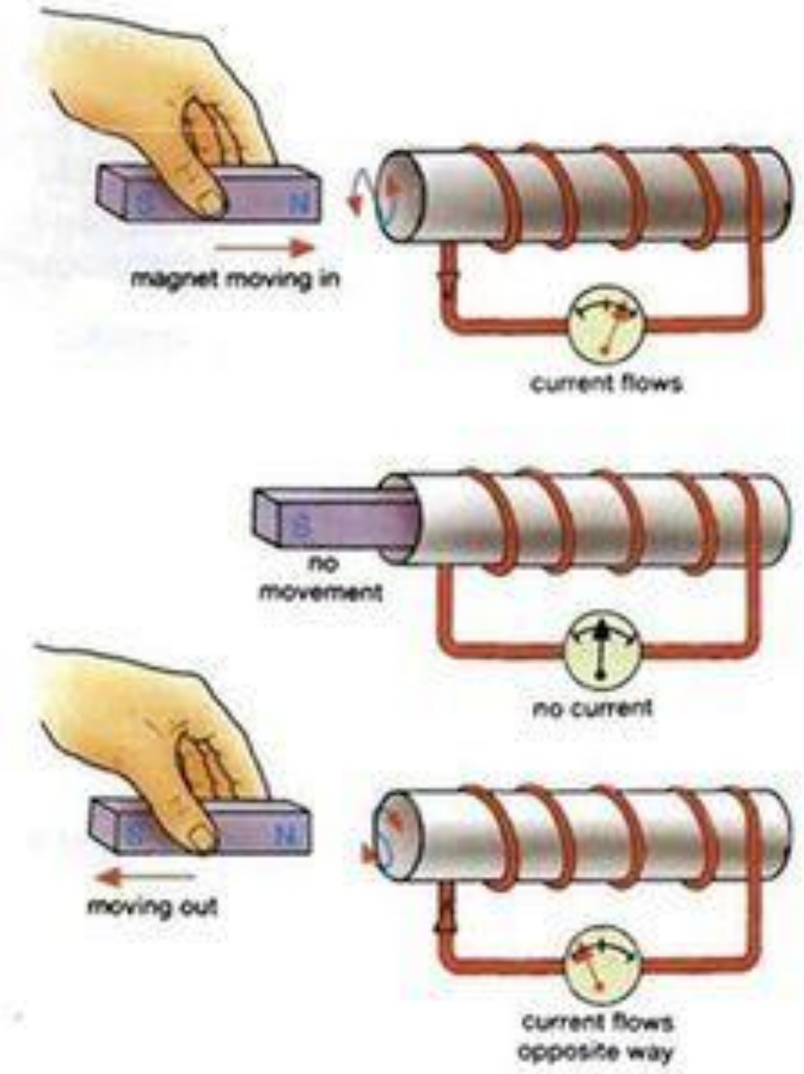
➢ When the magnetic flux linking a conductor or coil changes, an e.m.f is induced in it.

OR

➢ Whenever a conductor cut the magnetic flux an e.m.f is induced in it.

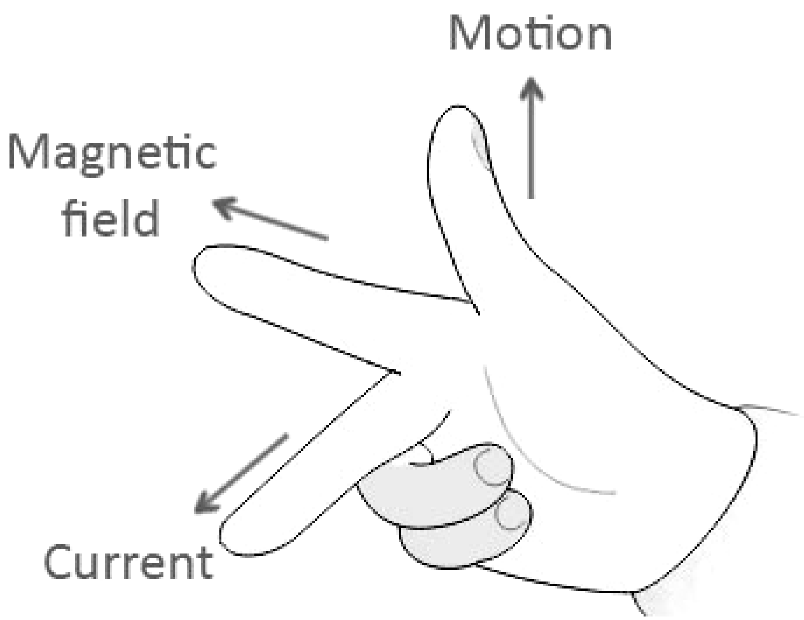
- ***Second law***

➢ The magnitude of the e.m.f induced in a conductor or coil is directly proportional to the rate of change of flux linkage.



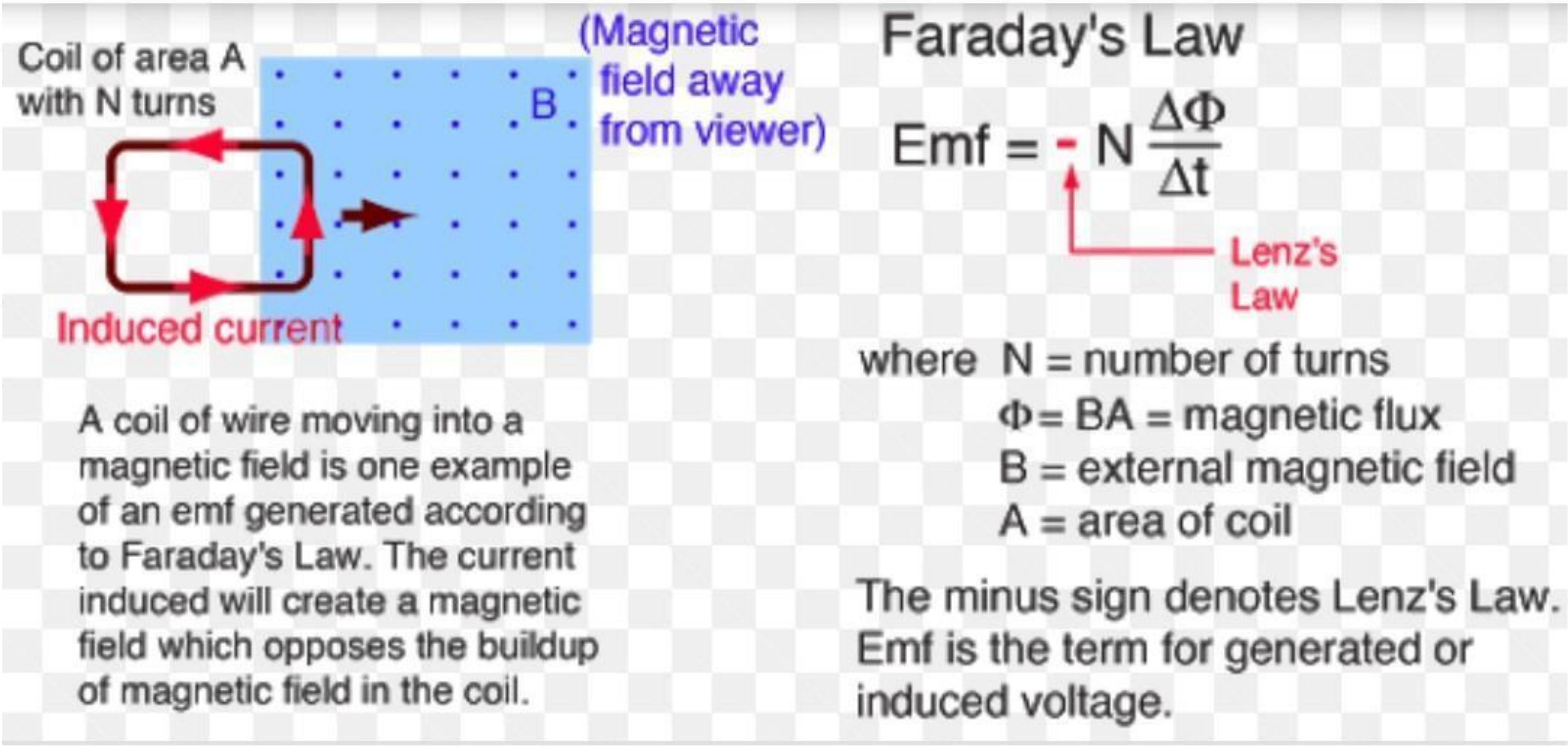
# FLEMING’S RIGHT HAND RULE

- This law is used to find the direction of the induced EMF of DC generator. Hold the fore finger, middle finger and thumb of the right hand so that they are at right angles to one another. If the fore finger points in the direction of magnetic field, thumb in the direction of motion of conductor then the middle finger will point the direction of induced current.



# LENZ’S LAW

- Lenz's law states that the direction of the electric current induced in a conductor by a changing magnetic field is such that the magnetic field created by the induced current opposes changes in the initial magnetic field.



**Statically And Dynamically Induced Emf.**

Induced electro motive forces are of two types. They are,

i) Dynamically induced emf.

ii) Statically induced emf .

**1. Statically Induced Emf** - Statically Induced emf is of two types. They are

1 .Self induced emf

2. Mutually induced emf.

**1.1 Self Induced emf**

Self induction is that phenomenon where by a change in the current in a conductor induces an emf in the conductor itself. i.e. when a conductor is given current, flux will be produced, and if the current is changed the flux also changes, as per Faraday's law when there is a change of flux, an emf will be induced. This is called self induction. The induced emf will be always opposite in direction to the applied emf. The opposing emf thus produced is called the counter emf of self induction.

1) Self Induced emf

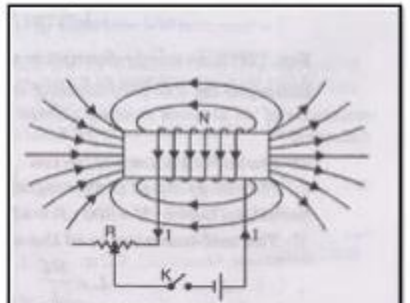


Fig. 34. Self-induced e.m.f. and self-induction.

Fig 13

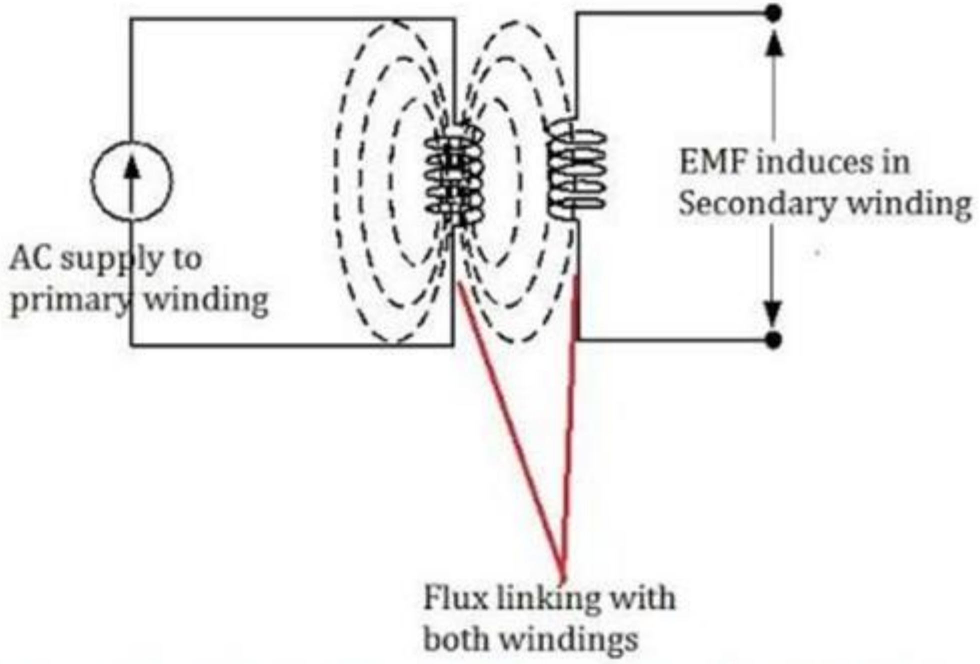
Uses of Self induction

1. In the fluorescent tubes for starting purpose and to reduce the voltage.
2. In regulators, to give reduced voltage to the fans.
3. In lightning arrester.
4. In auto- transformers.
5. In smooth choke which is used in welding plant.

**1.2 Mutually Induced EMF**

- It is the electromagnetic induction produced by one circuit in the near by second circuits due to the variable flux of the first circuit cutting the conductor of the second circuit, that means when two coils or circuits are kept near to each other and if current is given to one circuit and it is changed, the flux produced due to that current which is linking both the coils or circuits cuts both the coils, an emf will be produced in both the circuits. The production of emf in second coil is due to the variation of current in first coil known as mutual induction.
- **Uses:**

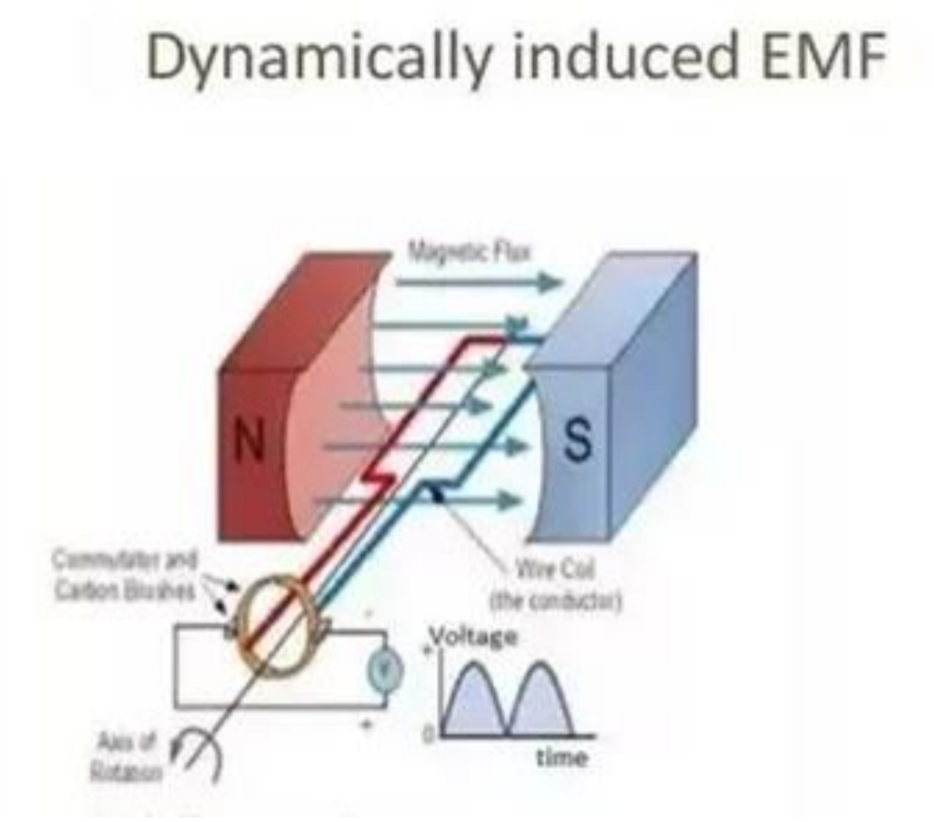
1. It is used in ignition coil which is used in motor car.
2. It is also used in inductance furnace.
3. It is used for the principle of transformer



Example of Statically and Mutually induced EMF

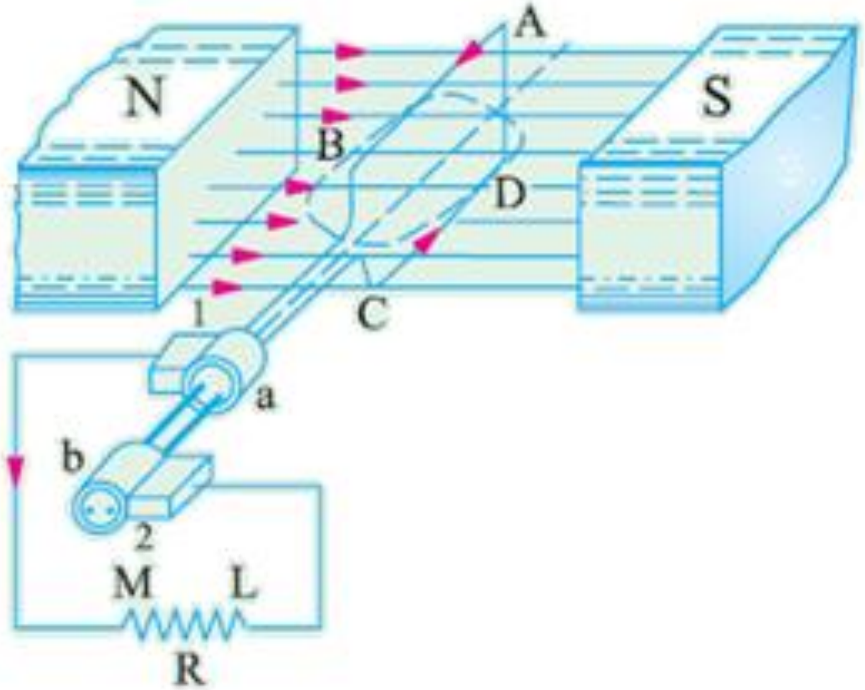
## 2. Dynamically induced EMF

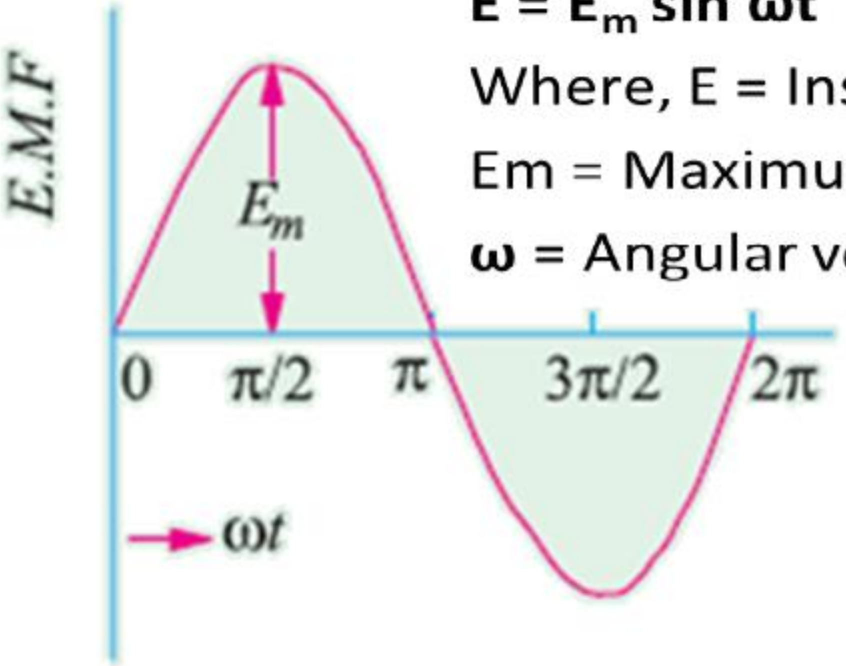
- Dynamically induced **emf** means an emf induced in a conductor when the conductor moves across a magnetic field.
- If the current carrying conductor is moving in magnetic field, then the dynamically induced emf is induced in the conductor. The magnitude of emf depends on strength of magnetic field ,length and velocity of movement



# Generation of AC voltage

- An alternating voltage is any voltage that varies both in magnitude and polarity with respect to time. Similarly, an alternating current is any current that varies in both magnitude and direction with respect to time.
- The reversal polarity of voltage or direction of current occurs at regular intervals of time. The circuits in which alternating currents flow are called alternating current (A.C) circuits.
- the induced E.M.F. varies as sine function of the time angle **ω**t. This curve is known as sine wave and the E.M.F which varies in this manner is known as sinusoidal E.M.F.




**$E = E_m \sin \omega t$**

Where, E = Instantaneous voltage

Em = Maximum voltage

**ω** = Angular velocity of the coil

**Alternator:**

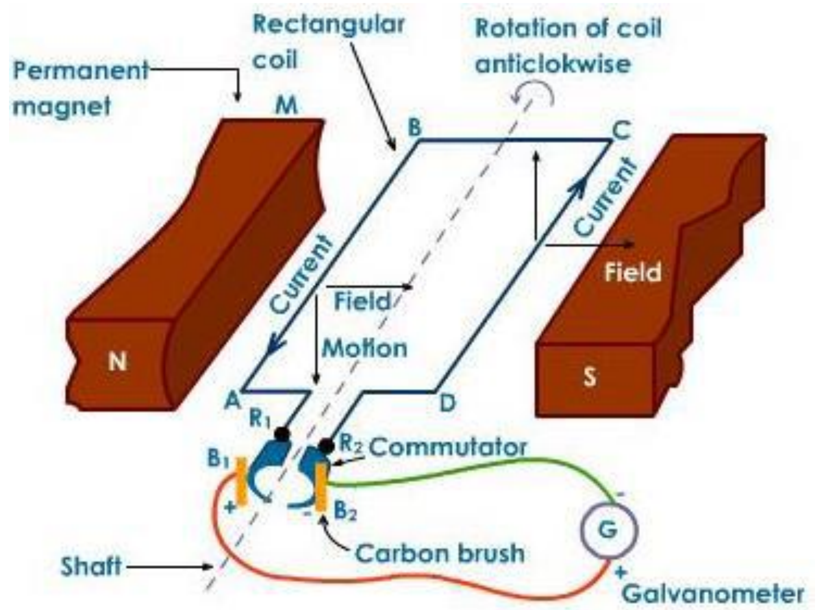
- An alternating current generator is called alternator. It works on the principle of electromagnetic induction. An alternator is also called as AC Generator or synchronous generator.

Working principle of alternator:

- An alternator works on the principle of faraday's law of electromagnetic induction. It states that when there is a relative motion between magnetic field and a conductor an e.m.f is induced in the conductor.
- Alternating voltages / current may be generated by two ways:
- By rotating a coil in a magnetic field.
- By rotating a magnetic field within a stationary coil.

The quantity of voltages / current generated depends upon:

- The number of turns in the coil.
- Strength of the magnetic field
- The speed at which the coil of magnetic fields rotates.



- **A.C Waveform:**
- The shape obtained by plotting the instantaneous ordinate values of either voltage or current against time is called an AC Waveform. An AC waveform is constantly changing its polarity every half cycle and alternating between a positive maximum value and a negative maximum value respectively with respect to time.
- The sinusoidal waveform or sine wave is the fundamental type of alternating current and alternating voltage. It is also referred to as a sinusoidal wave or simply sinusoid. The electrical service provided by the power company (Electricity Board) is in the form of sinusoidal voltage or current.
- AC waveforms can also take the shape of either *Complex Waves*, *Square Waves* or *Triangular Waves* and these are shown below.

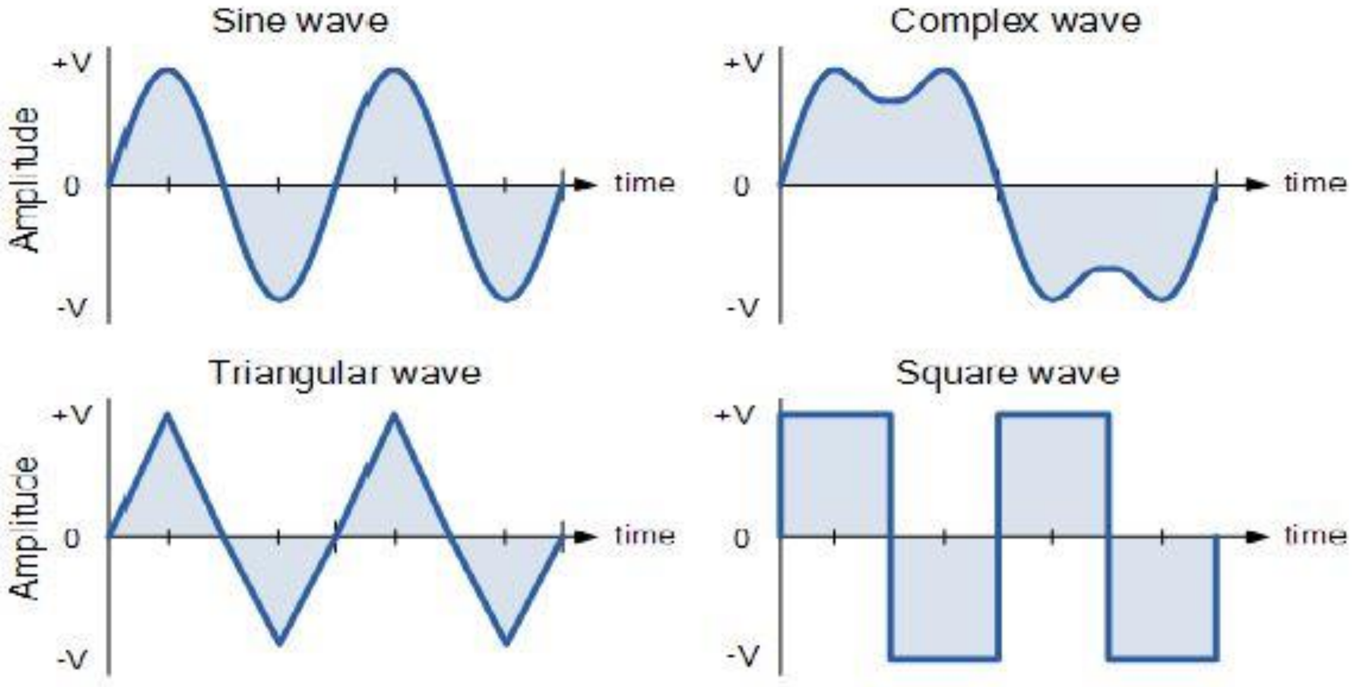



**Fig. Types of periodic waveform**

**AMPLITUDE**

- The maximum positive or negative value of an alternating quantity is called amplitude. It is the highest value attained by the current or voltages in a half cycle either positive or negative half cycle of an alternating quantity.

**Cycle:**

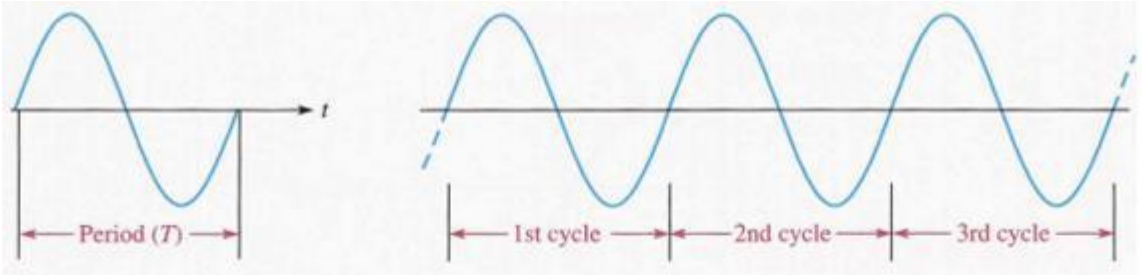
- One complete set of positive and negative value of an alternating quantity is called a cycle.

**FREQUENCY**

- The number of cycles completed in one second is called the frequency (f). The unit of frequency is Hertz (Hz).
- 1 Hertz = 1 cycles per second or 1 Hz = 1 c/s

**TIME PERIOD**

- The time required to complete one cycle is called the periodic time or simply the period (T).
- The unit of time period is the second(s)
- The period of a sine wave can be measured from a zero crossing to the next corresponding zero crossing as shown in figure. The period can be also being measured from any peak in a given cycle to the corresponding peak in next cycle




**Relationship between frequency and Time:**

$$\text{Frequency} = \frac{1}{\text{Time Period}} \qquad \text{Time Period} = \frac{1}{\text{Frequency}}$$

$$F = \frac{1}{T} \qquad T = \frac{1}{F}$$

**ROOT MEAN SQUARE VALUE OF SINE WAVE (RMS)**

- Root Mean Square value of an alternating current is given by the steady D.C current, which produce the same heat as that produced by the alternating current in a given time and given resistance.

R.M.S value is also defined as

$$\text{RMS Value} = \sqrt{\frac{\text{Area under the squared curve}}{\text{Base length or period}}}$$

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

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

- **AVERAGE OR MEAN VALUE**
- The average or mean of an alternating quantity over a given interval is the sum of all instantaneous values divided by the number of values taken over that interval.
- If the alternating quantity is represented by a curve, the average value is the average height of the curve.

Average value can also be defined as

$$\text{Average Value} = \frac{\text{Area Under the curve of half cycle}}{\text{Base of half cycle}}$$

$$I_{av} = \frac{2\,I_m}{\pi}$$

$$V_{av} = \frac{2\,V_m}{\pi}$$

## Power factor

Power factor is a measure of efficiency .it is the ratio of power used to the power suplied

$$\text{Power factor} = \frac{\text{power USED}}{\text{power SUPPLIED}}$$

**Form factor:**

It is defined as the ratio of RMS value to the average value of alternating current or voltage.

$$\text{Form Factor} = \frac{\textbf{RMS Value}}{\textbf{Average Value}} = \frac{\frac{I_m}{\sqrt{2}}}{\frac{2I_m}{\pi}} = 1.11$$

**Peak factor: (Crest factor)**

It is defined as the ratio of maximum value to the RMS value of alternating current or voltage.

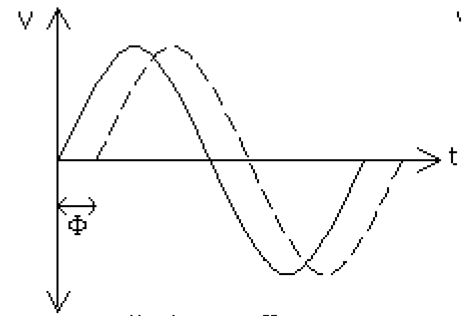
$$\text{Peak Factor} = \frac{\textbf{Maximum Value}}{\textbf{RMS Value}} = \frac{I_m}{\frac{I_m}{\sqrt{2}}} = 1.414$$

**Phase:**

The phase of an alternating quantity at any time ‘t’ is defined by the angle by which the phasor makes with reference value.

- **Phase Difference:**

The difference in angle (ϕ) between two voltages or currents is known as *phase difference*.



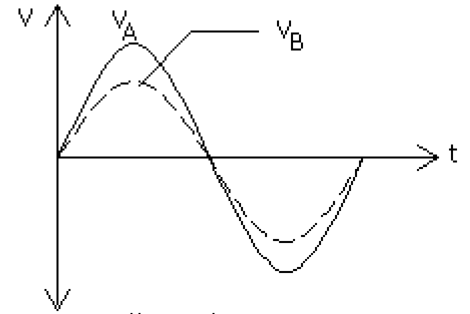
(i) Phase Difference

- **In-phase:**

If the phase difference between the two voltages is zero, then that are said to be in-phase.

In fig, VA and VB start at the same point and reach the maximum value at the same time.

The angle between VA and VB is equal to zero



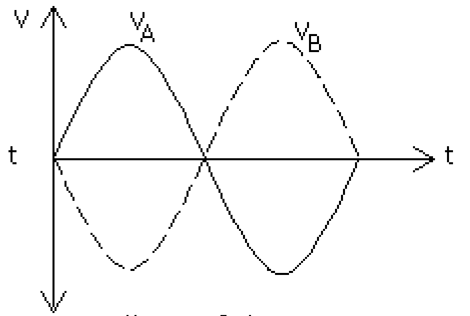
(i) In Phase

- **Out of phase:**

If the phase difference between two voltages is 180 then they are said to be out of phase.

From the figure VA and VB are out of phase. Their starting points are same,

but when voltage VA reaches its positive maximum value, VB reaches its negative maximum value.



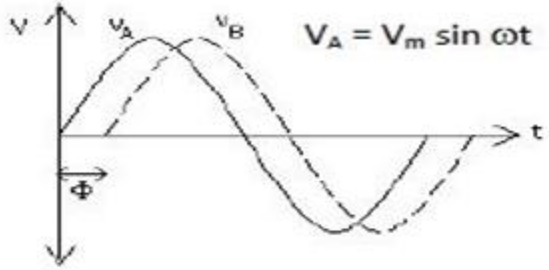
(i) Out of Phase

**Phase angle (θ):**

It is defined as the angle between the voltage and current. It is represented by 'θ'.

**Phase lag:**

A lagging alternating quantity is one, which reaches its maximum (or zero) value later as compared to another alternating quantity. $V_B$ lags $V_A$ by an angle $\phi$. A negative sign is used to denote the lagging angle.

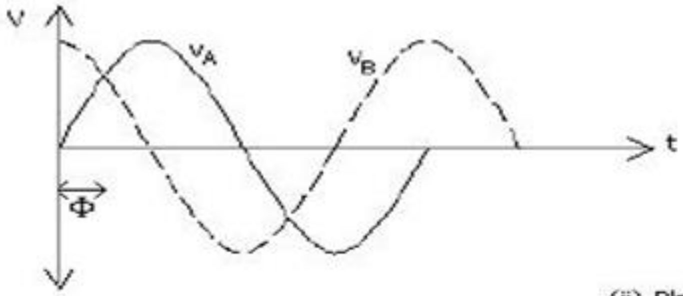



$V_A = V_m \sin \omega t$ $\quad$ $V_B = V_m \sin(\omega t - \phi)$

**Phase lead:**

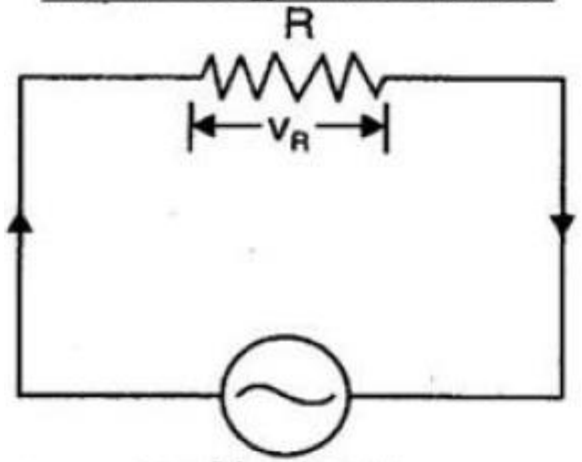
A leading quantity is one which reaches its maximum (or zero) value earlier than the other alternating quantity.

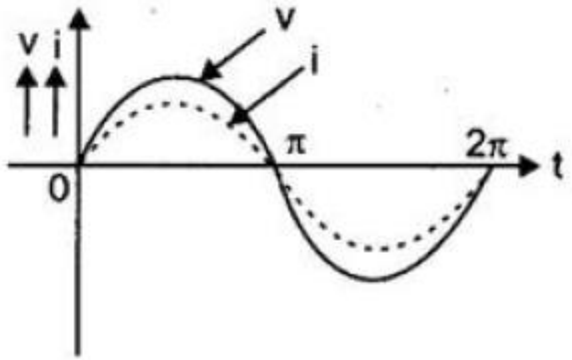
$V_A = V_m \sin \omega t$, and $\quad V_B = V_m \sin(\omega t + \phi)$ $\quad$ Where, '+' sign indicates leading




(ii) Phase Lead

## AC through resistance




when an alternating voltage is applied across resisto alternating current flows through it.

$$V = v_m \sin\omega t$$

$$V = iR$$

$$I = \frac{V}{R}$$

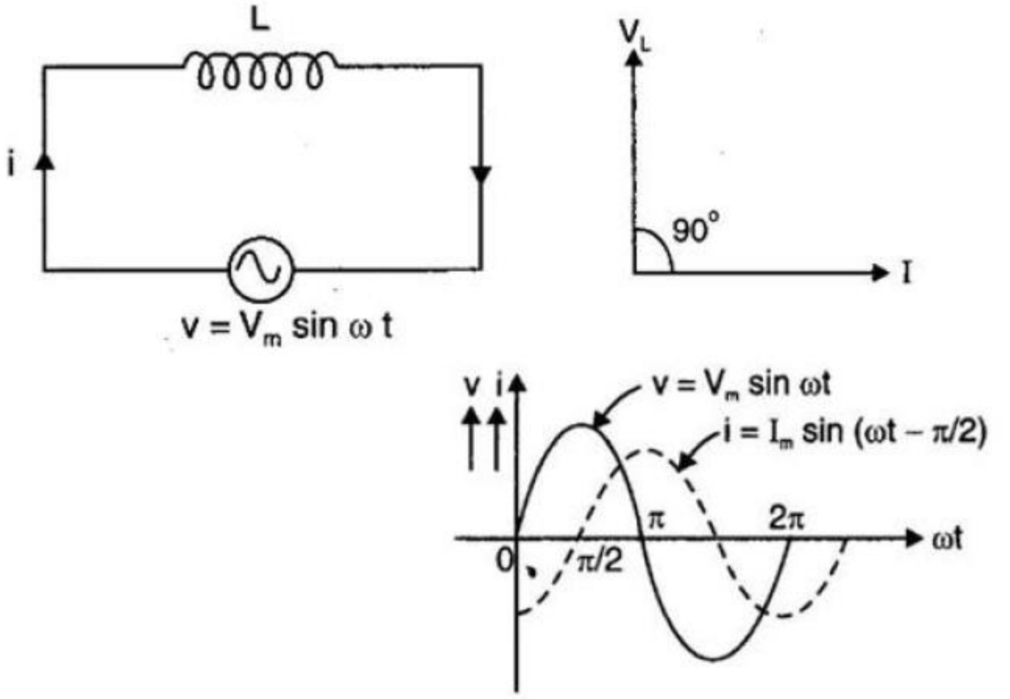
$$I = \frac{v_m}{R}\sin\omega t$$

$$i = I_m \sin\omega t$$

- Phase angle between voltage and current is zero.

# REACTANCE (INDUCTIVE)

**AC through inductance**




**When an alternating voltage is applied across inductor, alternating current flows through it.**

$$V = v_m \sin\omega t$$

$$i = I_m \sin(\omega t - \pi/2)$$

- **Phase difference between voltage and current is 90⁰. Current lag voltage by 90⁰.**

- Reactance that occurs in an inductor is known as inductive reactance. When inductive reactance is present, energy is stored in the form of a changing magnetic field, and the current waveform lags the voltage waveform by 90 degrees. Inductive reactance is caused by devices in which wire is wound circularly — such as coils and transformers.

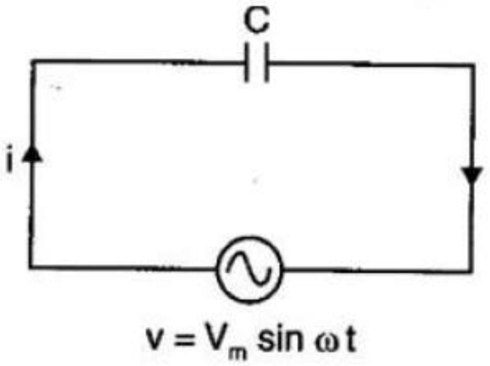
# REACTANCE (CAPACITIVE)

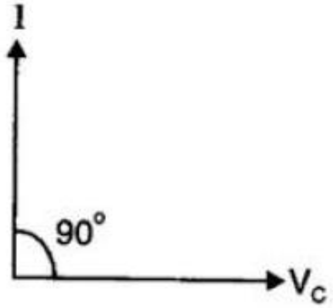
<u>AC through capacitance</u>

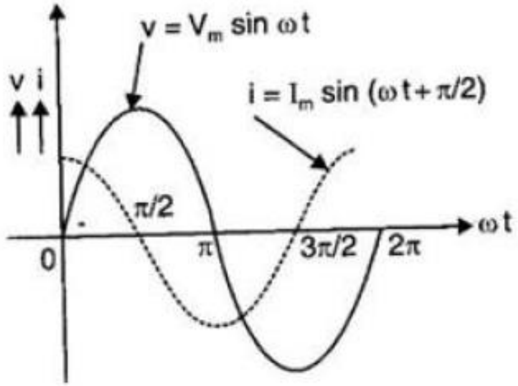
**When an alternating voltage is applied across capacitor, alternating current flows through it.**

$$V = v_m \sin\omega t$$

$$i = I_m \sin(\omega t + \pi/2)$$



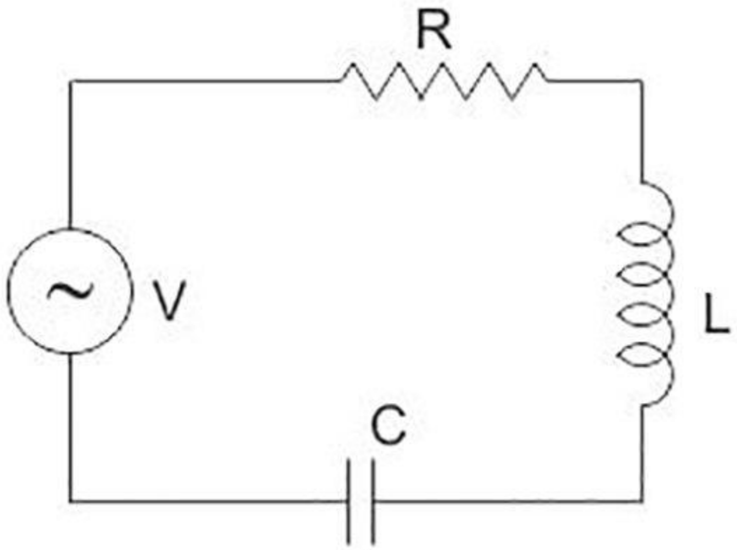




- **Phase difference between voltage and current is $90^0$. Current lead voltage by $90^0$.**

- Reactance that occurs in a capacitor is known as capacitive reactance. Capacitive reactance stores energy in the form of a changing electrical field and causes current to lead voltage by 90 degrees. Capacitance is created when two conducting plates are placed parallel to one another with a small distance between them, filled with a dielectric material (insulator).

# IMPEDANCE

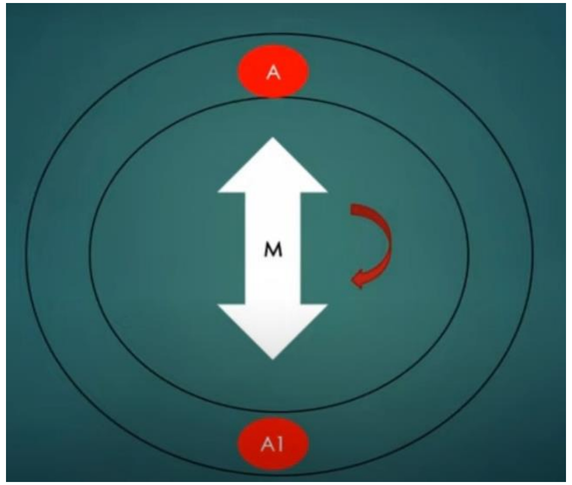
- **Impedance** is a combination of resistance and Inductive resistance and capacitive resistance. It is essentially anything and everything that obstructs the flow of electrons within an electrical circuit. It is present in all the possible components of the circuit. Impedance unit Is **ohm**.



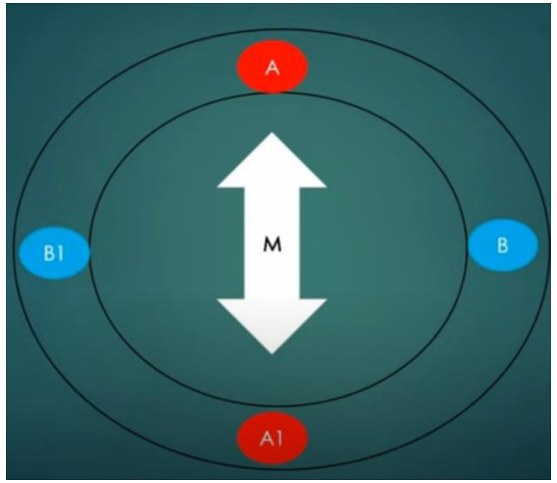

AC through resistor , inductor, capacitor

# SINGLE PHASE AND THREE PHASE

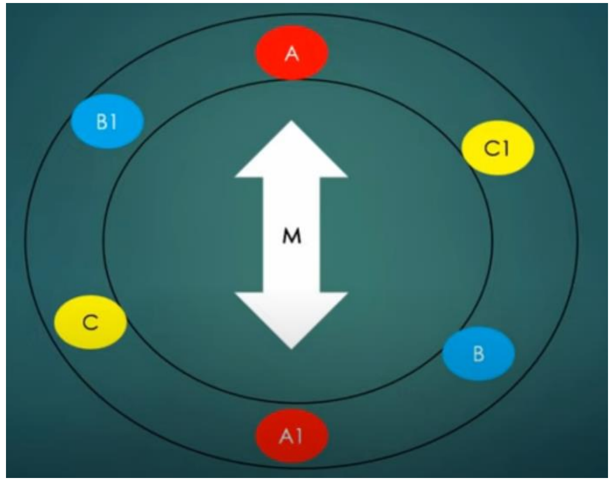
- Electrical energy is generated transmitted and distributed in the form of three-phase power. Homes and small premises are connected with single-phase power. three-phase power is more preferred over single-phase power. The three-phase machineries are more efficient than single-phase
- In single phase only one winding is there and if magnet rotates only one sinusoidal voltage will be induced in windings and power output is fluctuating and average power is half of peak power .and in two phase ,the windings are arranged in 90 degree and power output is constant and equal to peak power .but in case of three phase windings are arranged in 120 degrees the power output is constant will be 1.5 times that of peak power



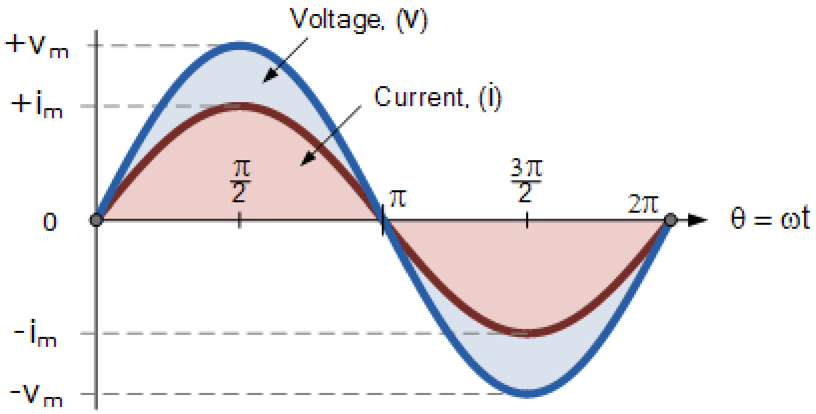

Single phase arrangement



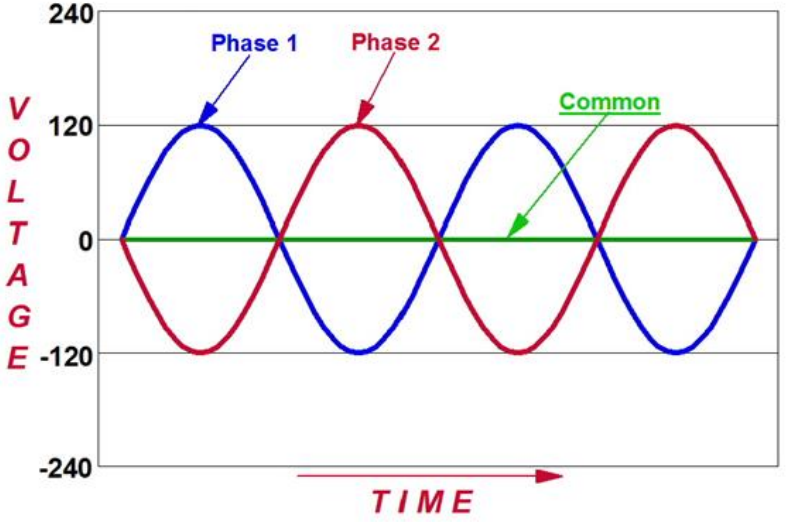

Two phase arrangement



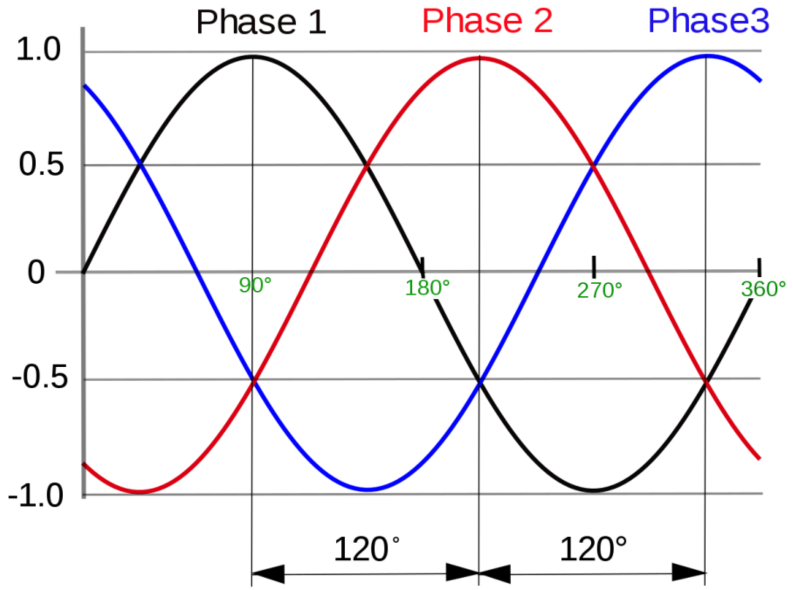

Three phase arrangement




Single phase
Voltage and current




Two phase




Three phase

| Single Phase Power Supply | Three Phase Power Supply |
|---|---|
| Single Phase Power Supply requires two conductors | Three Phase Power Supply requires three conductors |
| The two wires (conductors) in single phase system are called Phase and Neutral | All the three wires (conductors) in three phase system are called phases |
| Since there is only a single wire, there is only one AC Signal (usually a Sinusoidal Wave) | The three wires in three phase supply carry AC signal of its own and the three signals are 120° apart |
| Power delivery in single phase supply is not consistent due to peaks and dips in voltage | Due to three conductors with 120° phase difference, the power delivery in three phase supply is always steady and consistent (the peaks and dips of the three AC signal are compensated by each other) |
| The supply voltage in single phase power supply is ≈230V | In three phase power supply, the supply voltage is ≈415V |
| Single Phase supply is relatively less efficient than a three phase supply for the same power delivery | Three Phase Power Supply is more efficient as it can deliver three times the power than a single phase power supply with just one additional wire |
| Usually, Single Phase Power Supply is served to residential and domestic needs (often, split phase from a three phase supply) | Three Phase Power Supply is usually served to large commercial centers and industries |
| It is ideal for small loads like lighting and heating | Three Phase Supply can handle large industrial motors |
| Single Phase Power Supplies always have a neutral wire (it acts as a return path from the load) | Neutral wire is optional in Three Phase Power Supplies (Delta Connections have no neutral wire, but Star Connections may or may not have neutral wire) |
| The chance of fault is higher as a Single Phase Power Supply has only one phase (if it fails, then there is no power) | Even if there is fault in one or two phases, the remaining phase(s) will continue to deliver power in Three Phase Power Supply. So, the chance of fault is less |

# STAR AND DELTA CONNECTION

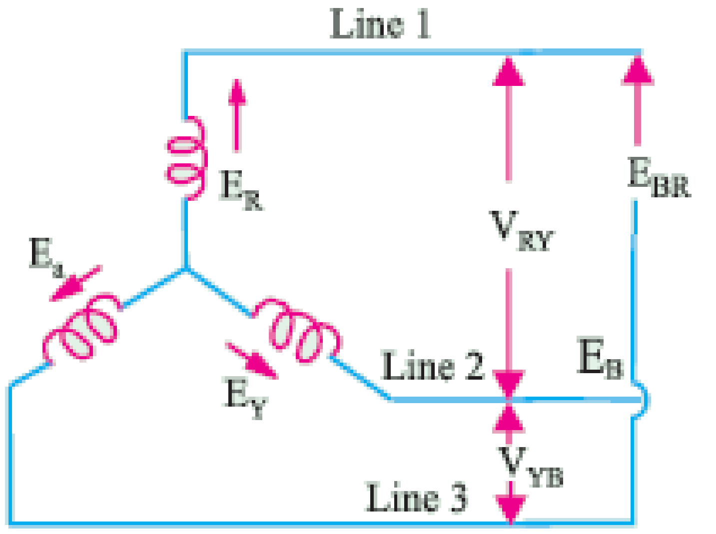
In a three phase system, there are three windings or phases. Each phase has two terminals ie, start and finish. The three windings are interconnected in two methods. They are

(1) Star or Wye connection (Y)

(2) Delta or Mesh connection (Δ)

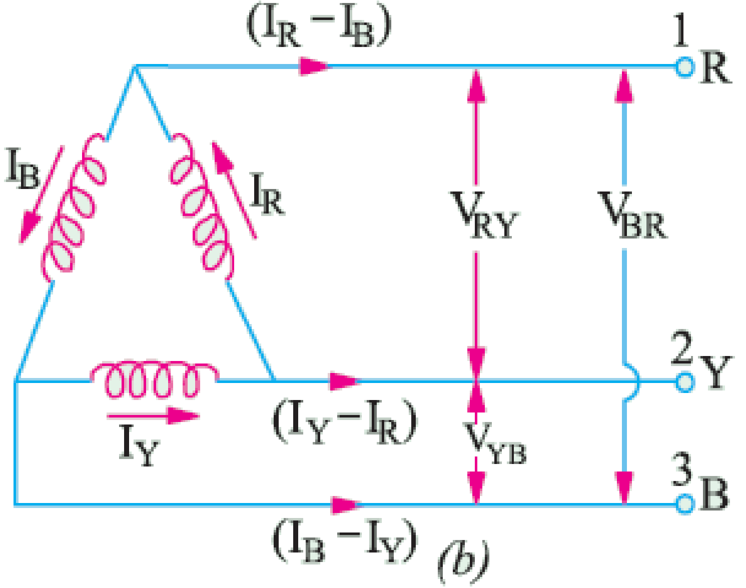
**STAR OR WYE CONNECTION (Y)**

- In this method similar ends of the three phases are joined together to form a common junction N. The junction N is called the star point or neutral point. star – star connected transfor transformer..



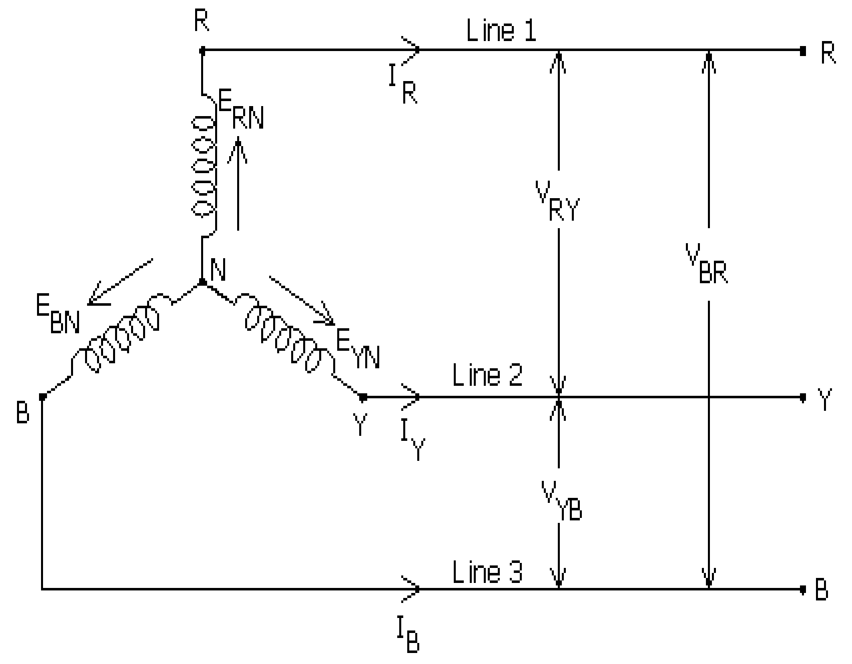

**DELTA OR MESH CONNECTION** (Δ)

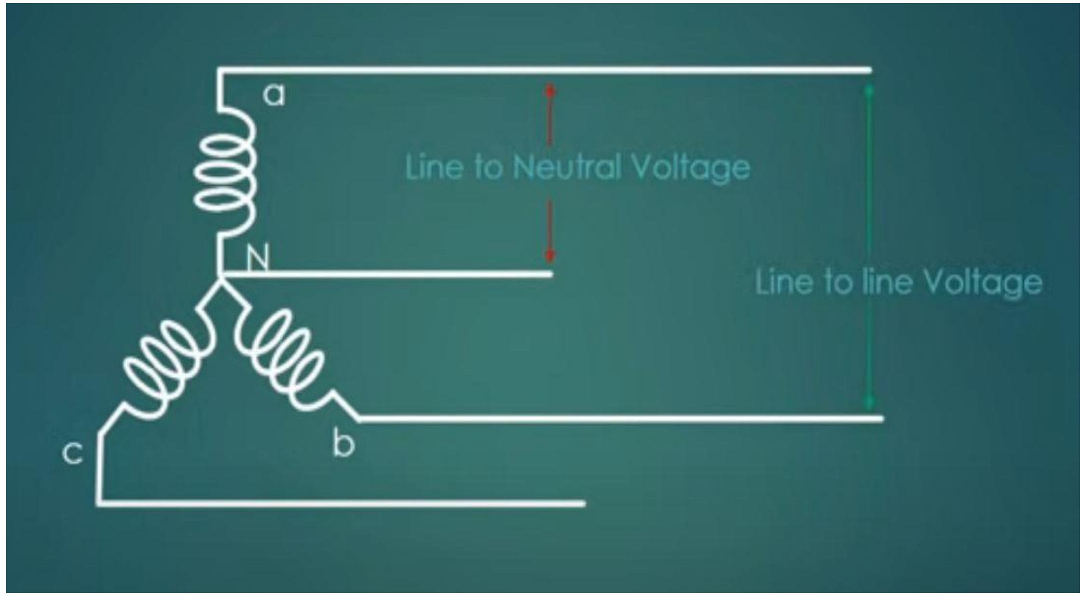
- In this method of interconnection, the dissimilar ends of three phase windings are joined together i.e., finishing end of one phase is connected to the starting end of the other phase Delta – delta connected transformer is generally used for high voltage transmission

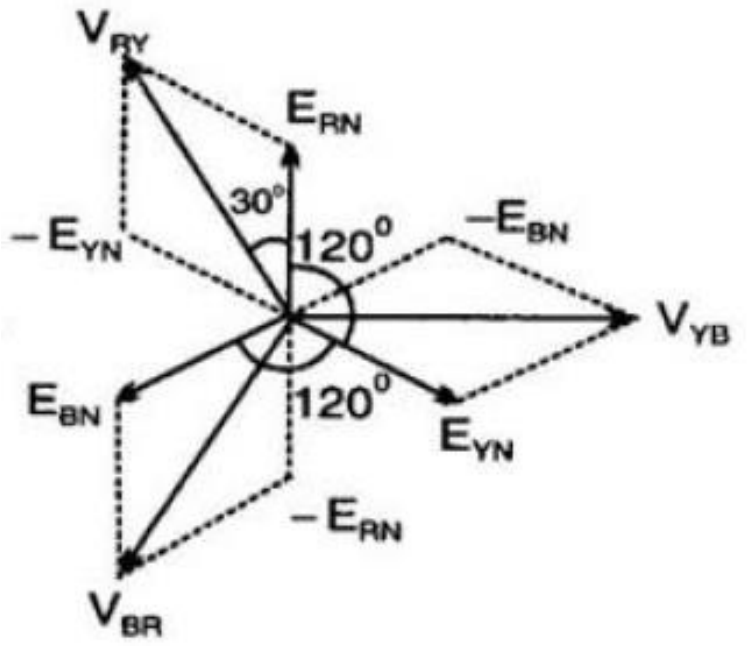


# Relationship between line current and phase current, line voltage and phase voltage in a star connected system

- In star connection, the three phases are joined together to form a common junction N. N is the star point or neutral point. When three phases supply feeds a balanced load, the current in three phase conductors will be equal in magnitude and displaced $120^0$ from each other.

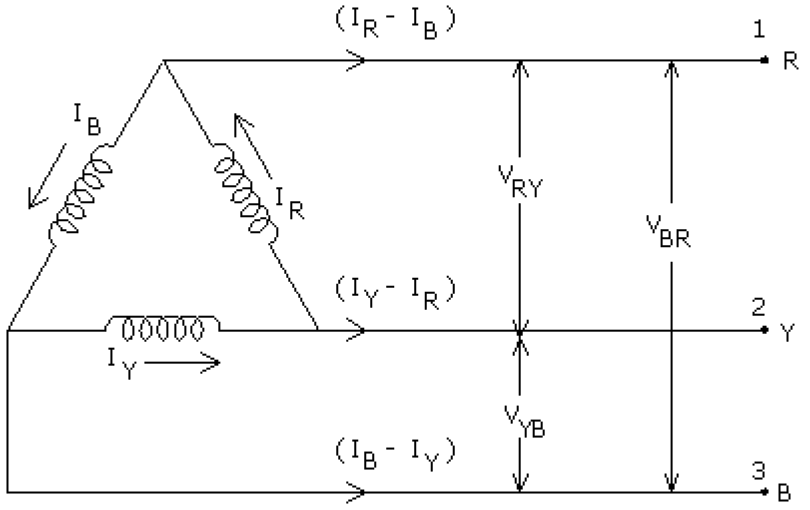


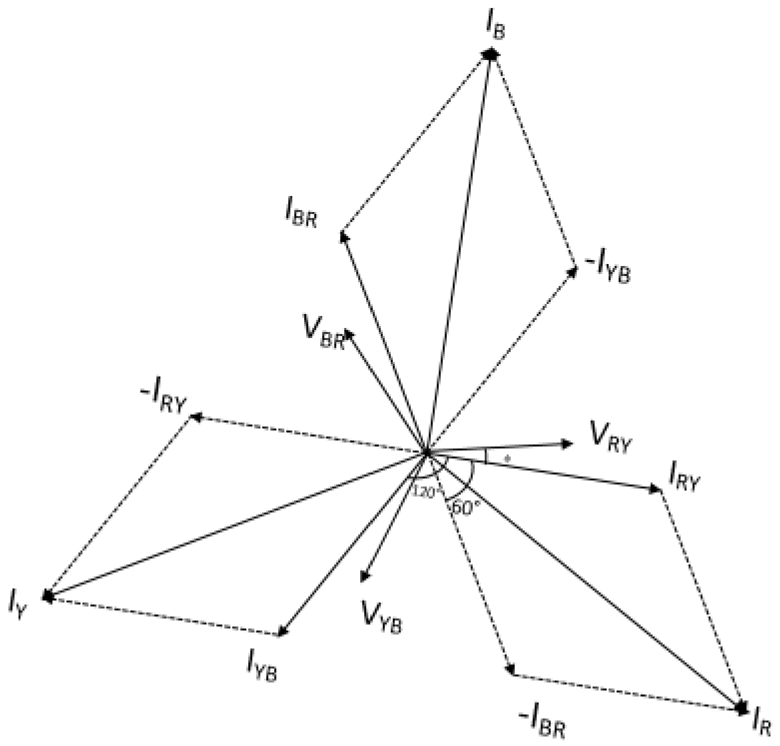



# Relationship between line current and phase current, line voltage and phase voltage in a delta connected system.

- In delta connection, the three windings are joined in series to form a closed mesh as shown in fig. If the system is balanced then sum of the three voltages around the closed mesh is zero. It has no common point.
- *Line Voltage and Phase Voltage:*
- In delta connection, Line voltage is equal to phase voltage.



| Star (Y) Connection | Delta (Δ) Connection |
|---|---|
| In STAR connection, the starting or finishing ends (Similar ends) of three coils are connected together to form the neutral point. A common wire is taken out from the neutral point which is called Neutral. | In DELTA connection, the opposite ends of three coils are connected together. In other words, the end of each coil is connected with the start of another coil, and three wires are taken out from the coil joints |
| There is a **Neutral** or **Star Point** | No Neutral Point in Delta Connection |
| Three phase four wire system is derived from Star Connections **(3-Phase, 4 Wires System)** We may Also derived 3 Phase 3 Wire System from Star Connection | Three phase three wire system is derived from Delta Connections **(3-Phase, 3 Wires System)** |
| Line Current is Equal to Phase Current. i.e.<br>Line Current = Phase Current<br>$I_L = I_{Ph}$ | Line Voltage is Equal to Phase Voltage. i.e.<br>Line Voltage = Phase Voltage<br>$V_L = V_{Ph}$ |
| Line Voltage is √3 times of Phase Voltage. i.e.<br>$VL = \sqrt{3}\ V_{Ph}$ | Line Current is √3 times of Phase Current. i.e.<br>$I_L = \sqrt{3}\ I_{Ph}$ |
| The Total Power of three phases could be found by<br>$P = \sqrt{3} \times V_L \times I_L \times \cos\Phi$ …. Or<br>$P = 3 \times V_{Ph} \times I_{Ph} \times \cos\Phi$ | The Total Power of three phases could be found by<br>$P = \sqrt{3} \times V_L \times I_L \times \cos\Phi$ … or<br>$P = 3 \times V_{Ph} \times I_{PH} \times \cos\Phi$ |

- **Advantages of star connection:**

i) In star connection, phase voltage $V_{ph}=V_l/\sqrt{3}$. Hence a star connected alternator will require less number of turns than a Δ - connected alternator for the same line voltage.

ii) For the same line voltage, a star connected alternator requires less insulation than a delta connected alternator

iii) In star connection, we can get 3-phase 4-wire system. This permits to use two voltages viz., phase voltages as well as line voltages.

iv) Single phase loads can be connected between any one line and neutral wire while the 3-phase loads can be put across the three lines. Such flexibility is not available in Δ - connection.

v) In star connection, the neutral point can be earthed.

- **Advantages of delta connection:**

1. Most of 3- phase induction motors are delta connected.
2. Delta connection is most suitable for rotary convertors.
3. High Reliability

## ELECTRICAL POWER

The electrical energy consumed by a electrical device in unit time is called electrical power.

Unit is watt (W)

Power (P) = $I^2R$

We have;

$I = V/R$

$P = (V/R)^2 \times R$

Power (P) = $V^2/R$

We have;

$R = V/I$

$P = I^2 \times V/I$

Power (P) = $I \times V$

## ELECTRICAL ENERGY

It is the total work done in an electrical circuit.

Unit is kilo watt hour (KWh)

Energy in KWh = $(P \times t)/1000$

Where;

P = power in watts

t = time in hours

**Relation between Mechanical, Electrical & Thermal Energy:**

1 N-M = 1 Joule = 1 watt-sec

**Electrical to Thermal energy:** {KWH = Kilo Watt Hour}

1 KWH = 1000 x 60 x 60 watt-sec (1 watt sec = 1 Joule)

**Electrical Power to Mechanical Power:**

1 KW = 1000 watts {KW = Kilo Watts}

## PROBLEMS

1) A residential house has the following loads

- 10 lamps of 60W working for 8 hrs/day.
- 4 lamps of 40W working for 6 hrs/day.
- 1KW motor working for 2 hrs/day.
- 1 heater of 2000W working for 1hr/day

Calculate the monthly electrical bill at the rate of 2.5/KWh, for a month of 30days.

2) A residential house has the following loads

- A fan of 60W working for 10 hrs/day.
- 3 lamps of 45W working for 5 hrs/day.
- 2 A/Cs of 1.5 KW working for 30 minutes/day.
- 1 heater of 2000W working for 1hr/day

Calculate the monthly electrical bill at the rate of 2/KWh, for a month of 30days.

# FUNDAMENTALS OF ELECTRICAL ENGINEERING

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GOVT POLY TECHNIC
MANANTHAVADY

# SYLLABUS

**Contents:**

DC Motors- Principle of operation - classification based on field connection-applications of dc motors.

Three Phase AC Motors -three phase induction motors- working principle -constructional details - applications

Single Phase AC motors-single phase induction motor - working principle -constructional details -applications

Starters - necessity for a starter-dc motor starters-connection and working of 3 Point starter -ac motor starters-connections and working of DOL,star-delta starters.

# DC MOTOR PRINCIPLE OFF OPERATION

- An Electric motor is a machine which converts electric energy into mechanical energy. Its action is based on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's Left-hand Rule and whose magnitude is given by $F = BIl$ Newton.

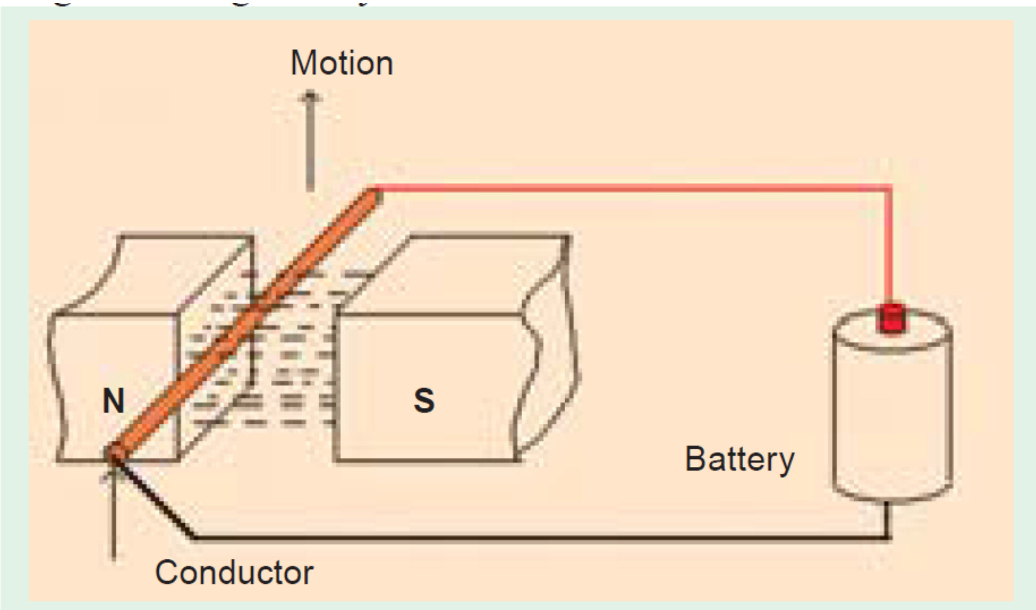
  F= Force experienced by the conductor

  B = Flux density in the air gap

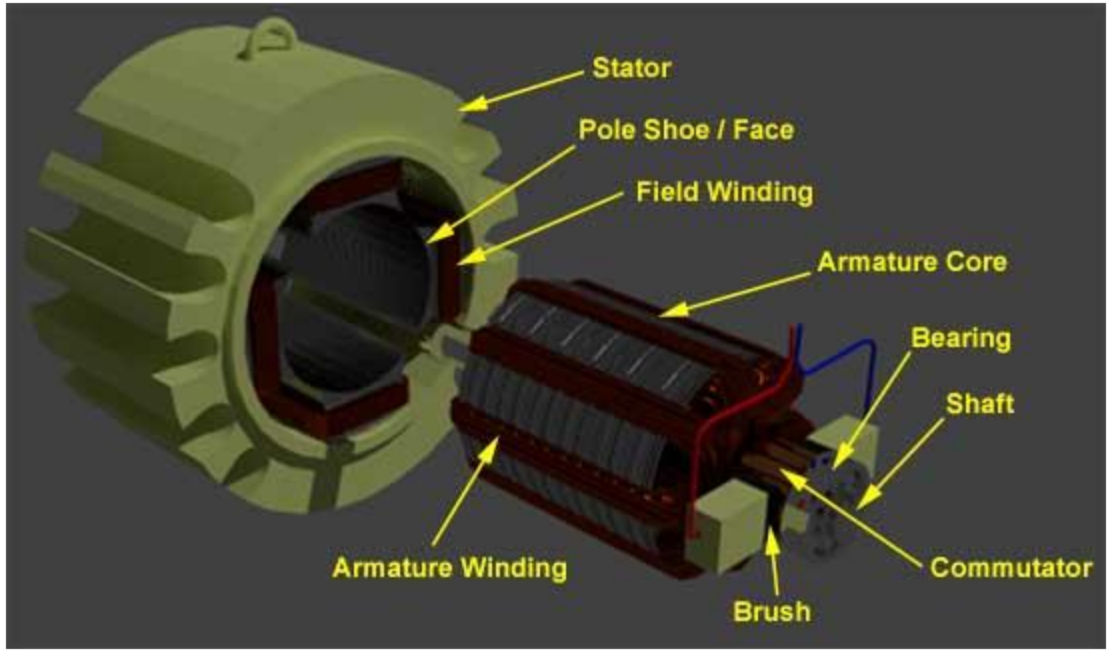
  I = Current carried by the conductor

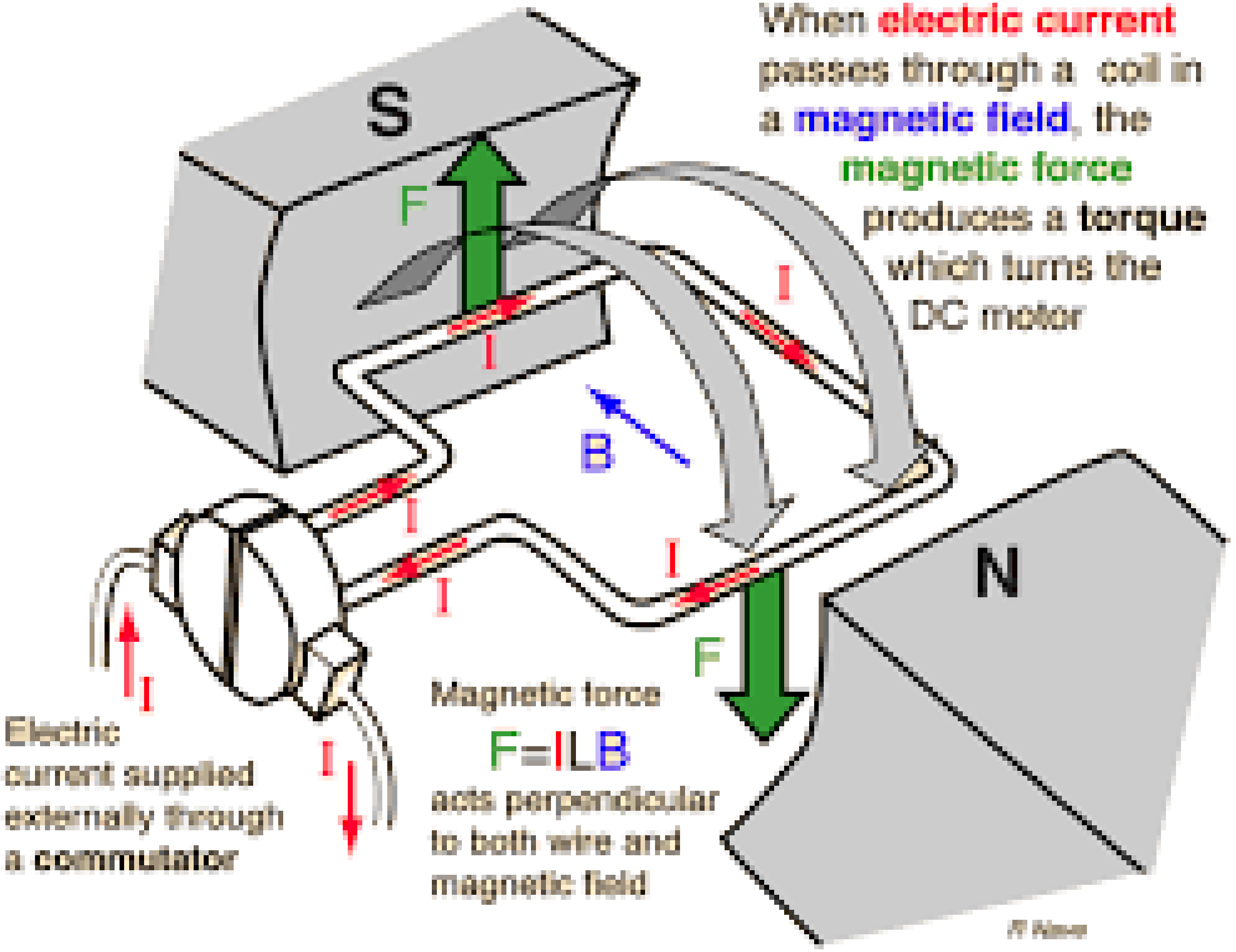
  l = Length of the conductor

- When DC motor field magnets are excited and its armature conductors are supplied with current from the supply mains, they experience a force tending to rotate the armature. Fleming's Left-hand Rule gives the direction of the force on each conductor. each conductor experiences a force $F$ which tends to rotate the armature. These forces collectively produce a driving torque which sets the armature rotating. the function of a commutator is to reverse the current in each conductor as it passes from one pole to another, it helps to develop a continuous and unidirectional torque.
- When armature coil completed 180 degree rotation, position of commutator changes. So direction of torque on a DC motor is uni-directional. So motor rotates in one direction.




Principle of Motor



**construction of DC motor**

- 1. Stator – The static part that houses the field windings and receives the supply and,
- 2. Rotor – The rotating part that brings about the mechanical rotations.

Other parts -1. Yoke of DC motor.

2. Poles of DC motor.
3. Field winding of DC motor.
4. Armature winding of DC motor.
5. Commutator of DC motor.
6. Brushes of DC motor.

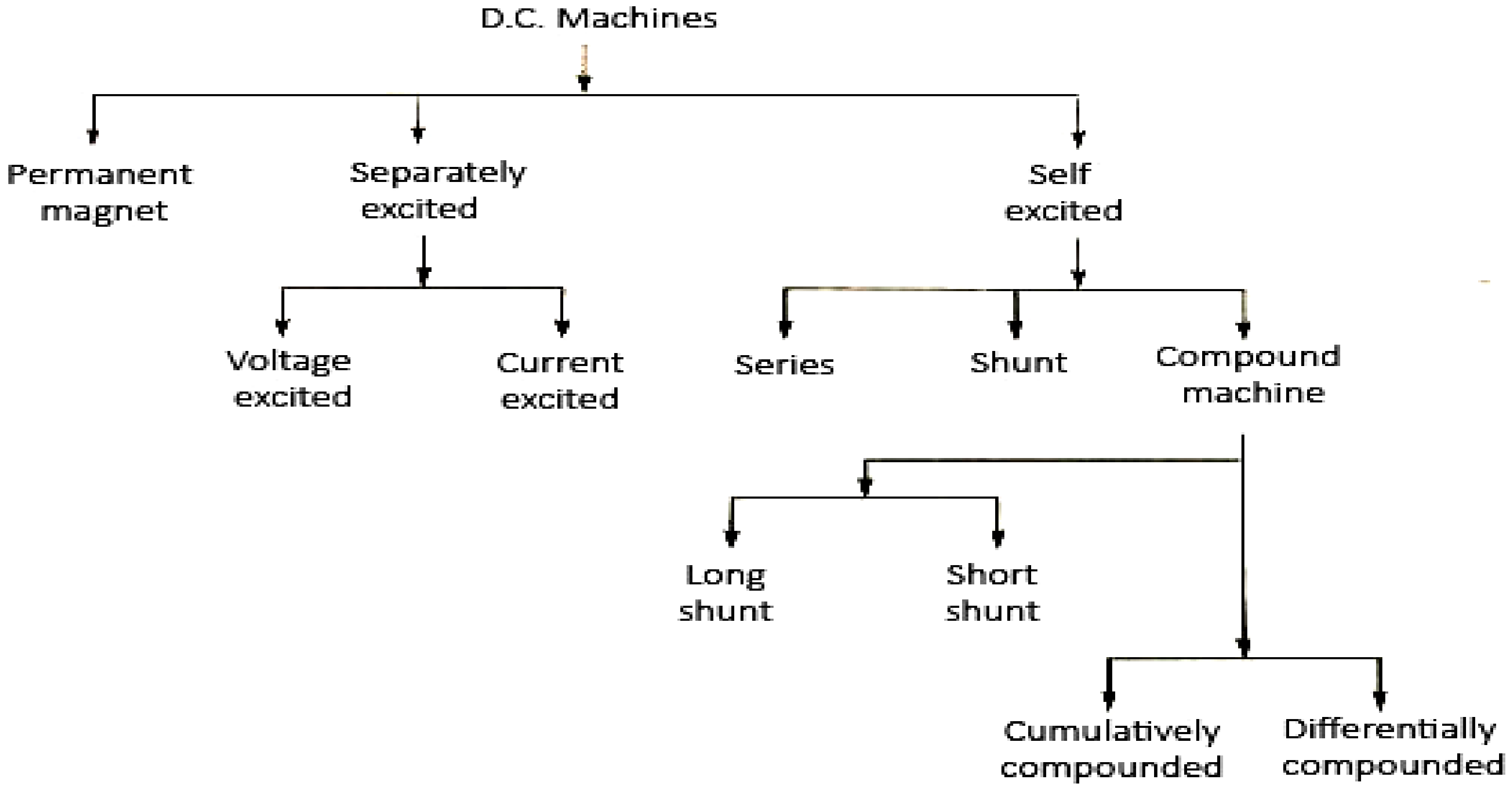
**BACK EMF(OR) COUNTER EMF:**

- When DC supply is given to DC motor its armature starts rotating. The armature rotates and cuts the static magnetic flux produced by the field magnets. Therefore an e.m.f is induced in the armature conductor as per Faraday's laws of Electromagnetic induction. By Lenz's law, this induced e.m.f will oppose the supply voltage. Hence the e.m.f induced in the armature is called back e.m.f (or) counter e.m.f (Eb).

**Significance of Back e.m.f:**

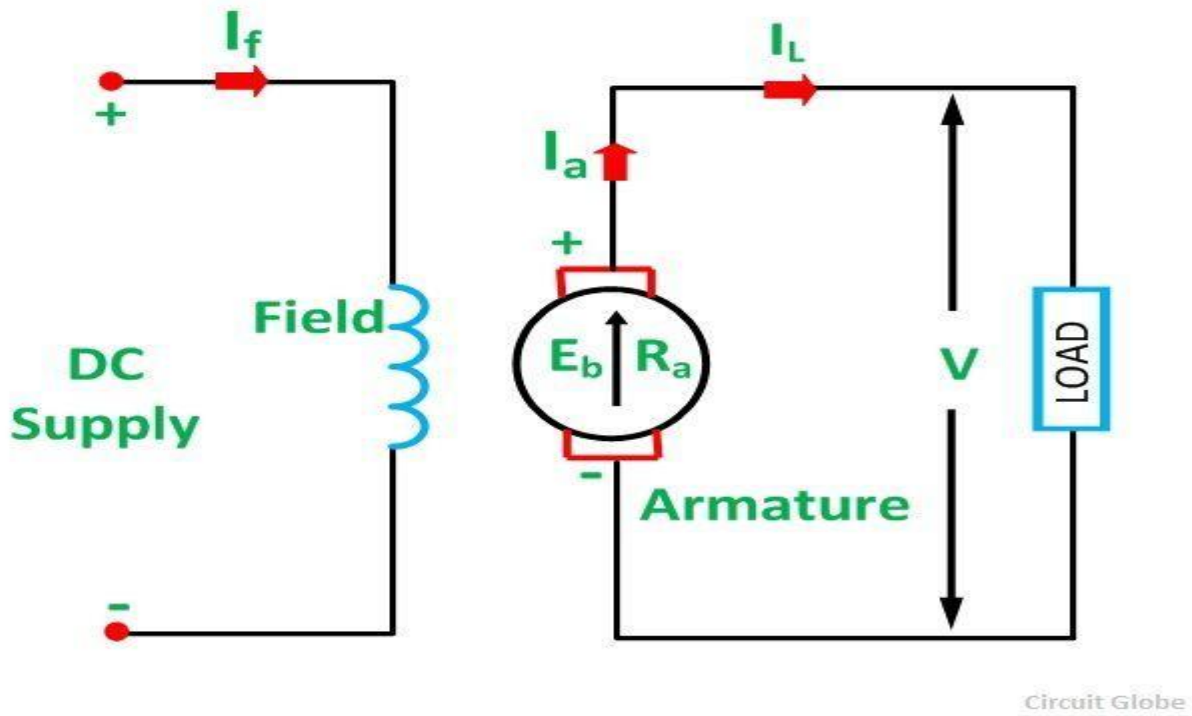
- 1. The back e.m.f in a DC motor regulates the flow of armature current, i.e. automatically changes the armature current to meet the load requirements and it makes the motor as a self regulating one.
- 2. The electric work done in overcoming and causing the current to flow against back EMF is converted into mechanical energy developed in the armature. Therefore the energy conversion in a DC motor is only possible due to the production of back EMF.

# CLASSIFICATION OF DC MOTOR



# 1. SEPARATELY EXCITED DC MOTOR

- $I_f$ = field current
- $I_a$ = armature current
- $I_l$ =load current
- $E_b$= back emf
- $R_a$=armature resistance




Here supply to field winding and armature winding is separate .

Here, the field coil is energized from a separate DC voltage source and the armature coil is also energized from another source. Armature voltage source may be variable but, independent constant DC voltage is used for energizing the field coil. So, those coils are electrically isolated from each other, and this connection is the specialty of this type of DC motor.

**Application**

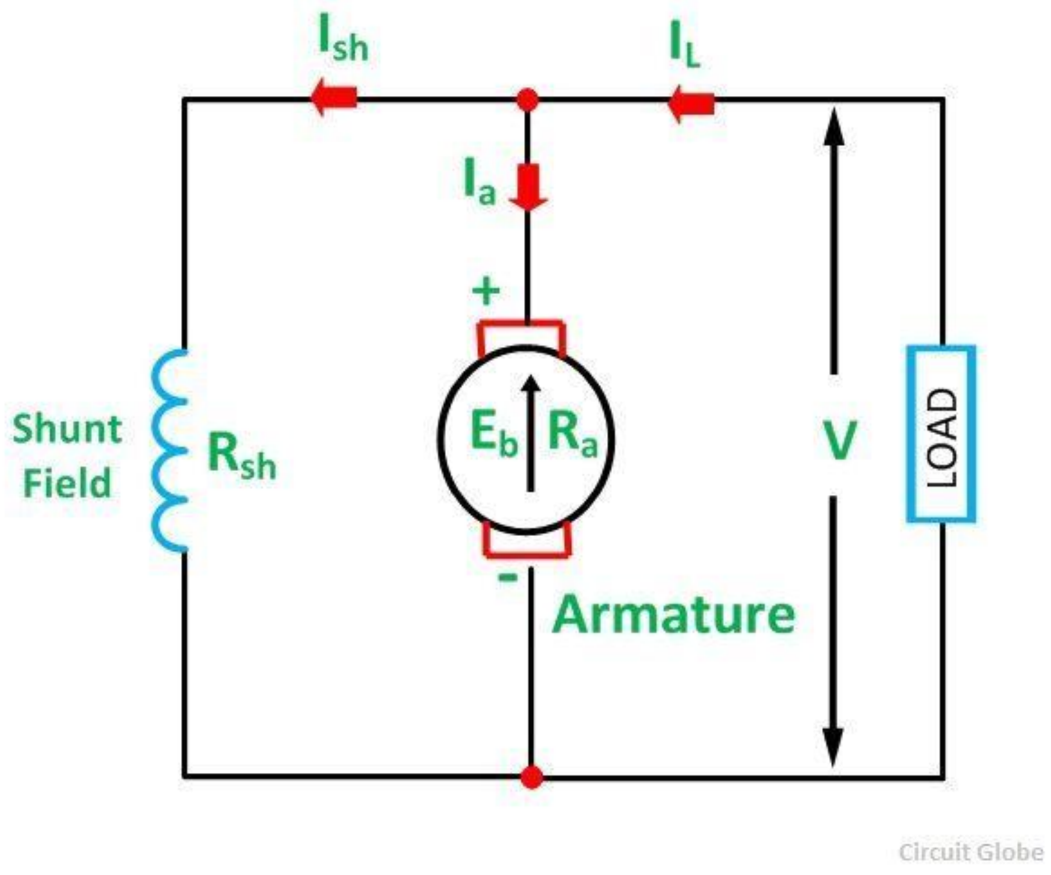
Separately excited dc motors have industrial applications. They are often used as actuators. This type of motors is used in trains and for automatic traction purposes.

# 2. SELF EXCITED DC MOTOR

in the case of self excited DC motor, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding. Based on field connection self excited DC motor is classified as

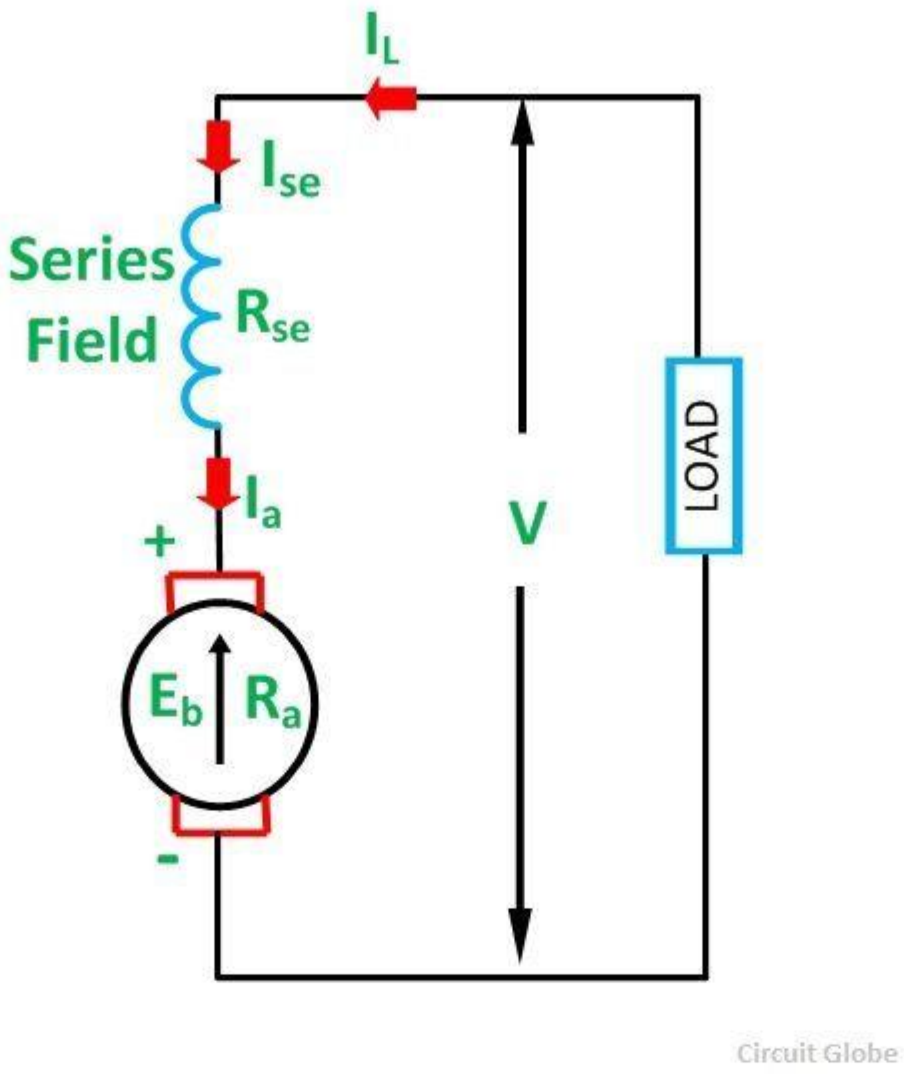
**A) DC Shunt motor**

- It is a self-excited DC motor
- Here field winding is connected in parallel to armature winding
- DC shunt motor is a constant speed motor, because its speed does not vary with variation of load on the motor
- The parallel combination of two windings is connected across a common dc power supply.
- The resistance of shunt field winding (Rsh) is always higher than that is armature winding.
- This is because the number of turns for the field winding is more than that of armature winding.
- The cross-sectional area of the wire used for field winding is smaller than that of the wire used for armature winding.
- Application: Used in Lathe , Centrifugal pump



**B) DC series motor**

- It is a self-excited DC motor
- Here field winding is connected in series to armature winding
- The field winding is connected in series with the armature.
- The current passing through the series winding is same as the armature current .
- Therefore the series field winding has fewer turns of thick wire than the shunt field winding.
- Also therefore the field winding will posses a low resistance then the armature winding.
- DC series motor is not a constant speed motor. Its speed can be widely varied.
- Starting torque of DC series motor is very high
- Application: Used for traction purpose, used in cranes, conveyors, rapid transit system



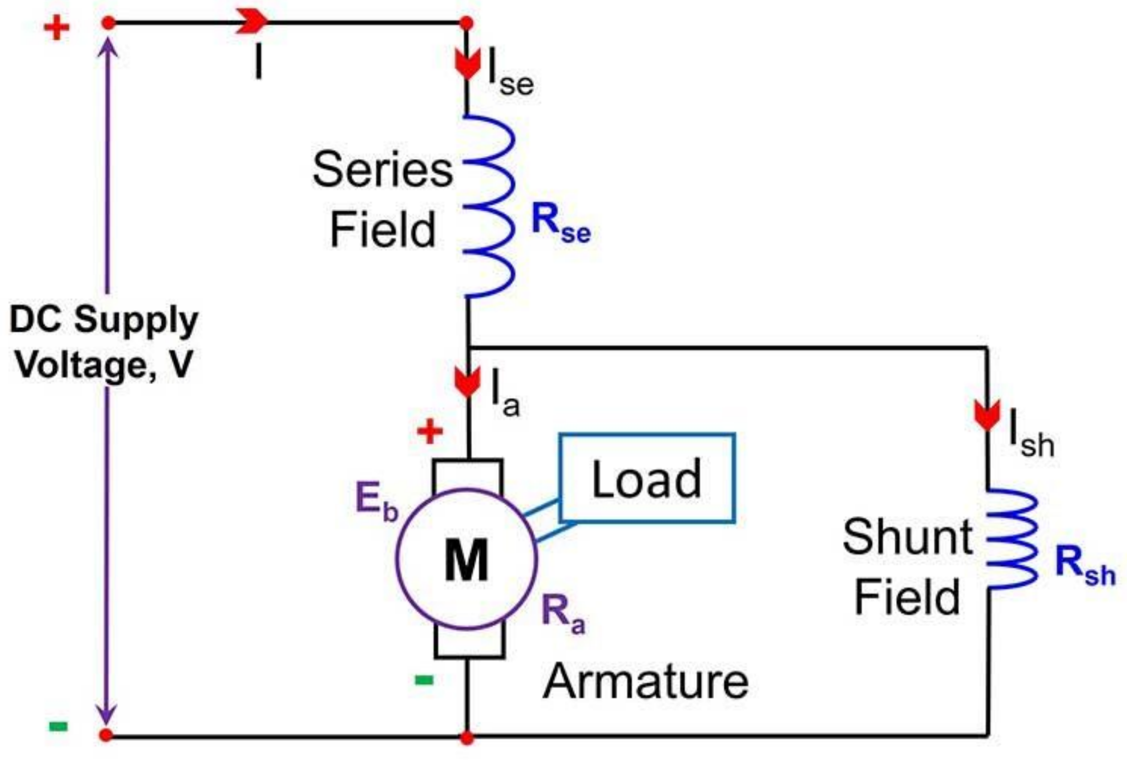
**C) DC Compound motor**

- It is a self-excited DC motor
- Here field winding is connected both in series and in parallel to the armature winding

a. Short shunt DC motor

Here shunt field winding is connected parallel to armature winding

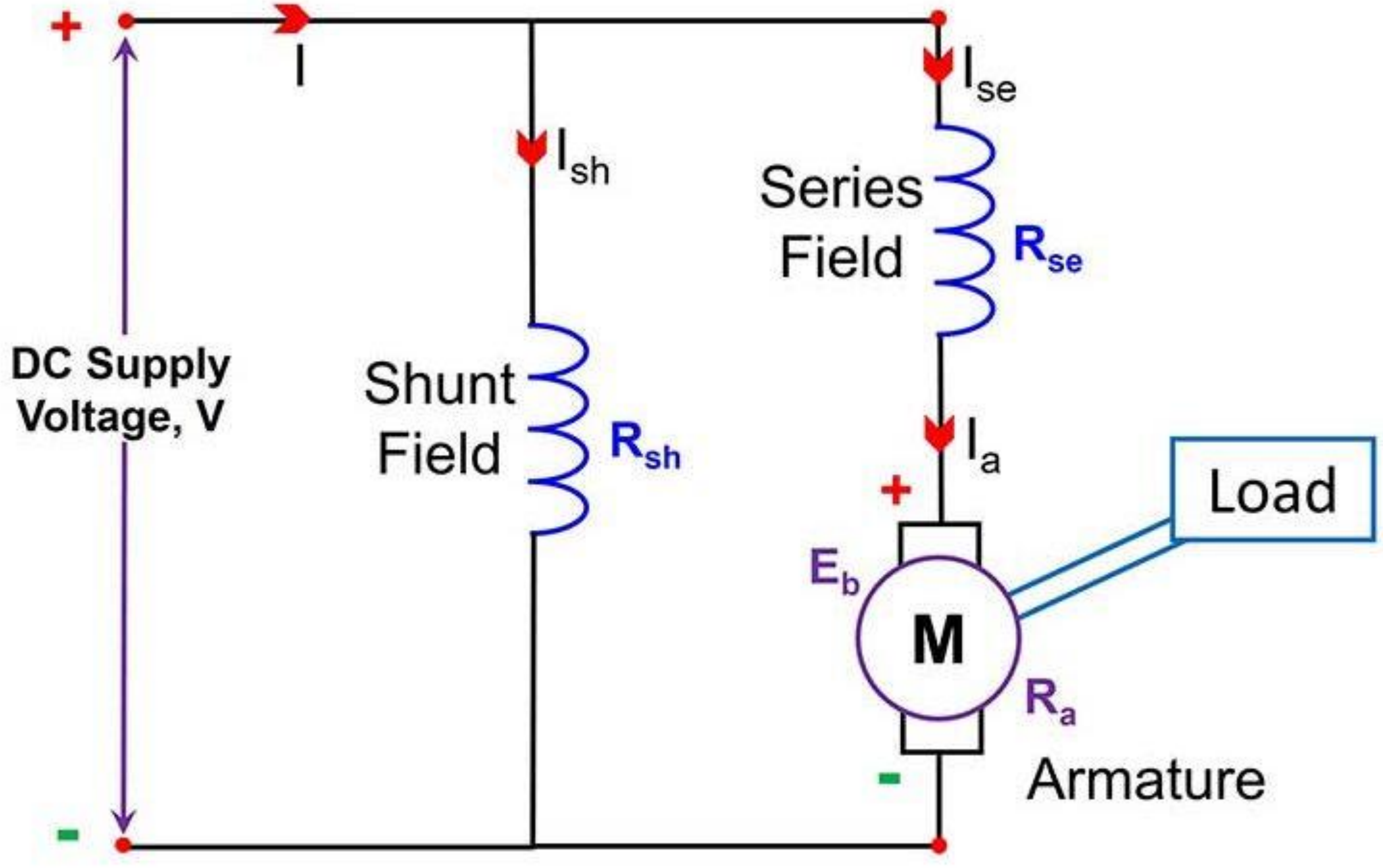
- In short shunt compound motor the series winding is connected in series to the parallel combination of armature and the shunt winding
- This is done to get good starting torque and constant speed characteristics.




**Short Shunt DC Compound Motor**

b. **Long Shunt DC motor**

- • In this the series winding is connected in series with the armature winding and the shunt winding is connected in parallel with the armature connection.
- • Application: Used in elevators, conveyors, rolling mills, punches




Long Shunt DC Compound Motor

DC compound motor can be further classified as

- a. **Cumulatively compounded DC motor**
- In this motor magnetic field produced by series field winding and shunt field winding is in same direction
- b. **Differentially compounded DC motor**
- In this motor magnetic field produced by series field winding and shunt field winding is in opposite direction

# APPLICATIONS OF DC MOTOR

- **Shunt motor:**

Dc shunt motors are used where the speed has to remain nearly constant with load and where a high starting torque is not required. Thus shunt motors may be used for driving centrifugal pumps and light machine tools, wood working machines, lathe etc.,

- **Series motor:**

Series motors are used where the load is directly attached to the shaft or through a gear arrangement and where there is no danger of the load being " thrown off". Series motors are ideal for use in electric trains, where the self-weight of the train acts as load and for cranes, hoists, fans, blowers, conveyers, lifts etc. where the starting torque requirement is high.

- **Compound motor:**

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

# THREE PHASE AC INDUCTION MOTOR (IM)

- **Application of 3 phase INDUCTION MOTOR**
- 1. Lifts
- 2. Crane
- 3. Hoist
- 4. Water pump (high rated)
- 5. Crushers (Eg- ice crusher)
- 6. Lathe machines
- 7. Oil extracting mills
- 8. Large capacity exhaust fan

# WORKING PRINCIPLE OF THREE PHASE INDUCTION MOTOR

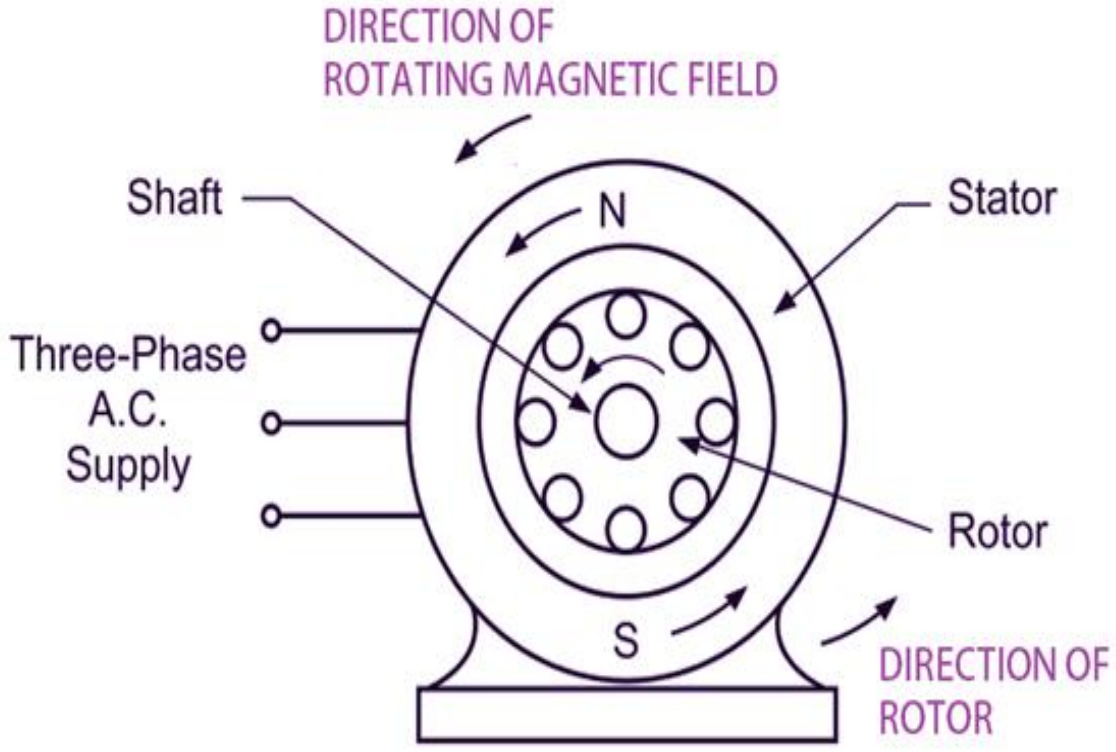
1. When a three-phase supply is given to three phase winding on the stator, a rotating magnetic field having constant magnitude and speed equal to synchronous speed is developed

2. This rotating magnetic field cuts the stationery rotor conductors. So an emf is induced in the rotor conductors according to faradays law of electromagnetic induction.

3. Since rotor circuit is closed, a rotor current will flow through rotor conductors due to the induced emf.

4. According to lenzs's law, direction of current in the rotor will be in such a way that it opposes the cause which producing it

5. Here the cause for producing rotor current was relative speed between rotating magnetic field and rotor. So according to Lenz's law to oppose the cause of production of rotor current, the rotor starts to rotate in the same direction of rotating magnetic field



- **Rotating magnetic field**

When a three-phase supply is given to 3 phase induction motor having three phase windings placed 120 degree apart from each other, a rotating magnetic field having constant magnitude and speed is obtained. Magnitude =1.5 times the flux in each phase and speed =Ns=120f/P

( f=frequency of supply, P= Number of poles in stator)

Ns=Synchronous speed is equivalent to a magnetic pole rotated mechanically.

**Slip**

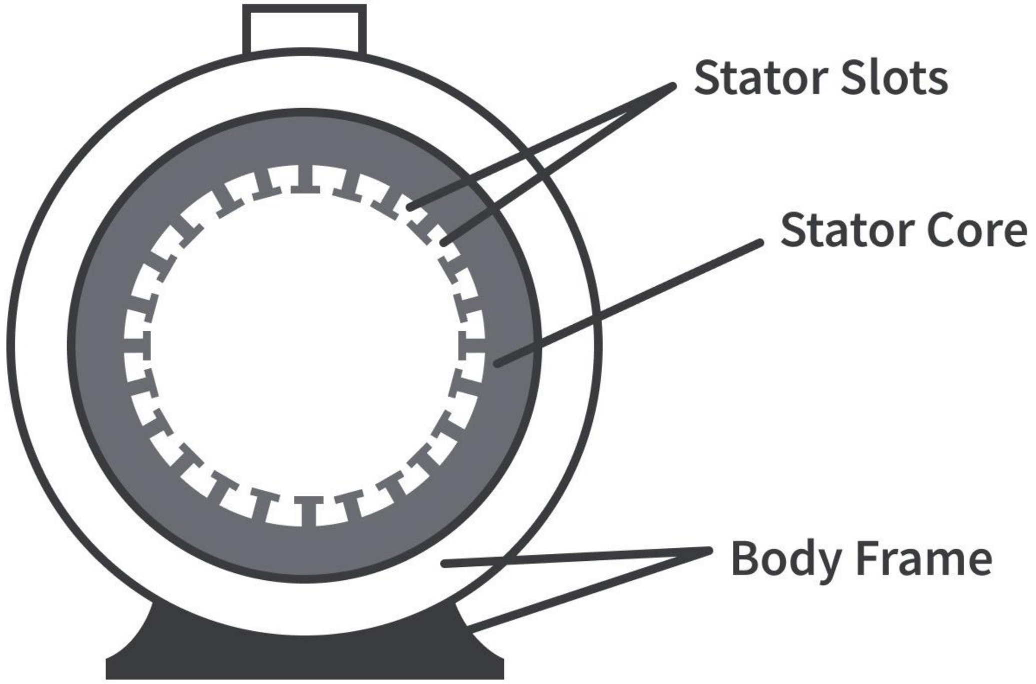
- The difference between synchronous speed of stator rotating magnetic field (Ns) and rotor speed(Nr) is called slip or slip speed. It is usually expressed as percentage of synchronous speed

% Slip=$\frac{(Ns-Nr)}{Ns}$. For an IM, Slip is between 0 and 1

- **Construction details of 3 phase induction motor**

INDUCTION MOTOR consists of mainly 2 parts. Stator and rotor.

- **Stator**
- It is the static part. The main parts of it are stator frame, stator core, stator winding and stator slots.
- Stator frame: It is used for providing mechanical protection to the motor from external forces. It is made of cast iron. Other function of this is to provide mechanical support to stator core.
- Stator core**:** It is made up of laminated silicon steel material. This stator core is connected to stator frame using nuts and bolts. It is laminated to reduce eddy current loss. Inner periphery of it contain slots. In this slot three phase winding made up of copper are present. This 3-phase winding in stator core may be either star connected or delta connected.




- **Rotor**

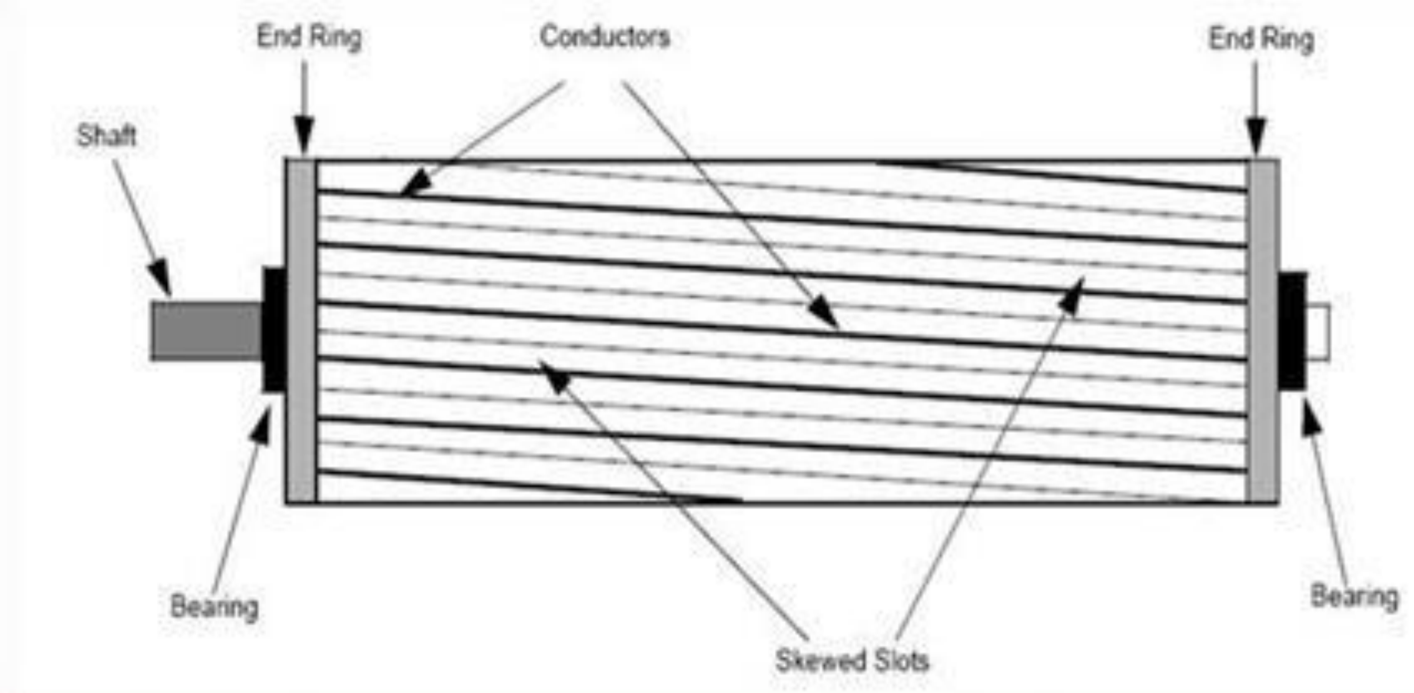
Based on rotor construction, rotors are divided in to two types

- 1. Squirrel cage type rotor
- 2. Wound rotor

**1. Squirrel cage rotor**

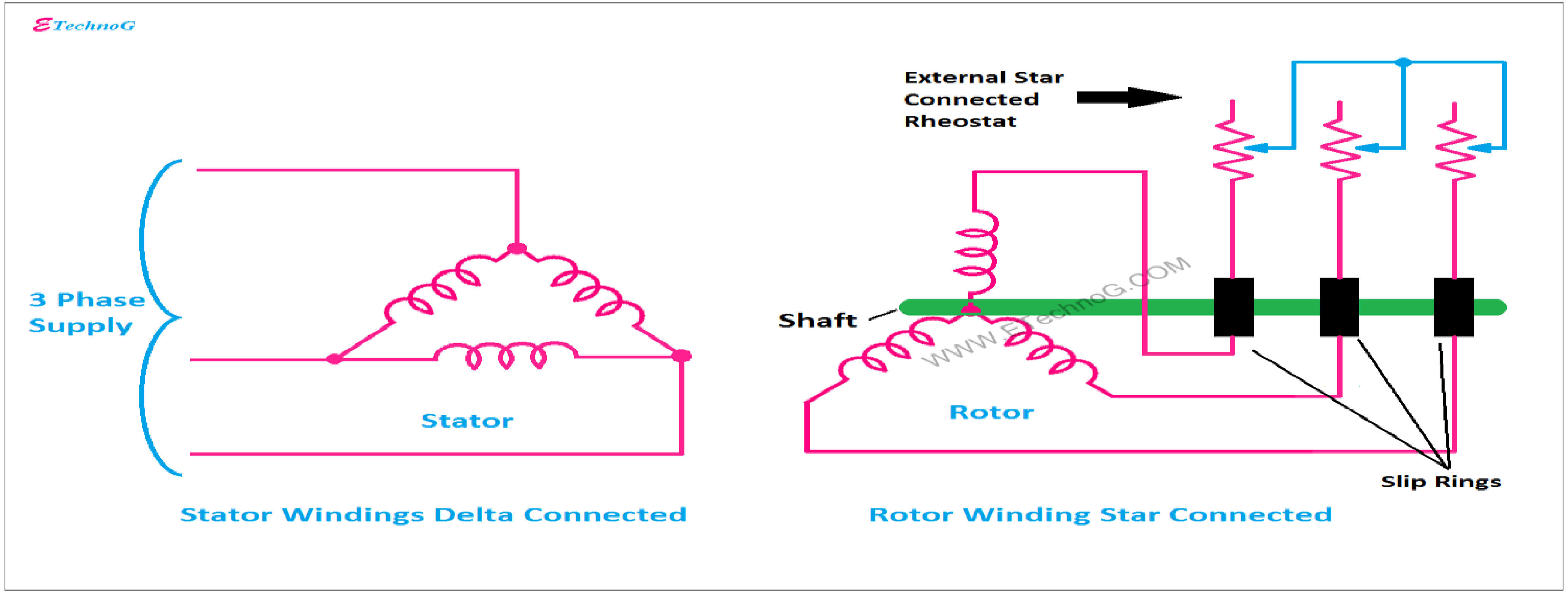
- It is the most common type of rotor because of its simple and rugged construction.it is cylindrical in shape and connected over shaft.it is made up of laminated silicon steel material. In the rotor skewed (slots are inclined with respect to shaft axis) slots are present. In this skewed rotor slots copper or aluminium bars are present. The both sides of rotor bars are permanently short circuited by end ring **so that the induced current can flow through it and produce required magnetic flux in order to rotate**.end ring is made up of copper or aluminium.
- Rotor slots are skewed (slots are inclined with respect to shaft axis) in order to

1. Reduce magnetic hum. It helps in silent operation of motor
2. Reduce locking tendency of rotor with stator while motor starting
3. Increases starting torque (starting torque is directly proportional to rotor resistance) because of skewed slot increases the rotor conductor length in slot compared to parallel slot



## 2. Wound rotor

- It is a cylindrical rotor having laminations to reduce eddy current loss. It is made up of silicon steel. Cylindrical rotor has slots. In this slot 3 phase windings are provided. The three-phase winding provided in rotor may be either star connected or delta connected depending on the type of connection in stator. I.e., if stator winding is star connected, then the rotor winding also will be star connected and vice versa.
- The three winding terminals are connected to 3 slip rings (slip ring  allows the transmission of power and electrical signals from a stationary to a rotating structure) mounted on the same shaft with brushes resting on it. The three brushes are connected to star connected rheostat.



## Difference between squirrel cage IM and slip ring IM

| | **Squirrel cage IM** | **Slip ring IM** |
|---|---|---|
| Construction | Simple | Difficult |
| Cost | Cheaper | Costly |
| Losses | Less | More |
| Efficiency | Less | More |
| Maintenance cost | Very less | More |
| Rotor winding | Squirrel cage winding | 3 phase winding |
| Starting torque | Low | High |
| Speed control | Difficult | Easy |
| Uses | It is popular | not popular like squirrel cage IM |

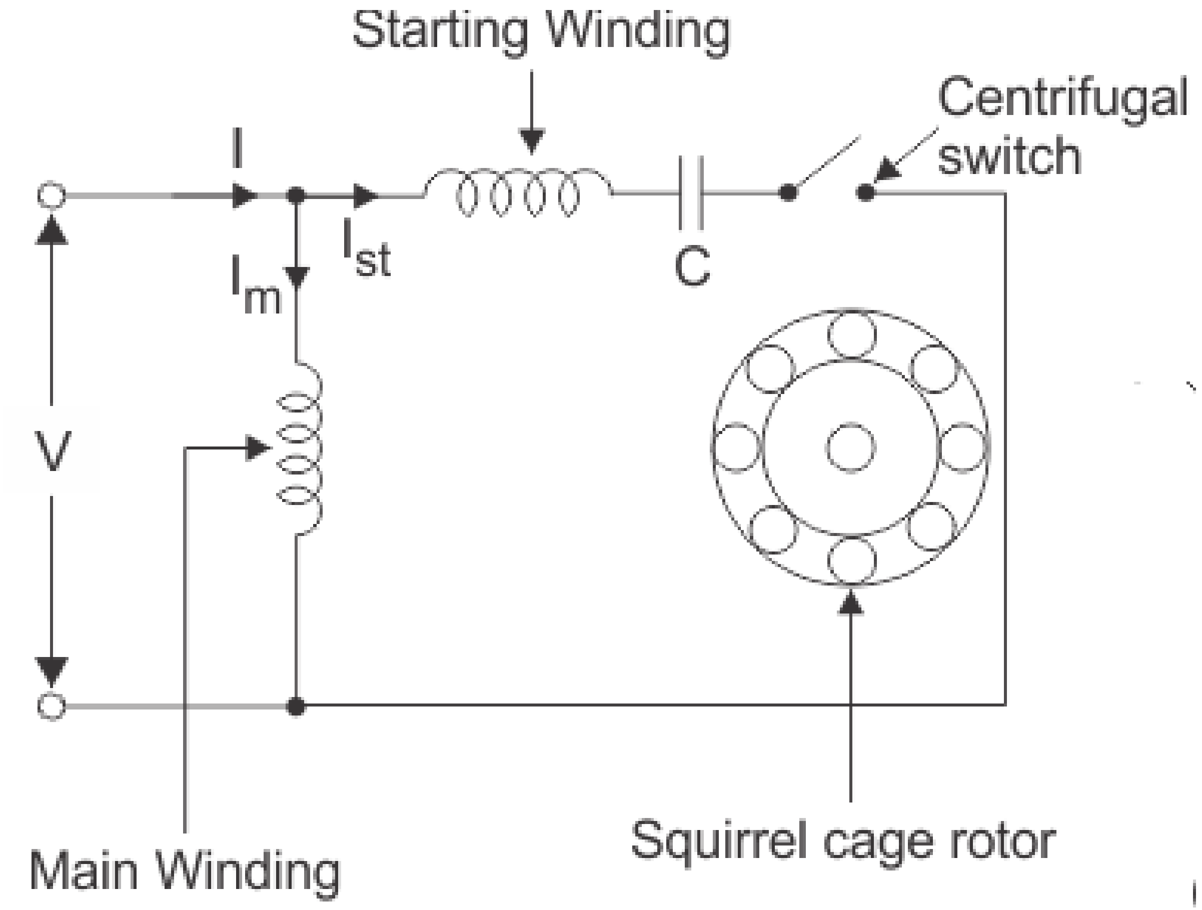
# SINGLE PHASE AC INDUCTION MOTOR

Induction motor which is working on single phase supply is called Single phase induction motor.

- Application of single phase induction motor
- 1. Used in ceiling fan,
- 2. As water pump motor
- 3. As motor in washing machine
- 4. As motor in grinder
- 5. As motor in AC outdoor unit
- 6. In refrigerator
- 7. Compressor
- 8. vacuum cleaners, centrifugal pumps, blowers etc

# WORKING PRINCIPLE OF SINGLE-PHASE AC INDUCTION MOTOR

- When a single-phase AC supply is applied to stator winding, an alternating flux is produced. This alternating flux links with the rotor and produces an alternating emf in the rotor. So, the torque developed in the rotor will be alternating in nature. Hence the single-phase induction motor is not self-starting.
- When rotor of single-phase induction motor gives an initial rotation, it continues to rotate in that direction.
- In order to make single phase induction motor self-starting, we are additionally providing starting winding along with main winding in stator. Both starting winding and main winding are placed 90 degree electrical apart. Now the motor behaves like a two -phase motor.
- When single phase supply is given to this two-phase motor, a rotating magnetic field is produced. So, rotor rotates in the same direction of rotating magnetic field.



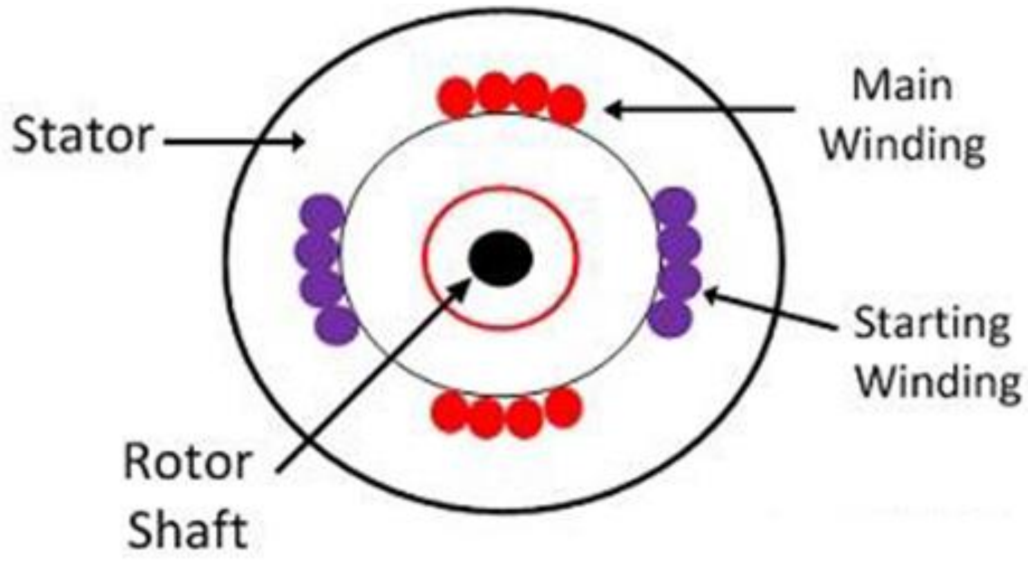

(a) Schematic representaion

# Why Single Phase Induction Motor is not Self Starting?

- When we apply a single phase AC supply to the stator winding of single phase induction motor, it produces  flux which can be divided into two components forward and backward.
- Now at starting condition, both the forward and backward components of flux are exactly opposite to each other. Also, both of these components of flux are equal in magnitude. So, they cancel each other and hence the net torque experienced by the rotor at the starting condition is zero. So, the **single phase induction motors** are not self-starting motors.
- a capacitor is employed to solve this problem. a capacitor is serially coupled with the beginning winding . The same phase enters the running winding and capacitor.
- because the capacitor adjusts the phase of the current, a shifted phase AC exits the capacitor and travels to the starting winding, while the applied phase AC remains in the starting winding.
- Magnetic rotation is generated by the two distinct phases in each winding, and therefore the rotor begins to rotate.
- As a result, a capacitor is employed in a motor to generate a phase difference in the current of the two windings, which produces a magnetic flux and causes the rotor to move.

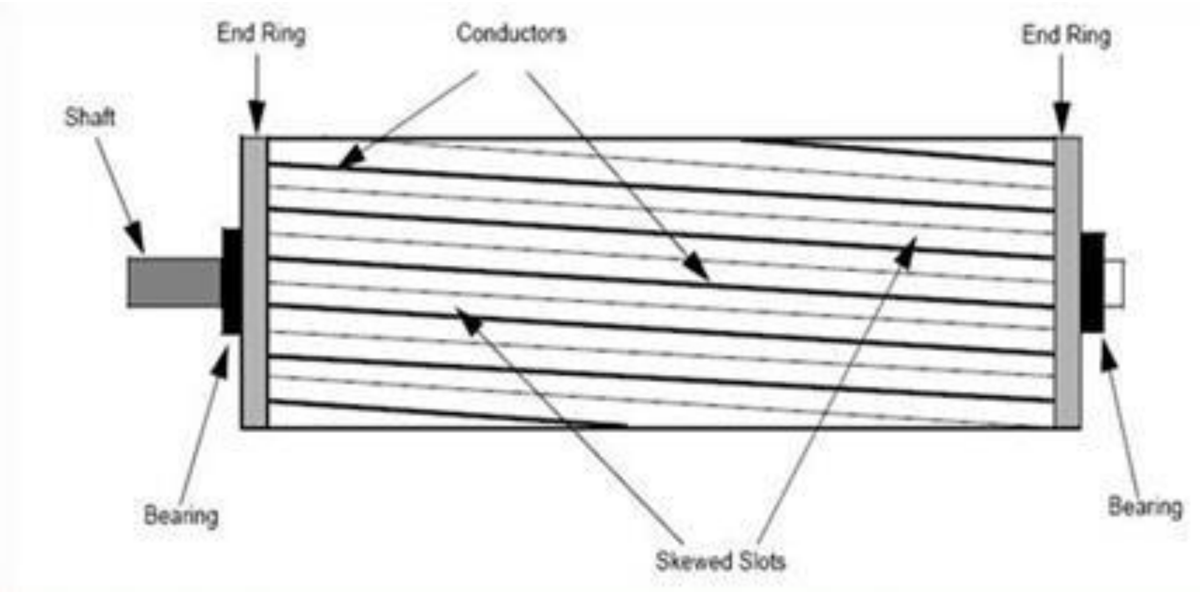
# CONSTRUCTION DETAILS OF SINGLE-PHASE INDUCTION MOTOR

- Major parts of single-phase induction motor are
- **1. Stator**
- It is the static part. The main parts of it are stator frame, stator core, stator windings and stator slots.
- **Stator frame**: It is used for providing mechanical protection to the motor from external forces. It is made of cast iron. Other function of this is to provide mechanical support to stator core.
- **Stator core:** It is made up of laminated silicon steel material. This stator core is connected to stator frame using nuts and bolts. It is laminated to reduce eddy current loss. Inner periphery of it contain slots. In this slot single phase main winding is present. In addition to main winding a starting winding is also present in the stator slots used for starting of single phase induction motor



**2. Rotor**

- Rotor used in single phase induction motor is squirrel cage rotor
- Squirrel cage rotor is the most common type of rotor because of its simple and rugged construction.it is cylindrical in shape and it is made up of laminated silicon steel material. In the rotor, skewed (slots are inclined with respect to shaft axis) slots are present. In this skewed rotor slots copper or aluminium bars are present. The both sides of rotor bars are permanently short circuited by end ring **so that the induced current can flow through it and produce required magnetic flux in order to rotate**.end ring is made up of copper or aluminium.




3. **Fan:** It I provided for cooling the motor

4. **Shaft**: To transfer mechanical power developed in the motor to load

5. **Bearing**: To help smooth rotation of motor

# *STARTERS*

- *Necessity of a starter*

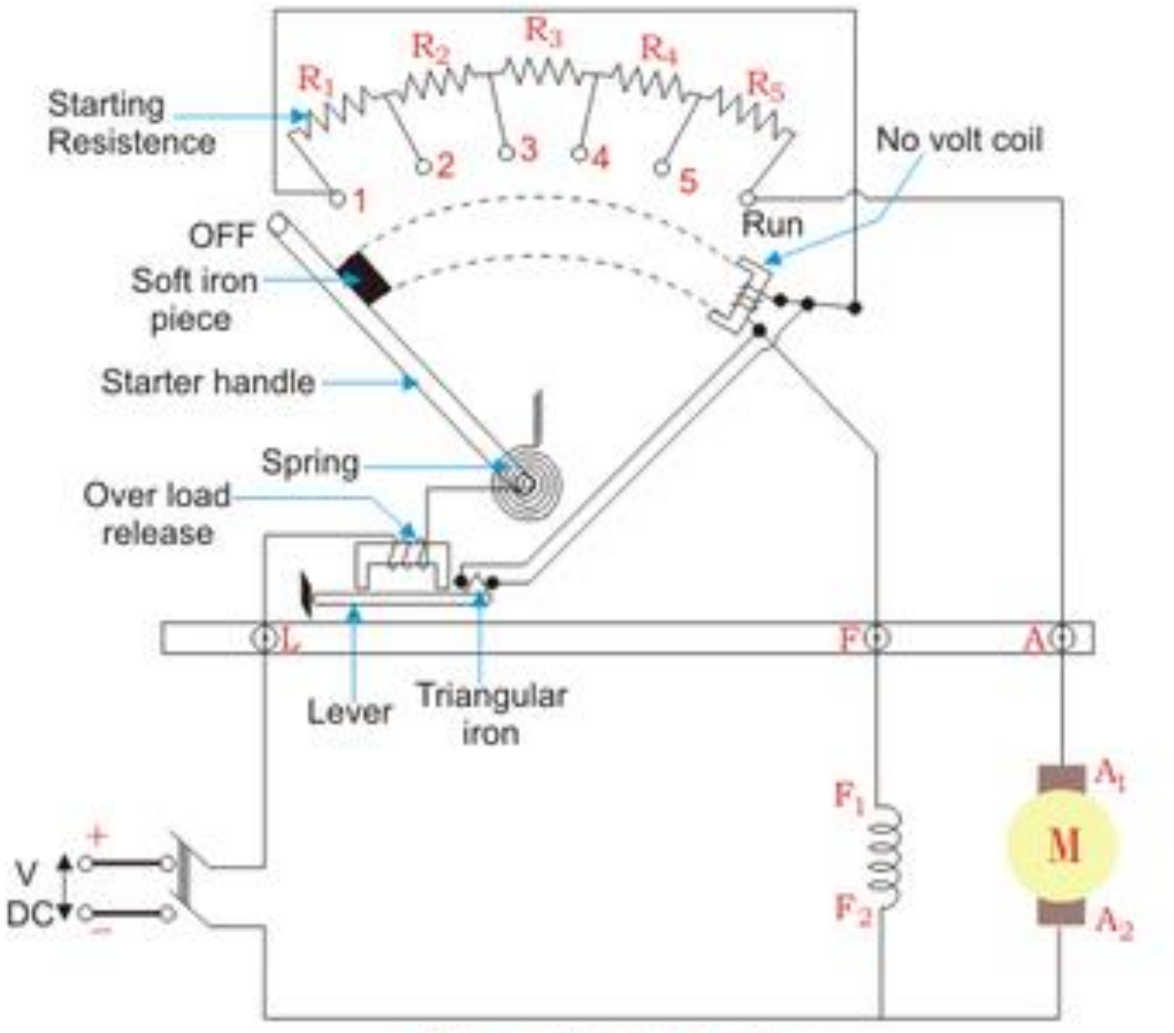
➢ When the motor is at rest, there is no back e.m.f developed in the armature. If now full supply voltage is applied across the stationary armature, it will draw a very large current because armature resistance is relatively small. This large current will blow out the fuses and cause damage to the motor. To avoid this a resistance is introduced in series with the armature which limits the starting current to a safe value. The starting resistance is gradually cut out as the motor gains speed

➢ A starter is basically a series resistance to armature circuit. When the motor is starting, this starter resistance fully comes in to series with armature. So starting current will be reduced. By attaining sufficient speed the starting resistance will be gradually cut out. If machine attained its full speed, Full back emf is developed. Now starting resistance is fully removed from the circuit

# DC MOTOR STARTER

## *Three point starter*

- To start the motor handle is moved from OFF position to the first contact. The full starting resistance is placed in series with the armature and field is connected directly to the supply line through no volt coil. As the motor takes speed, the armature develops back e.m.f and the current falls. As the handle is further moved and the starting resistance is gradually cut out till, when the handle reaches the running position, all the resistance is cut out.
- There is a soft iron piece attached to the handle which in the running position is attracted and held by an electromagnet energized by the shunt field current.
- If the motor becomes over loaded the over load release activates , thus short – circuiting the no- volt release coil. The no- volt coil is demagnetized and the starting handle is pulled to the OFF position by the spring. Thus the motor is automatically disconnected from the supply.



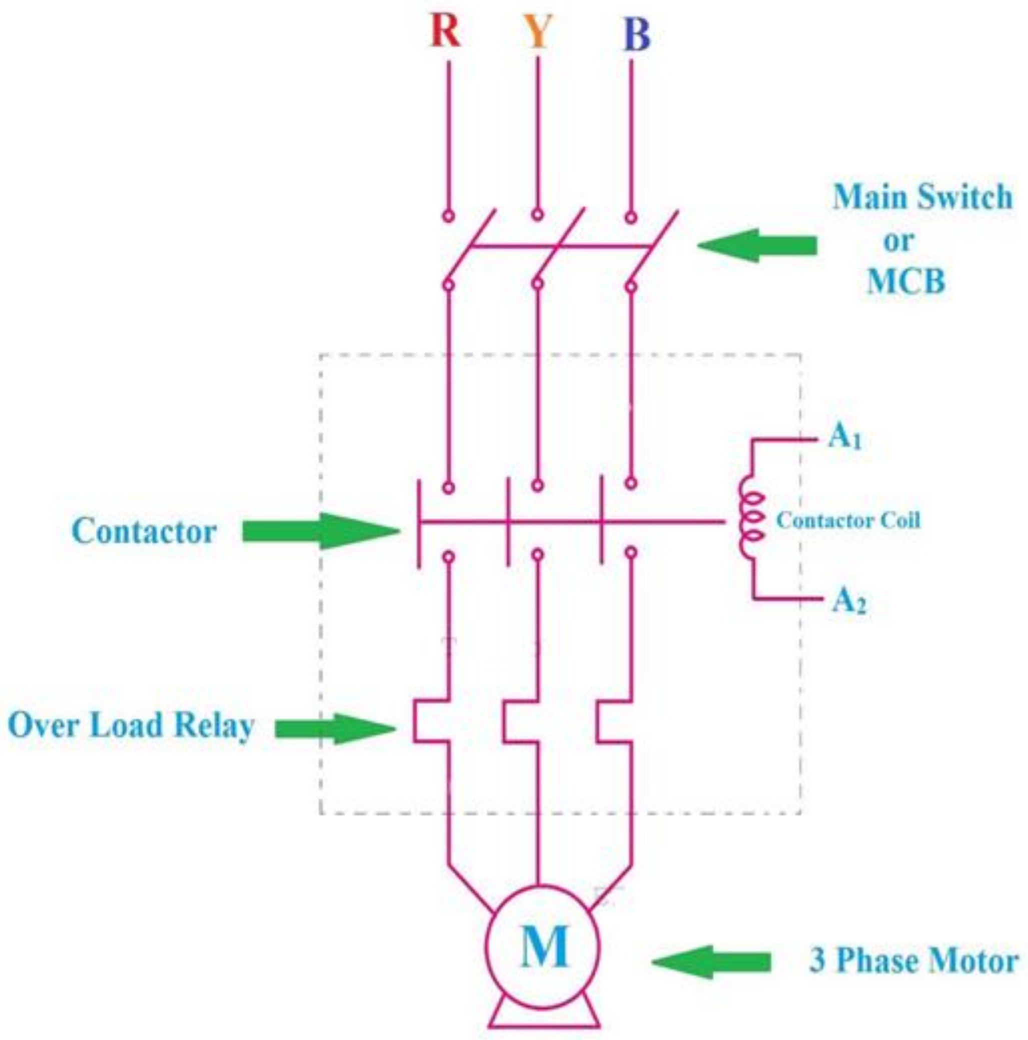

Three Point Starter

# AC MOTOR STARTER

## 1.Direct on line starter(DOL starter)

Working

- To start the motor when we push the start button No Voltage coil get energized. This energized coil closes the three main contact and it attract the plunger which close all the main contacts and auxiliary contacts, motor get full supply voltage and motor starts to run.
- To stop the motor when we push the stop button supply through holding coil is stopped and No Voltage coil gets demagnetized and it release the plunger which open all the main contacts and auxiliary contacts, motor will stop.
- overload relay (OLR) disconnect motor supply when motor is overloaded. OLR is made up of Bimetal strip.
- when overcurrent exist, bimetal strip deflect and relay will operate and disconnect the supply through holding coil.

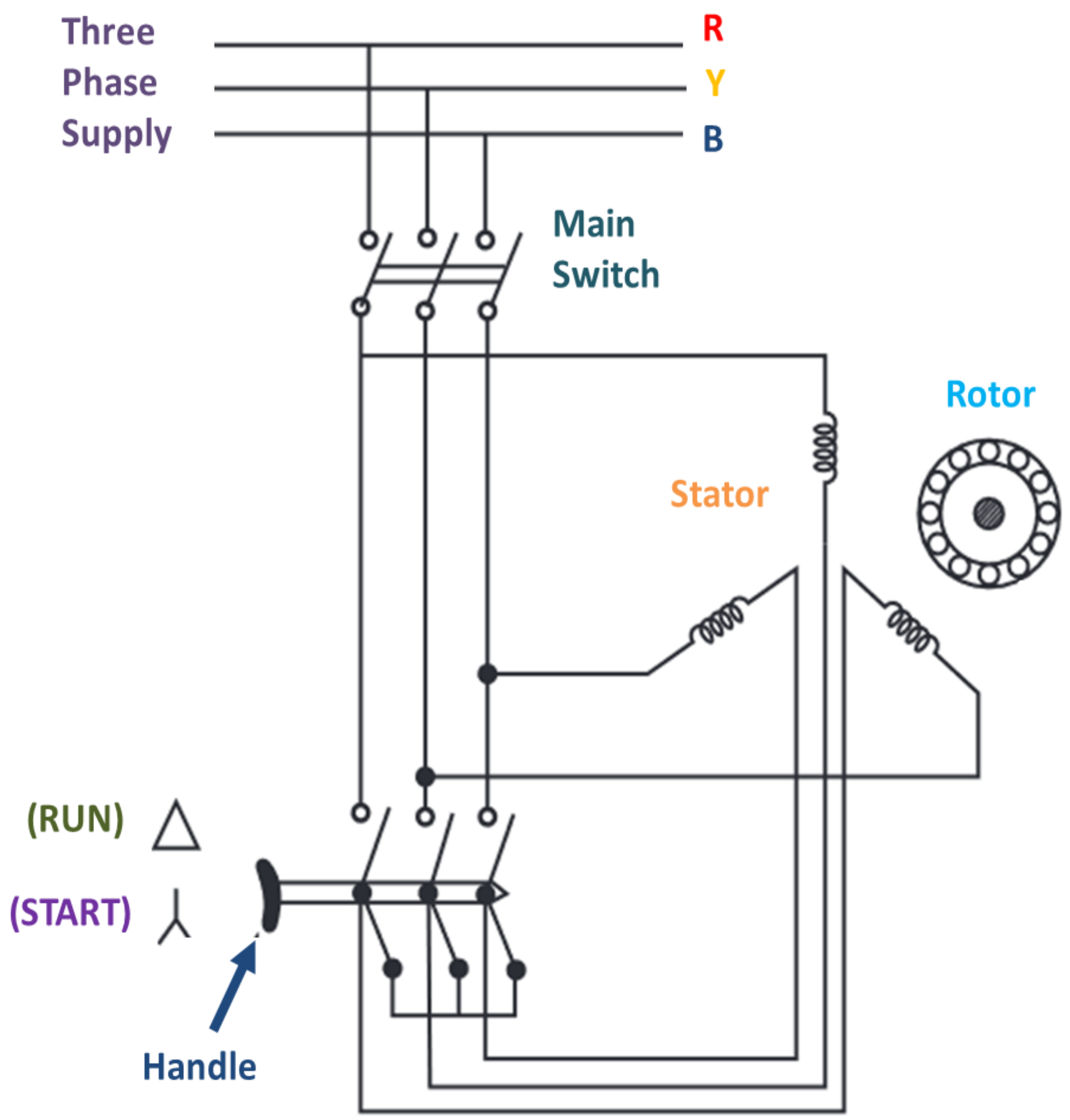



DOL Starter

# 2.Star –delta starter

Working

- In start position the starter windings are connected in star. Then voltage on each phase winding will be equal to **Line voltage/√3** . Due to this reduced voltage the starting current will also reduced to **1/3** times the current which would have been taken while starting the motor direct across the line in delta.
- When the motor gains speed , the starter is quickly changed to run position, thus connecting the stator winding in delta.
- In delta because phase voltage = line voltage full line voltage is applied to the winding and motor will be running on normal speed taking normal current.




Star-delta starter

# Comparison between star delta starter and DOL starter

| **Star delta starter** | **DOL Starter** |
|---|---|
| Widely Used for high rated induction motors | Widely Used induction motors whose rating is below 5hp |
| Starting current is reduced | No reduction in starting current |
| It increases the life of the motor because of low starting current | It reduces the life of the motor because of high starting current |
| Compared to DOL starter, its cost is high | Low cost |

# FUNDAMENTALS OF ELECTRICAL ENGINEERING

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# SYLLABUS

**Contents:**

Single phase transformers - working principle -classification based on core- emf equation - transformation ratio

Special purpose transformers- auto transformer- working- welding transformer – construction - working

Electric heating-Basic principle -modes of heat transfer- methods of electric heating - induction heating-dielectric heating (principle of operation only).

Electric furnaces- working- induction and arc furnaces-applications

# Transformer

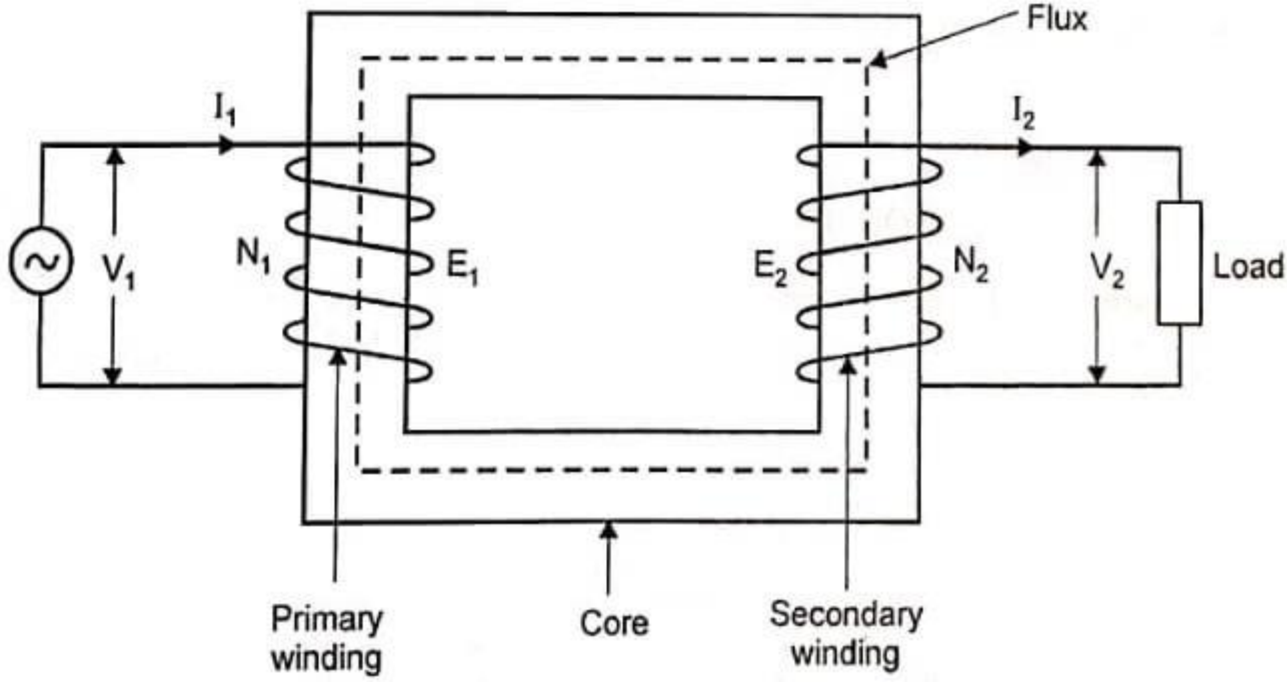
- It is an electromagnetic device. It transfers electrical energy from one circuit to other circuit which is electrically isolated and magnetically linked.it work based on the principle of faradays law of electromagnetic induction , specifically mutual induction.
- **Working principle**

1. When AC supply is applied to primary winding wounded on the core of the transformer, it produces an alternating magnetic field.

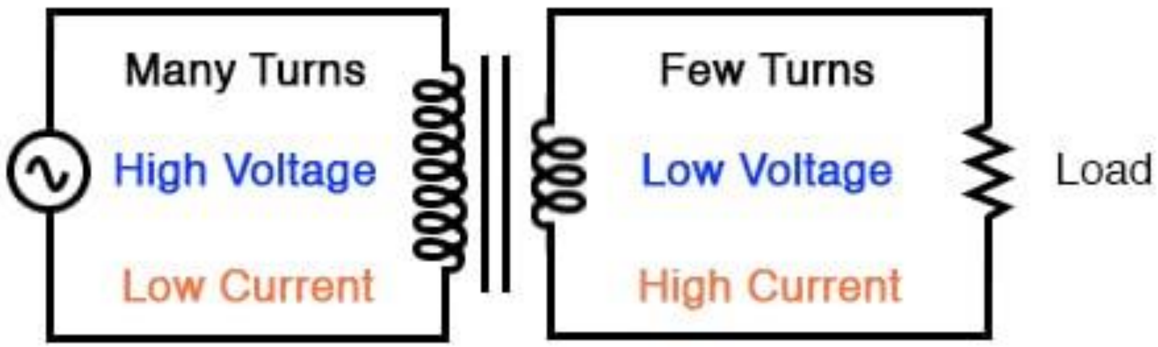
2. This alternating magnetic field produced by the primary winding is carried by the core

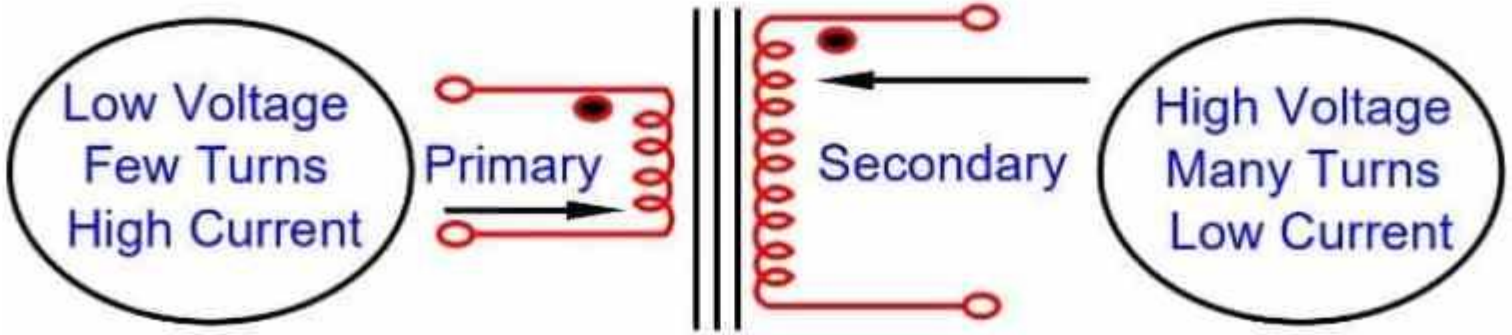
3. Since secondary winding is also wounded on the same core, this alternating magnetic field is links with secondary winding.

4. So according to faraday law of electromagnetic induction an e.m.f will be induced in the secondary. Value of this induced emf will be directly proportional to rate of change of flux linkage. So, input power in primary is transferred to secondary through magnetic field



Step-down Transformer




Step up Transformer

# EMF Equation Of The Transformer

Let,

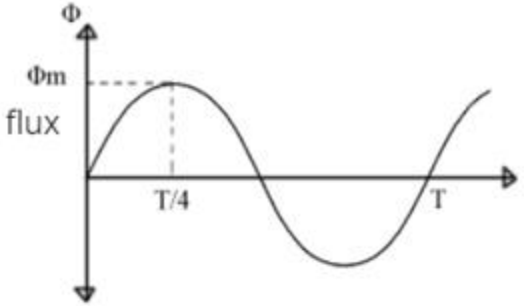
$N_1$ = Number of turns in primary winding

$N_2$ = Number of turns in secondary winding

$\Phi_m$ = Maximum flux in the core (in Wb) = ($B_m$ x A)

f = frequency of the AC supply (in Hz)

flux reaches the maximum value in one quarter of the cycle i.e in T/4 sec




Therefore,

average rate of change of flux = $\Phi_m / (T/4)$ = $\Phi_m / (1/4f)$ = 4f $\Phi_m$

( T = 1/f).

Induced emf per turn = rate of change of flux per turn

Therefore, average emf per turn = 4f $\Phi_m$

Now, we know, Form factor = RMS value / average value

Therefore, RMS value of emf per turn = Form factor X average emf per turn.

As, the flux Φ varies sinusoidally, form factor of a sine wave is 1.11

Therefore, RMS value of emf per turn = 1.11 x 4f $\Phi_m$ = 4.44f $\Phi_m$.

RMS value of induced emf in whole primary winding ($E_1$) = RMS value of emf per turn X Number of turns in primary winding

$E_1 = 4.44f\, N_1\, \Phi_m$ .............................. eq 1

Similarly, RMS induced emf in secondary winding ($E_2$) can be given as

$E_2 = 4.44f\, N_2\, \Phi_m$. ............................ eq 2

from the above equations 1 and 2,

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44f\,\Phi m$$

This is called the **emf equation of transformer**, which shows, emf / number of turns is same for both primary and secondary winding.

For an ideal transformer on no load, $E_1 = V_1$ and $E_2 = V_2$ .

where, $V_1$ = supply voltage of primary winding

$V_2$ = terminal voltage of secondary winding

- Transformation ratio
- It is the value obtained by dividing number of turns in secondary to number of turns in primary. It is represented using symbol “ K”.
- Voltage transformation ratio(K)
- It is the ratio of secondary voltage (VS )to primary voltage(Vp )
- Voltage transformation ratio=VS /Vp .
- • in a transformer, if VS>VP, Transformer will be step up type
- • in a transformer, if VS<VP, Transformer will be step down type

# Autotransformer

It is a single winding transformer. In this transformer a part of the winding is common to both primary and secondary. Here both primary and secondary are magnetically and electrically connected. So in a autotransformer, unlike a common transformer both primary and secondary are not electrically isolated

- **Advantages of auto transformer**

It can give continuous variable output voltage

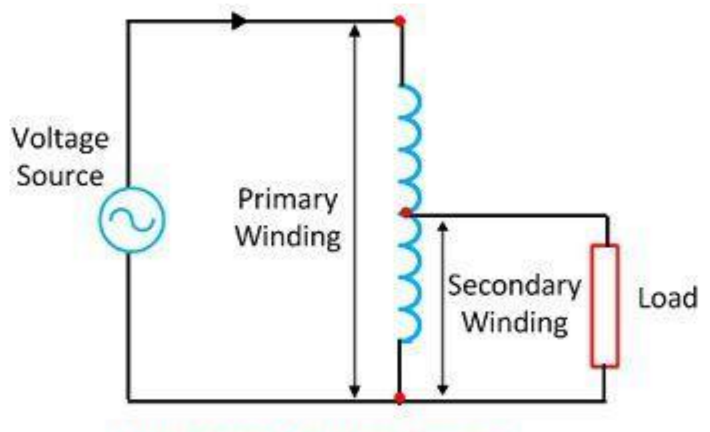
- Size of this transformer is very small
- Cost of this transformer is very small
- Losses are very less
- Efficiency is high
- Construction is simple

- **Application of autotransformer**

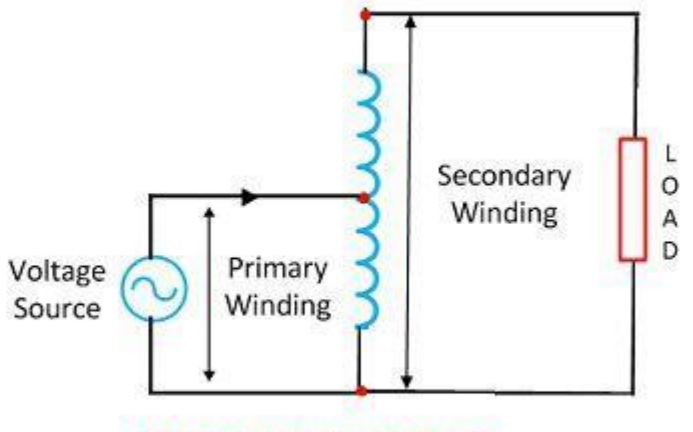
1. Used as starter for induction motor and synchronous motor
2. Used as voltage booster in power cables
3. Used in testing laboratories
4. Used as voltage regulators

# Working principle of autotransformer

- When primary of autotransformer is applied with AC supply. An alternating current flows through primary winding. this alternating current produces alternating flux in the core. This alternating flux links with the secondary winding wounded on the same core. So magnetic flux linking with secondary winding also changes. By faradays law of electromagnetic induction an emf will be induced in secondary. ie, power transmitted from primary to secondary through induction.in addition to this power transfer, In auto transformer both primary and secondary are electrically connected. So a power transmission takes place between primary and secondary through conduction also.




Stepdown Autotransformer




Step-up Autotransformer

- **Welding transformer**

<u>working</u>

- It is a step down transformer .Its secondary current will be very high and secondary voltage will be very small.it have more number of turns in primary and less number of turns in secondary. Thickness of primary winding will be very small because of very small current in primary. But thickness of secondary winding will be large because of very high current in the secondary .

<u>Construction of welding transformer</u>

1. Welding transformer is a step-down transformer.

2. It has a magnetic core with primary winding which is thin and has large number of turns .

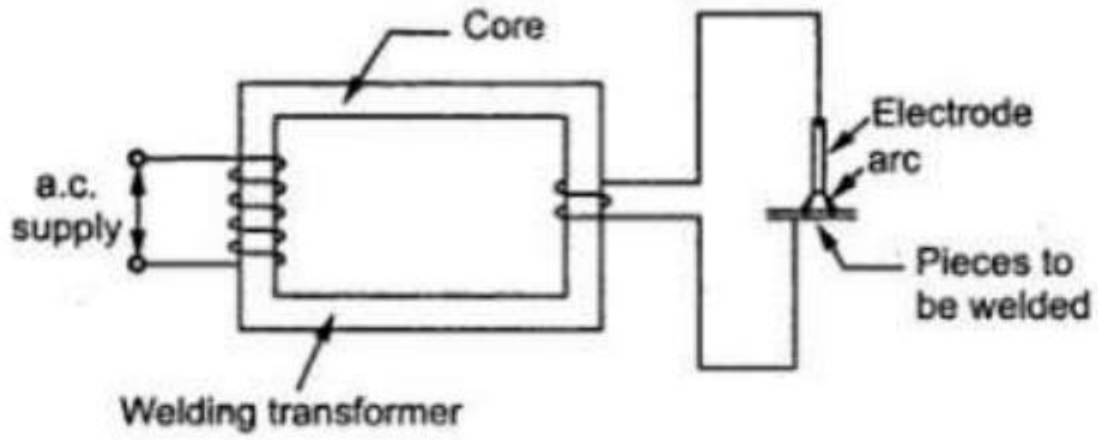
3. A secondary winding with a smaller number of turns and high cross-sectional area .

4. Due to this type of windings in primary and secondary it behaves as step down transformer. So, we get less voltage and high current from the secondary winding output. This is the construction of AC welding transformer.

5. A dc welding transformer also has same type of winding the only

difference is that we connect a rectifier at the secondary to get dc output.

6. Inductor or filter is used to smooth the dc current.




**Welding transformer**

# Classification of transformer

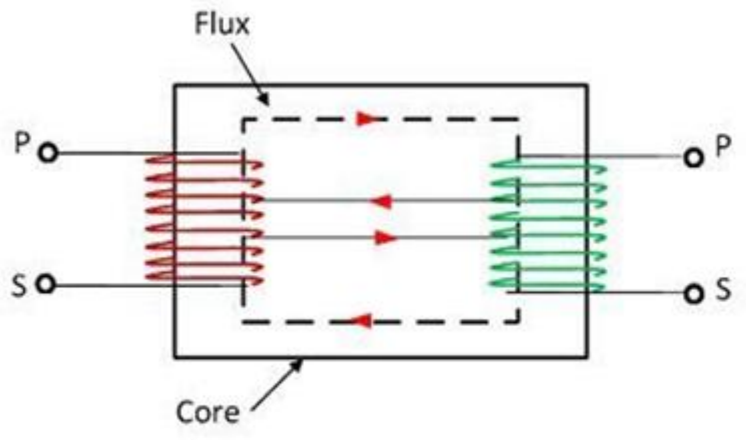
- **A. Based on core**
- 1. Core type transformer
- 2. Shell type transformer

<u>core type transformer</u>,

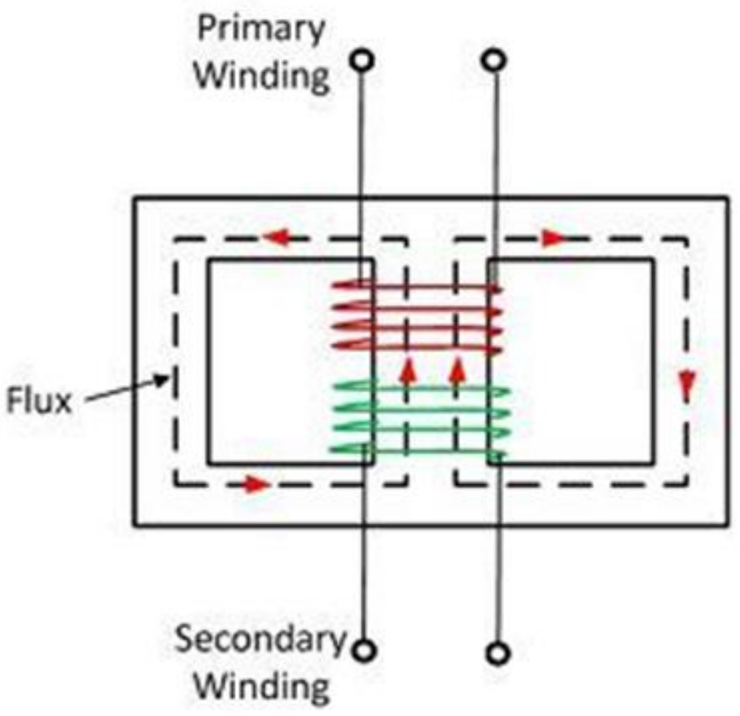
- ➢ the low voltage winding and the high voltage winding is placed on opposite limbs.
- ➢ Less insulating material required.
- ➢ easier to dismantle for repair and maintenance.
- ➢ natural cooling in a core type transformer is efficient.
- ➢ need higher magnetizing current.
- ➢ used in high voltage applications such as distribution and power transformers.

<u>shell type transformer</u>,

- ➢ the low voltage winding and high voltage winding  are alternatively placed on the central limb **.**
- ➢ it gives better support against the electromagnetic forces between the current carrying conductors.
- ➢ provides a shorter magnetic path, thus it requires smaller magnetizing current.
- ➢ it has poor natural cooling.
- ➢ Used in low voltage applications such low power circuits and electronic circuits




Core Type Transformer




Shell Type Transformer

**Comparison between core type and shell type transformer**

| Core type | Shell type |
|---|---|
| Winding surrounds the core | Core surrounds the winding |
| It's core have 2 limbs only | It's c ore have 3 limbs |
| Windings are placed on two opposite limbs | Windings are present in the central limb only |
| Construction is difficult | Construction is simple |
| Cross sectional area of each limb is same | Cross sectional area of central limb is larger than limbs on opposite side |
| Rate of heat dissipation is low | Rate of heat dissipation is high |
| Rarely used | Widely used |
| Overall cost is high | Overall cost is low |
| Overall transformer losses are more | Losses are less compared to shell type transformer |

# ELECTRICAL HEATING

**Principle of electrical heating**

• Electrical heating is a process in which electrical energy is converted into heat energy. The heating element inside every electric heater is an electrical resistor, and works on the principle of Joule heating: an electric current passing through a resistor will convert that electrical energy into heat energy.

• Principle of heating is different for different heating

**Types of Electric Heating**

**1. Dielectric Heating**

**2. Induction Heating**

**3. Resistance Heating**

1. **Resistance heating**- When a current flow through a resistor, resistor converts this electrical energy into heat energy. That is when a current =I flow through a resistor having resistance=R for a duration of t seconds, then heat produced by resistor= $I^2Rt$

2. **Induction heating-**Induction heating takes place due to the flow of eddy current through the material to be heated. Due to this eddy current flow, heating of the material takes place

3. **Dielectric heating**- when a dielectric material is applied by AC supply, dielectric loss will be produced. This loss appears as heat and heating take place

**Advantages of electric heating**

- No pollution
- Cost is less compared to other heating systems
- It is safer compared to other heating systems
- It is easy to control heat produced by electric heating equipment’s
- Starting time needed for heat production is less
- It is free from dirt particles. So, cleaning required after electrical heating is less
- Efficiency is high

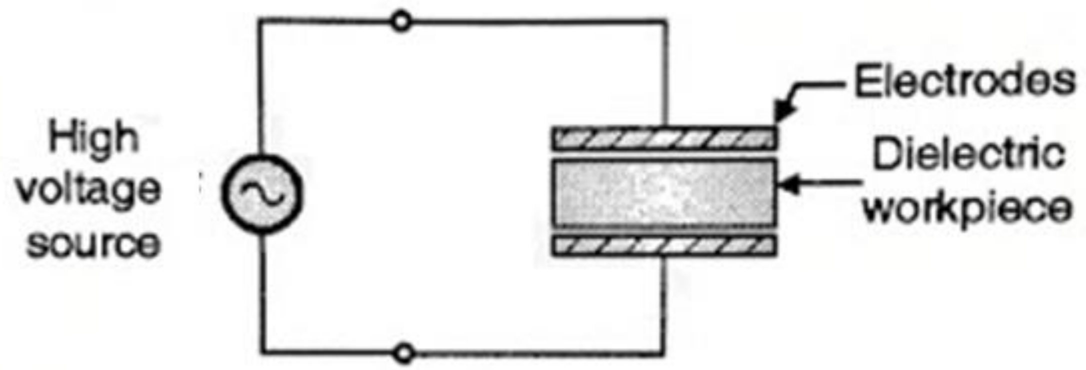
# Dielectric Heating

**Principle**

• This heating only used for heating of insulating material

• In this method of heating, material to be heated (it must be insulating material) is placed in between two metal electrodes. Then a high voltage, high frequency input supply is applied across the metal electrodes. Due to the high frequency high voltage input supply, a dielectric loss will be present in the heating material. This dielectric loss appears as heat. Thus, electrical energy is converted to heat energy.

• The dielectric loss is directly proportional to supply frequency and square of supply voltage. So, in a dielectric heating, heating effect can be varied by varying supply frequency and supply voltage.




Principle of Dielectric Heating

**Advantages**

- It is the only method of heating of insulating material heating like wood, plastic etc..
- Heating is uniform
- Heating rate can be easily controlled by varying frequency and supply voltage
- This Heating can be stopped suddenly if we wish
- It does not create pollution
- No need of cleaning after this heating due to absence of dust, smoke etc
- It is safer

**Disadvantages**

- It is limited to insulating material heating only
- it is costly
- efficiency is less

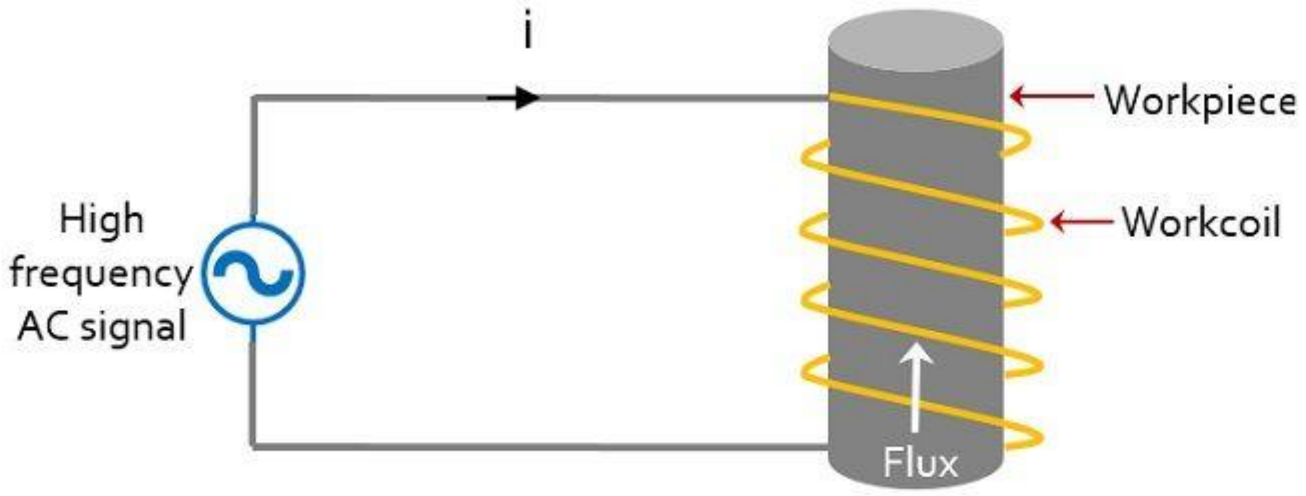
**Application of Dielectric Heating**

1. food processing
2. Sterilisation of food and medical instruments
3. Welding of PVC
4. Drying of tobacco, paper and wood
5. Heating of bones and tissues
6. Used in the production of artificial fibres
7. Wood gluing

# INDUCTION HEATING

**Principle**

- It works based on the principle of induction principle
- Basic induction heating circuit is shown below.
- AC supply is connected to inductive coil. Inside of inductive coil material to be heated is placed. When AC supply is given to inductive coil, it produces alternating magnetic field. This alternating magnetic field links with material to be heated .so a induced current will flow through the material to be heated. This current is called eddy current. Due to the flow of eddy current through the material to be heated, resistance heating takes place. So, material heats up




Induction Heating

**Advantages of Induction Heating**

- Used to heat conducting materials
- Heating rate can be easily controlled
- Heating area is concentrated over work place only
- No pollution
- Efficiency of Induction heating is more than dielectric heating
- Time required to reach set temperature at starting is less
- It is safer
- Cleaning requirement after this heating is minimum
- Even unskilled workers can do this heating

**APPLICATIONS**

- Used for melting applications of metals and alloys
- Used in soldering applications
- Used for welding of metals
- Used for brazing of metals
- Used for sterilisation of surgical instruments
- Used for annealing of brass and bronze
- Surface hardening of metals

# ELECTRIC INDUCTION FURNACE

**INDUCTION FURNACE**

• Induction furnace is used to melt metal alloys which melt at high temperature. A simple diagram of induction furnace is shown.

• Induction furnace works based on the principle of induction heating

• It consists of crucible. Inside of this crucible is coated by refractory material to resist flow of heat from inside to outside. The material to be heated (also called charge) is collected in the crucible. This crucible is surrounded by water cooled primary copper coils which is connected to high frequency AC supply.

• When AC supply is given to copper coils, it produces alternating magnetic field. It induces eddy currents in the charge. Due to the flow of eddy current in the charge, heating of charge takes place and it melts.

Types of Induction furnace

- 1. Coreless Induction furnace
- 2. Core type induction furnace

# CORE TYPE INDUCTION FURNACE

- The core type induction furnace is a low frequency electrical heating furnace used to melt metals. This furnace is similar to that of a transformer in which the primary winding is supplied by low frequency electric supply and the secondary is a single turn cubicle which contains the charge to be heated. The primary and secondary are magnetically coupled by an iron core.
- When low frequency electric supply is given to primary winding, it produces alternating flux. It links with the iron core. Since secondary also wounded around same iron core, this alternating flux also links with secondary. According to faradays law of electromagnetic induction, emf will be induced in the charge on secondary. It causes the flow of eddy current through charge and will flow and heating of charge takes . This furnace is operated at very low frequencies in the order of 10 Hz .

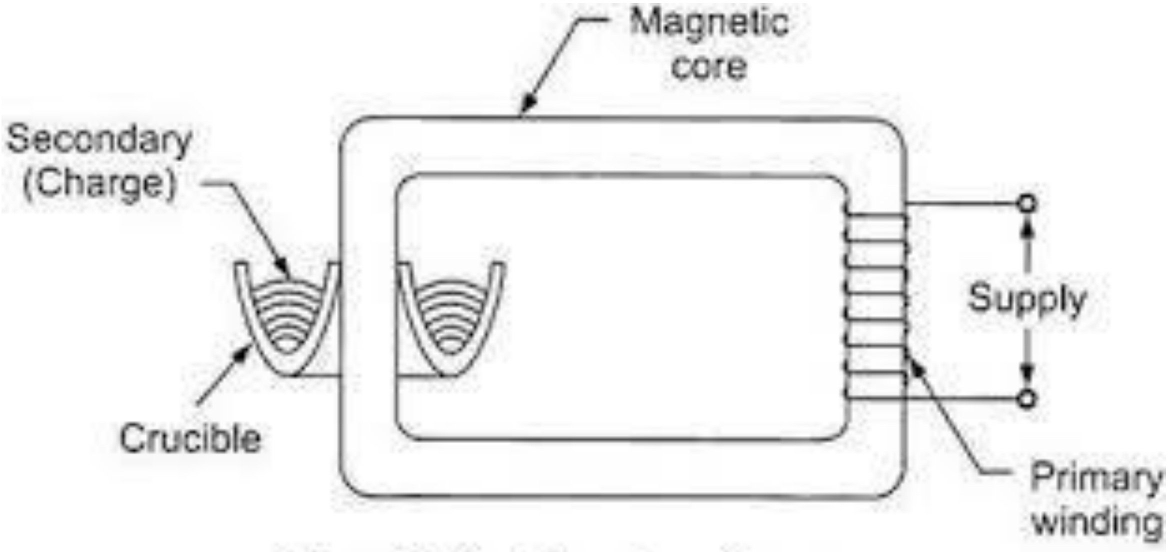
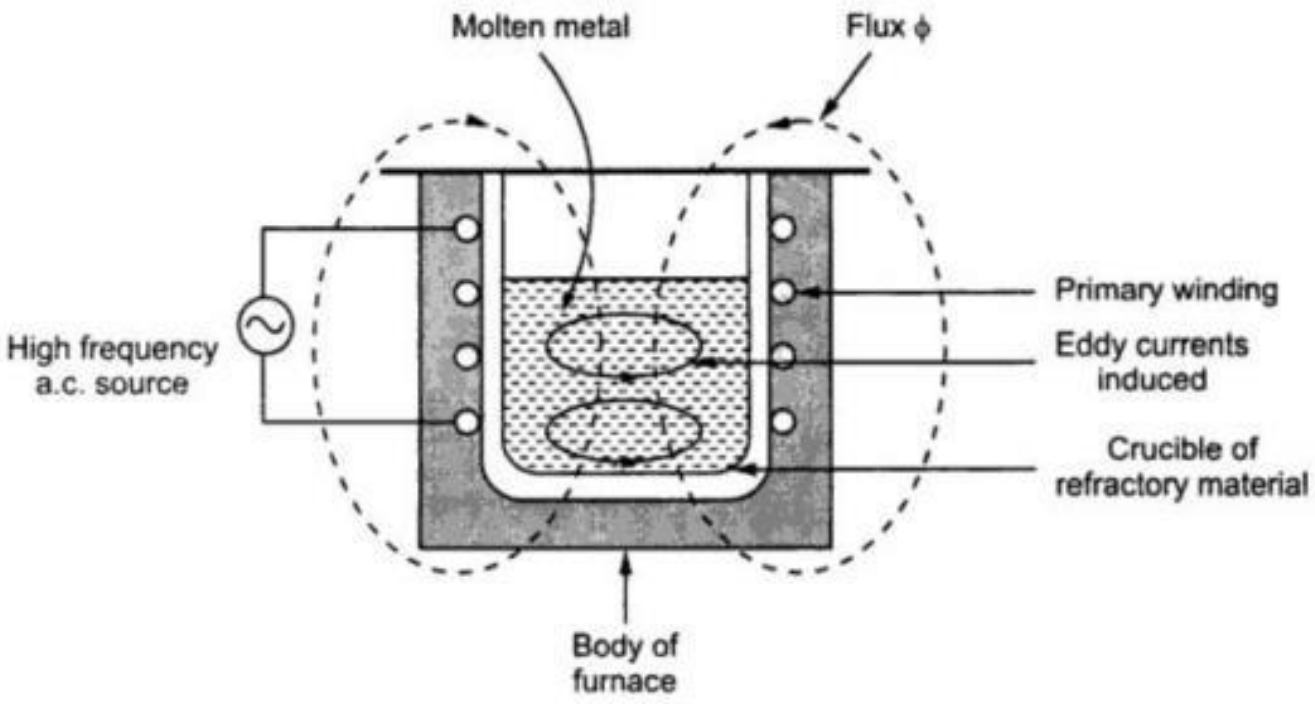



**Fig. 3.12** *Core type furnace*

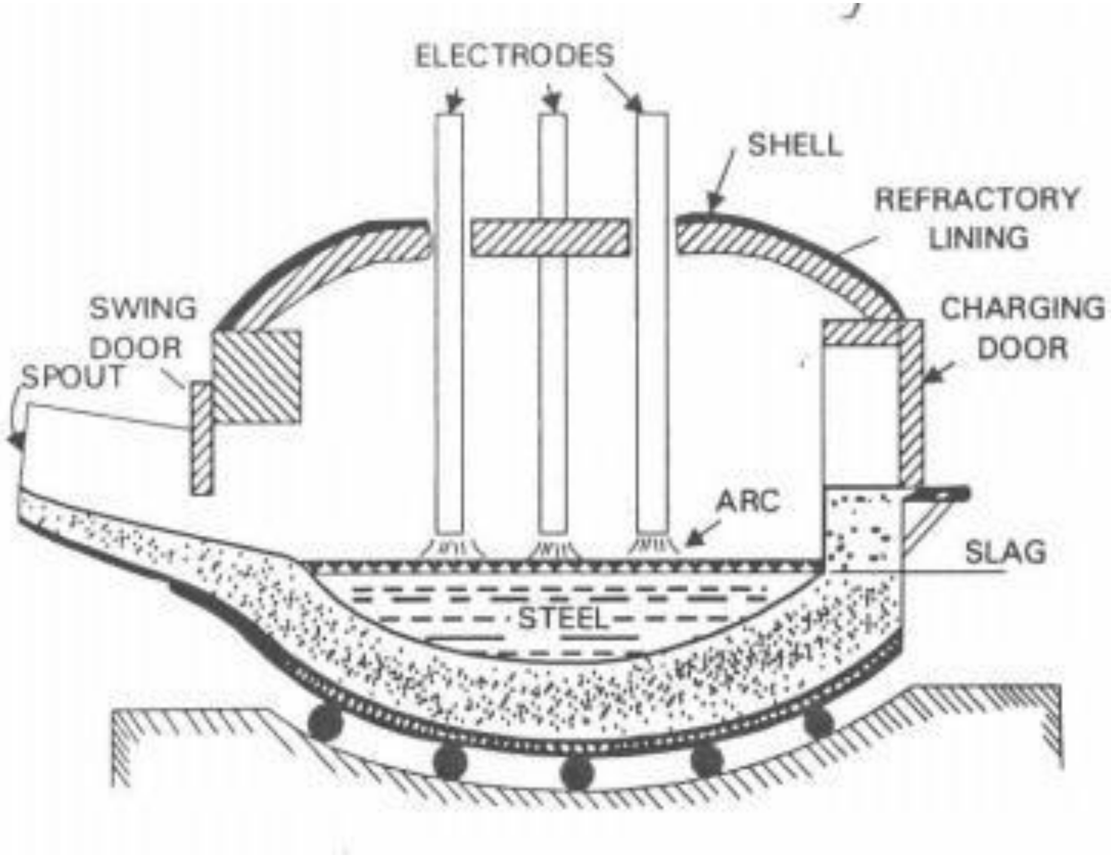
# CORE LESS INDUCTION FURNACE

- Induction furnace is used to melt metal alloys which melt at high temperature. A simple diagram of induction furnace is shown.
- Induction furnace works based on the principle of induction heating
- It consists of crucible. Inside of this crucible is coated by refractory material to resist flow of heat from inside to outside. The material to be heated (also called charge) is collected in the crucible. This crucible is surrounded by water cooled primary copper coils which is connected to high frequency AC supply.
- When AC supply is given to copper coils, it produces alternating magnetic field. It induces eddy currents in the charge. Due to the flow of eddy current in the charge, heating of charge takes place and it melts.



# Electric arc Furnace

- It consists of steel shell coated by refractory material. The main part of electric arc furnace is Hearth, walls and roof. The roof is provided with openings and in this opening's graphite electrodes are placed. A three-phase electric arc furnace consists of three number of graphite electrode and it is connected to three phase supply. The bottom of graphite electrode must be just near to material to be heated
- when graphite electrode is connected to three phase supply, an arc will be formed between electrode and charge (material to be heated). Due to this arc current flows through charge and heating takes place. Due to this heating, charge melts.
- There are 2 types of electric arc furnaces
- 1.Direct arc furnace
- 2.Indirect arc furnace



# DIRECT ARC FURNACE

- Arc furnace is said to be direct arc furnace if arc formed is between electrode and charge (material to be heated). Since arc is having a direct contact with charge, very high temperature can be achieved
- It consists of graphite electrodes which is connected to electric supply. The arc Is formed between electrode and charge by applying input supply to electrodes
- Direct arc furnace is usually used for steel production purpose. But initial cost for direct arc furnace is high

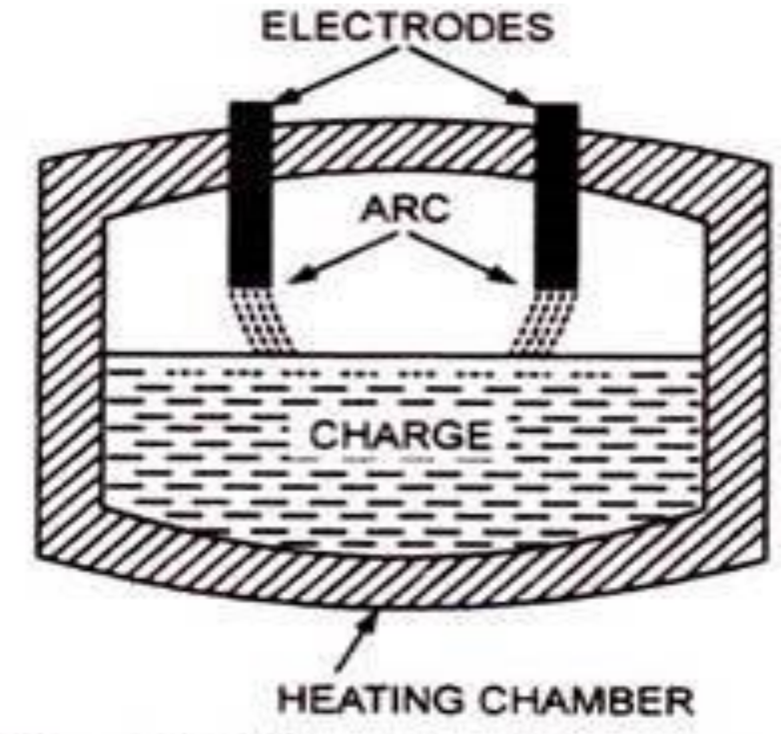



**Fig. 5.4.** ***Direct Arc Furnace***

# INDIRECT ARC FURNACE

- In this arc furnace arc is formed between two electrodes. Arc is not having any direct contact with charge (material to be heated). Heat energy formed from arc is passed to charge by radiation. Main drawback of indirect arc furnace is the charge can achieve lower temperature than direct arc furnace.
- This method of heating is used for melting non-ferrous metals

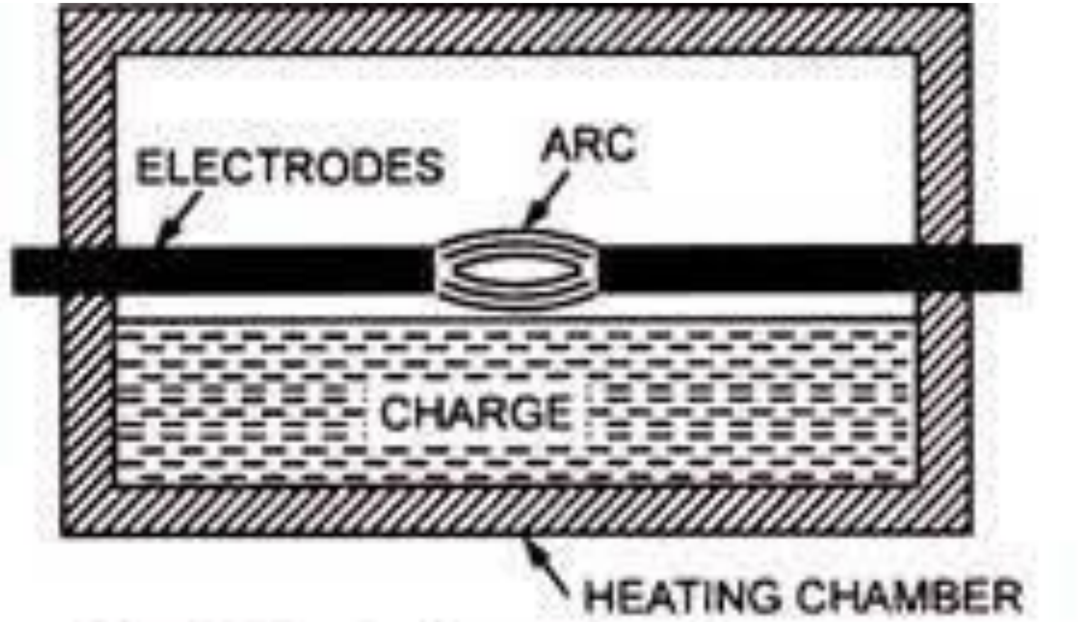



Fig. 5.5. *Indirect Arc Furnace*

# Fundamentals of Electrical Engineering

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# SYLLABUS

Contents:
Electronic components- Active and Passive Components-Different types of resistors and capacitors used in electronics.
PN junction diode - working-rectifier circuits using diodes
Transistor- working – transistor as a switch
Power electronic components- SCR- working-SCR based circuits- basic diagram and working-rectifier-chopper
Introduction to electric drives (block diagram approach only)- basic block diagram of EV charging system

| Characteristic | Active Component | Passive Component |
|---|---|---|
| ***Power*** | Supply power to a circuit. Thus they are a source of power. | Uses or stores power in a circuit. |
| ***Type of Elements*** | Transistors, Diodes, SCR, Cells, Batteries, etc. | Capacitors, Resistors, Transducer, Transformer, Inductor, etc. |
| ***Operational Requirements*** | They need an external source to facilitate their functioning. | They don't require an external source. |
| ***Power gain*** $= \frac{\text{output}}{\text{input}}$ | Can give power gain in a similar manner to an amplifier. $\text{output} \neq \text{input}$ | They lack the ability for power gain. $\text{output} = \text{input}$ |
| ***Capability to Store Energy*** | Incapable of energy storage. | An inductor and capacitor can store energy. |
| ***Energy Behavior*** | They are an energy donor. | Conversely, they are an energy acceptor. |
| ***Current flow control*** | Able to regulate current flow rate/ current supply. | Incapable of the flow of charge regulation. |

# Passive electronic components:

These components can store or maintains energy either in the form of current or voltage.

- **Resistors**

A resistor is a two-terminal passive electronics component, used to oppose or limit the current. Resistor works based on the principle of Ohm's law which states that "voltage applied across the terminals of resistor is directly proportional to the current through it.V=IR Where R is the constant called resistance and The units of the resistance is ohms Resistors are further classified based on the following specifications such as the power rating, type of material used and resistance value. This resistor types are used for different applications.

- *Fixed resistors:*

This type of resistor is used to set the right conditions in an electronic circuit. The value of resistance in fixed resistors are determined during the design phase of the circuit, based on this there is no need to adjust the circuit.

- *Variable resistors:*

A device that is used to change the resistance according to our requirements in an electronic circuit is known as a variable resistor. These resistors comprise of a fixed resistor element and a slider which taps on to the resistor element. Variable resistors are commonly used as a three terminal device for calibration of the device.

- **Capacitors**

A capacitor made from two conductive plates with an insulator between them and it stores electrical energy in the form of an electric field. A capacitor blocks the DC signals and allows the AC signals and also used with a resistor in a timing circuit.

The stored charge is Q=CV where C is the capacitance of a capacitor and V is the applied voltage.

These capacitors are different types like film, ceramic, electrolytic and variable capacitors.

- Ceramic Capacitors

The material used in this capacitor type is dielectric. Also, ceramic capacitors are non-polar devices which means that they can be used in any direction in the circuit. Ceramic capacitors are used in printed circuit boards and transmitter

- Film Capacitors

Film capacitors are also known as a polymer film, plastic film, or film dielectric. The advantage of film capacitors is that they are inexpensive and have longer life. The film capacitor uses a thin dielectric material. Depending on the application, the film capacitor is rolled into thin films. The general voltage range of these capacitors is from 50 V to 2 kV. These capacitors are used for safeguarding the devices from sudden voltage spikes.

- electrolytic capacitors

An electrolytic capacitor is a type of capacitor that uses an electrolyte to achieve a larger capacitance than other capacitor types. An electrolyte is a liquid or gel containing a high concentration of ions. Almost all electrolytic capacitors are polarized, which means that the voltage on the positive terminal must always be greater than the voltage on the negative terminal

# Active electronic components

- These components rely on a source of energy and are able to control the electron flow through them. Some of these components are semiconductors like diodes, transistors, integrated circuits.

***Diodes***

A diode is a device that allows current to flow in one direction and usually made with semiconductor material. It has two terminals, anode and cathode terminals. These are mostly used in converting circuits like AC to DC circuits. These are different types like PN diodes, LEDs, photo diodes, etc

***Transistors***

A transistor is a three terminal semiconductor device. Mostly it is used as switching device and also as an amplifier. This switching device can be a voltage or current controlled.By controlling the voltage applied to the one terminal controls the current flow through the other two terminals. Transistors are of two types, namely bipolar junction transistor (BJT) and field effect transistors (FET). And further these can be PNP and NPN transistors

***Integrated Circuits***

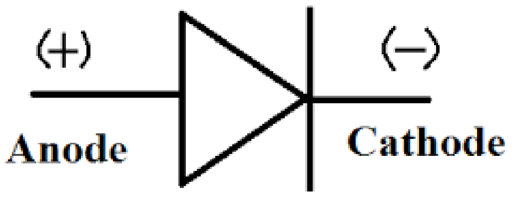
An Integrated circuit is a special component which is fabricated with thousands of transistors, resistors, diodes and other electronic components on a tiny silicon chip. These are the building blocks of current electronic devices like cell phones, computers

# PN JUNCTION DIODE

- **Semiconductor**
- It is a material having the property of both conductor and insulator.
- **Doping**: The process of adding impurities to a pure semiconductor is called doping.
- **Intrinsic semiconductor**: A semiconductor without any doping (That is no impurities are added) is called intrinsic semi-conductor
- **Extrinsic semiconductor**: a semiconductor in which impurities are added or a doped intrinsic semiconductor is called extrinsic semiconductor
- **P type Semiconductor**: When an intrinsic semiconductor is doped with trivalent impurities, such semiconductor is called P type semiconductor. I.e, if silicon is doped with 13th group element aluminum or boron, p type semiconductor is formed. Majority charge carrier in P type semiconductor is Holes
- **N type Semiconductor:** :When an intrinsic semiconductor is doped with pentavalent impurities, such semiconductor is called N type semiconductor. I.e, if silicon is doped with 15th group element arsenic or antimony, N type semiconductor is formed. Majority charge carrier in N type semiconductor is free electrons

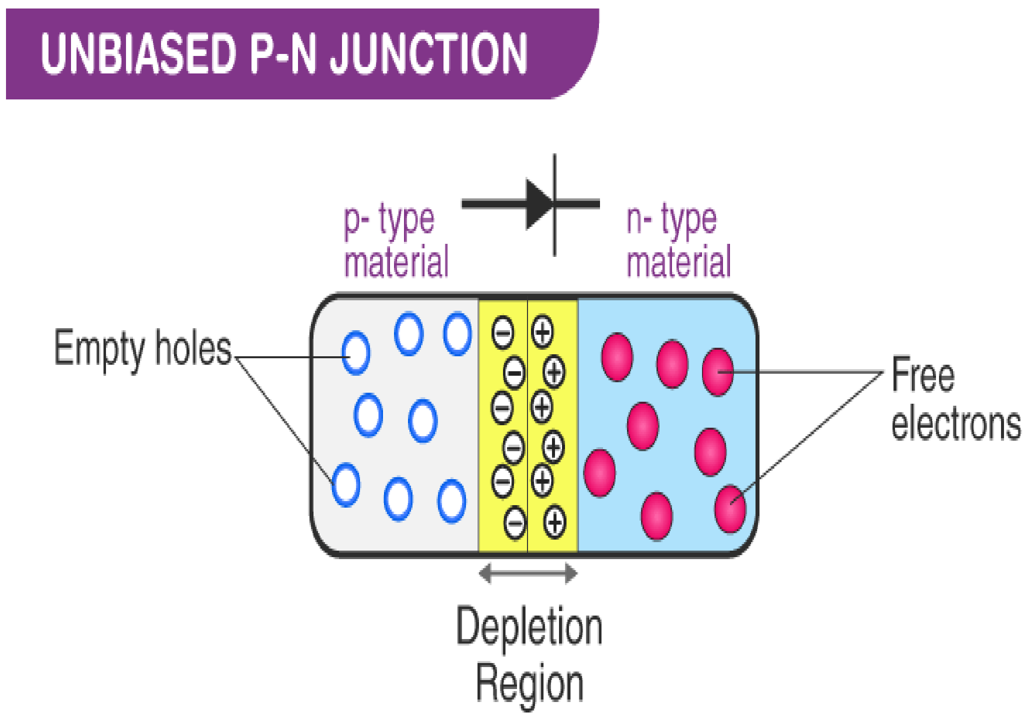
**Diode**

- It is a 2 terminal electronic component. It is a uni-directional device, because it allows only the flow of current in one direction only.it is formed by jointing P type material and N type material



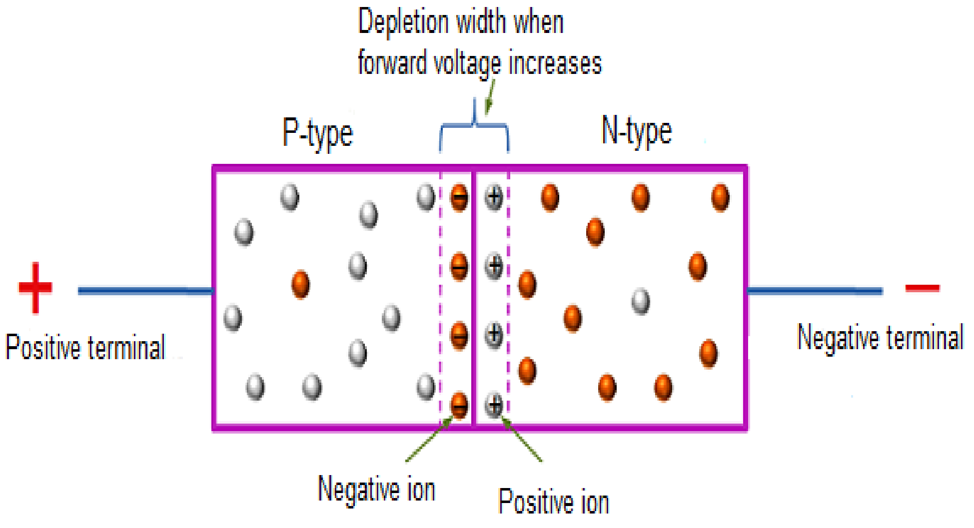

**Working principle of a diode**

- Diode is a PN junction device formed by jointing P type and N type semiconductor.
- In P type semiconductor, majority charge carrier is holes
- In N type semiconductor, majority charge carrier is free electrons.
- When they joined to form diode, at the P-N junction area, holes in P type semiconductor moves to N type semiconductor and free electrons in N type semiconductor moves to P type semiconductor region due to concentration deference.
- Due to this flow of holes and electrons a depletion region is formed with a barrier potential at PN junction area.
- This barrier potential prevents the further flow of electrons and holes.



## Forward biased PN junction

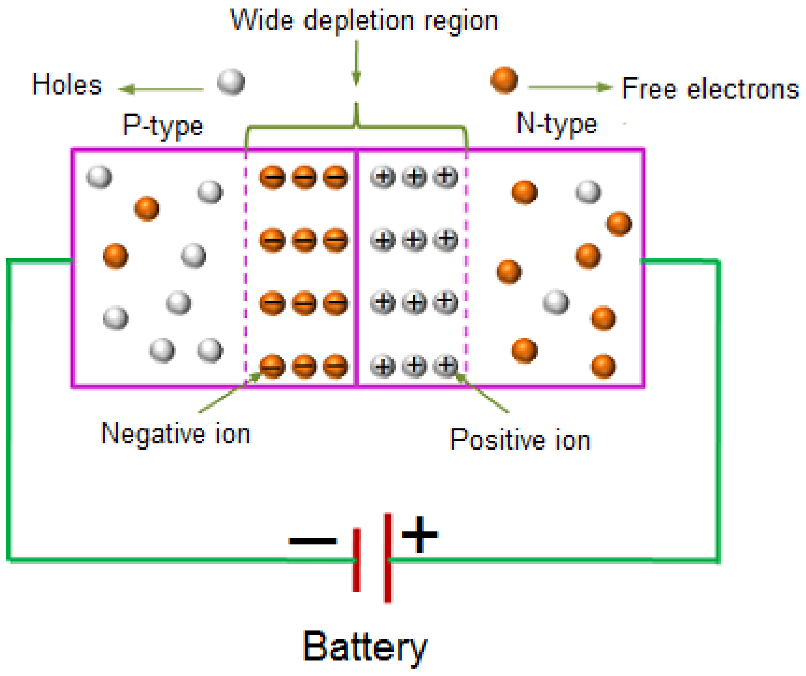
- P type part  is connected to positive terminal of the battery
- N type part is connected to Negative terminal of the battery
- holes on the P type region is attracted to negative terminal of the battery. So, it moves towards the N type region by crossing PN junction.
- Similarly, free electrons in the N type region is attracted by the positive terminal of the battery, so it moves towards the P type region by crossing.
- Due to the flow of this majority carriers across the junction, the width of depletion region reduces.




Forward biased

## Reverse biased PN junction

- P type  part of diode is connected to negative terminal of the battery
- N type part of diode is connected to positive terminal of the battery
- here, holes on the P type region is attracted to negative terminal of the battery
- free electrons in the N type region is attracted by the positive terminal of the battery.
- Due to this holes in P type region and free electron in N type region are moved away from PN junction.
- So width of depletion layer increases. In this reverse biased condition only less charge carriers in the P type and N type region crosses the PN junction and contribute to the flow of current. This current is very small.



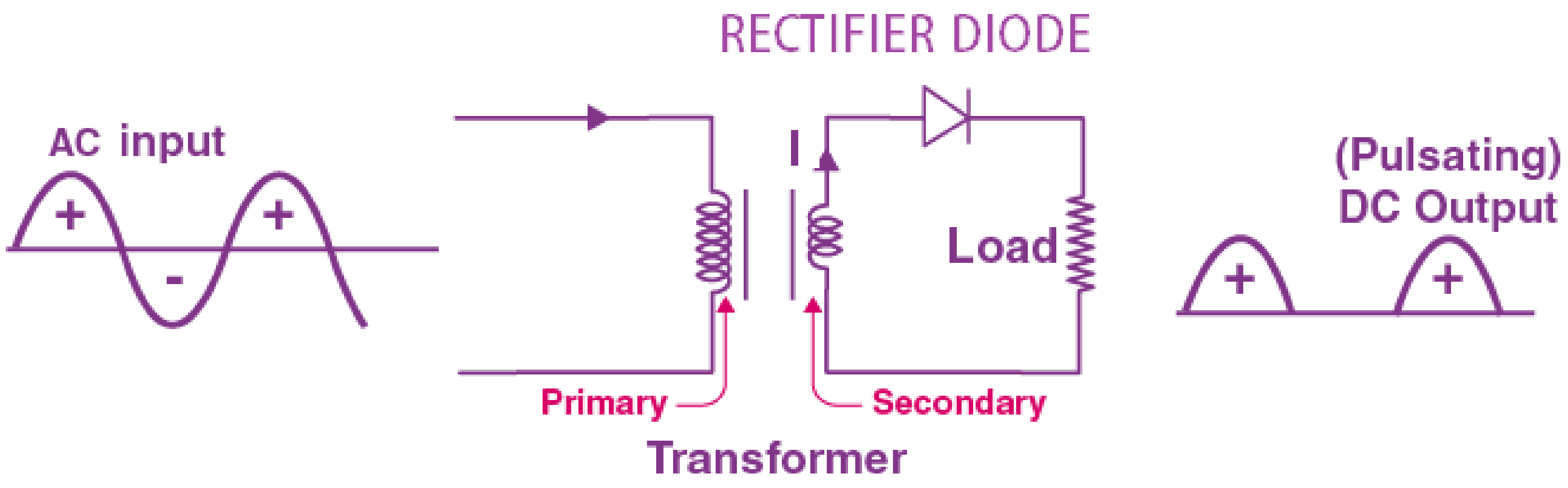

Reverse bias

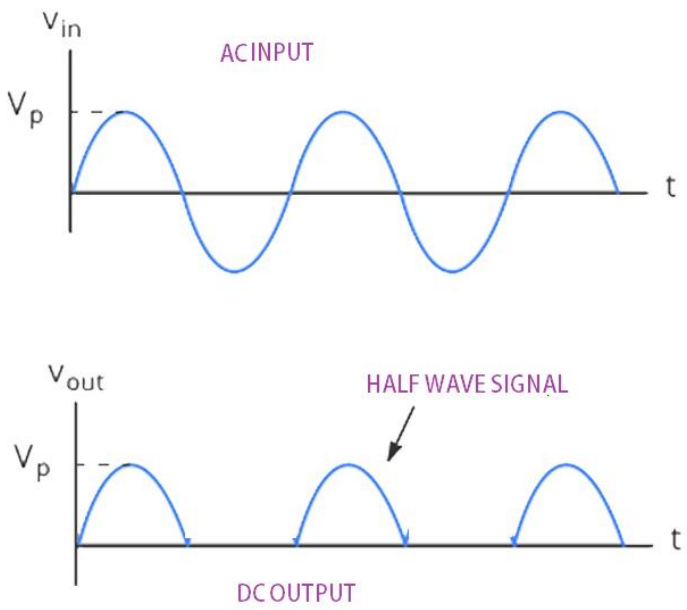
# Rectifier

- Diode can act as rectifier. A rectifier is a device which convert AC in to DC. Diode can act as rectifier.

Types of rectifier

**1.half wave rectifier**

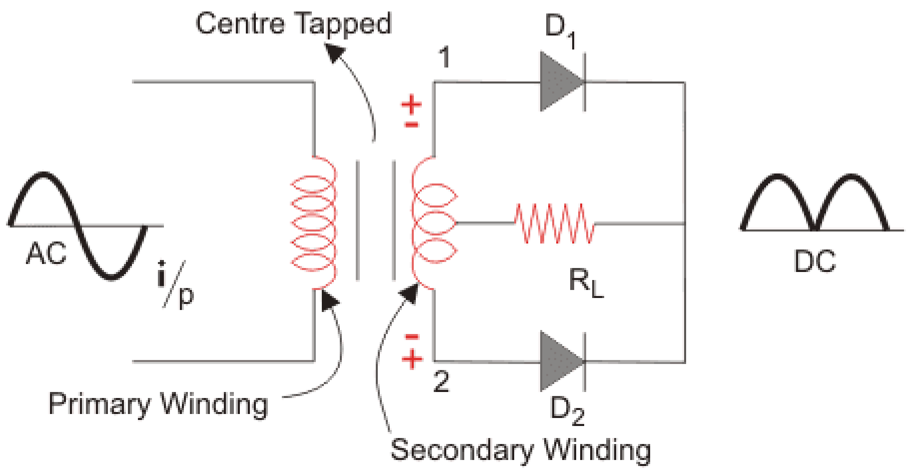


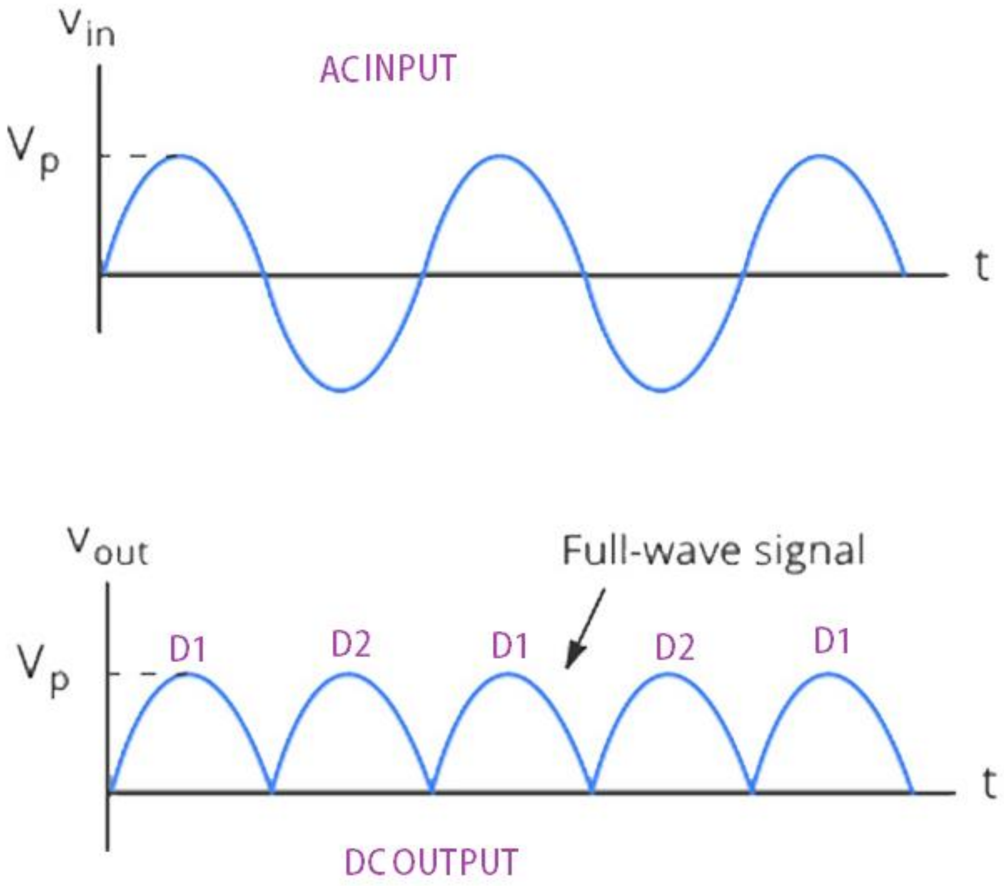

- During positive half cycle of input AC supply, diode will be forward biased. So, diode conduct. So output is obtained across the load.
- During negative half cycle diode is reverse biased. So, diode can’t conduct. So, no output is obtained across the load.

## 2. Full wave rectifier

### a. Centre tapped rectifier or Full wave rectifier using 2 diodes

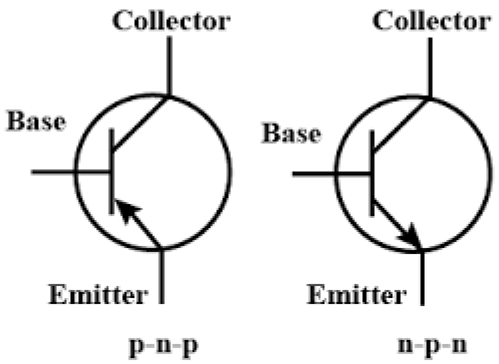



Centre Tapped Full Wave Rectifier




- During positive half cycle of input, D1 will be forward biased and D2 is reverse biased. So D1 conduct. Now the current flow through the load resistor is from A to B.
- During negative half cycle of input, D2 will be forward biased and D1 is reverse biased. So D2 conduct. Now the current flow through the load resistor is from A to B.
- In both positive half cycle and negative half cycle of input, the direction of output current is same.

# TRANSISTOR or BIPOLAR JUNCTION TRANSISTOR(BJT)

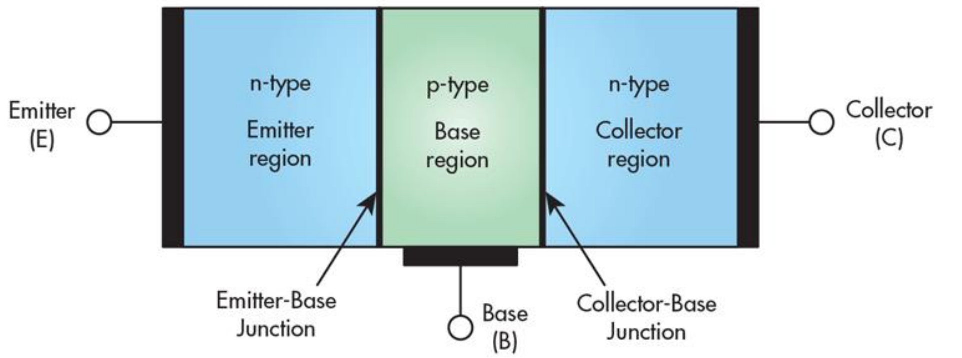


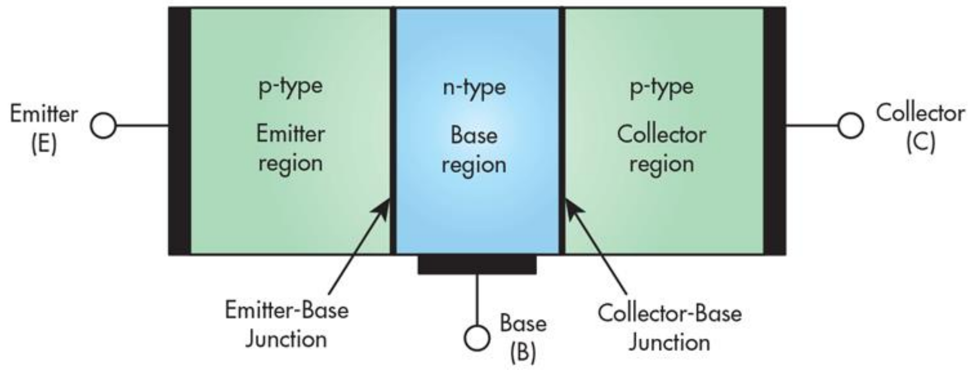

- It is a three-layer semiconductor device.
- It has three terminals. Emitter, base and collector

Application of transistor

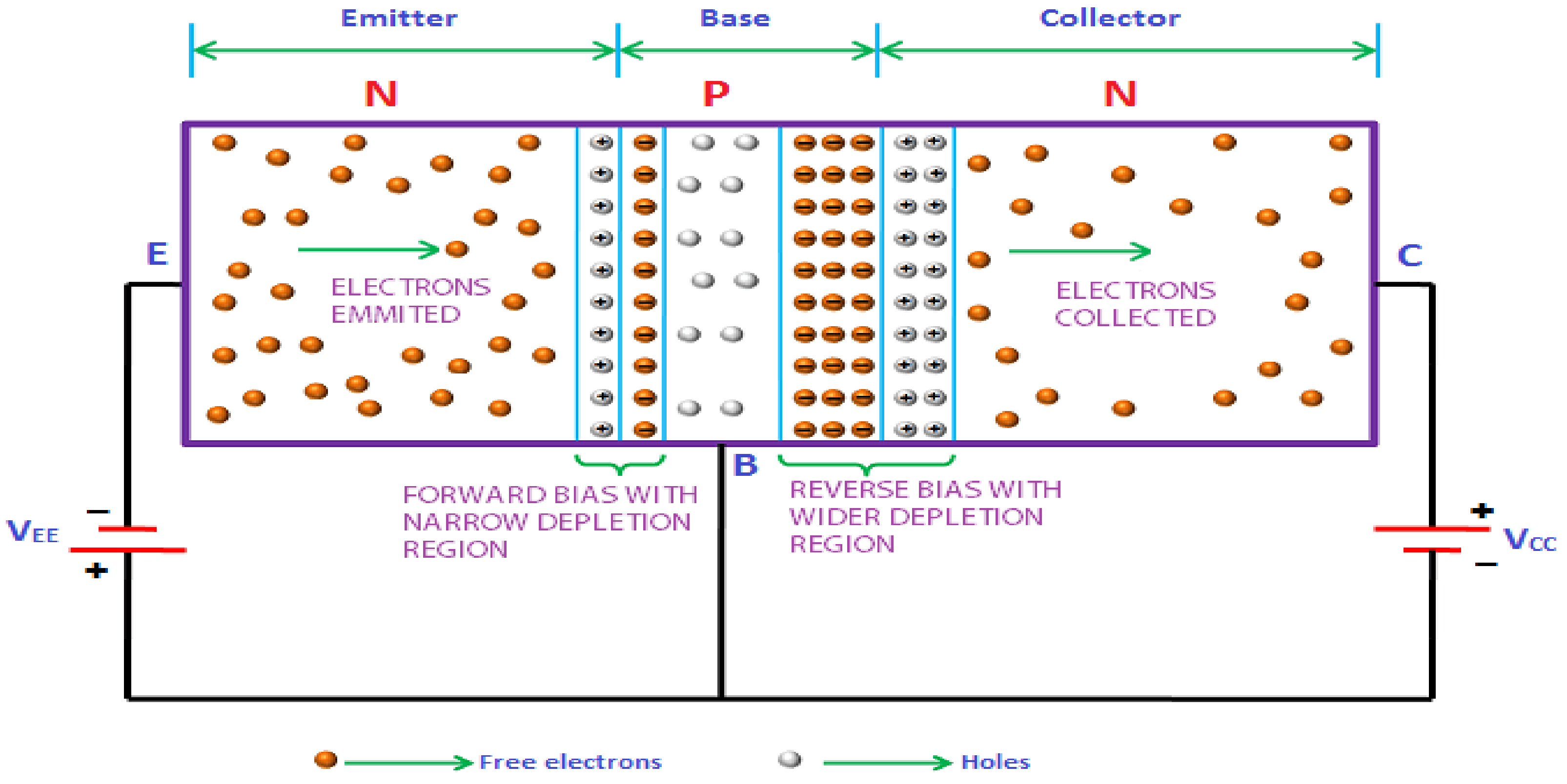
1. Used as amplifier
2. Used in computer memory chips
3. Used as switch

- There are two types of transistor
- **1. NPN Transistor**
- It consists of 2 nos of N type semiconductor and in between them a P type semiconductor.
- The P type semiconductor acts as base region of the transistor.
- Majority charge carriers in this NPN transistor is free electrons
- **2. PNP TRANSISTOR**
- It consists of 2 nos of P type semiconductor and in between them a N type semiconductor. The N type semiconductor acts as base region of the transistor. Majority charge carriers in this PNP transistor is Holes



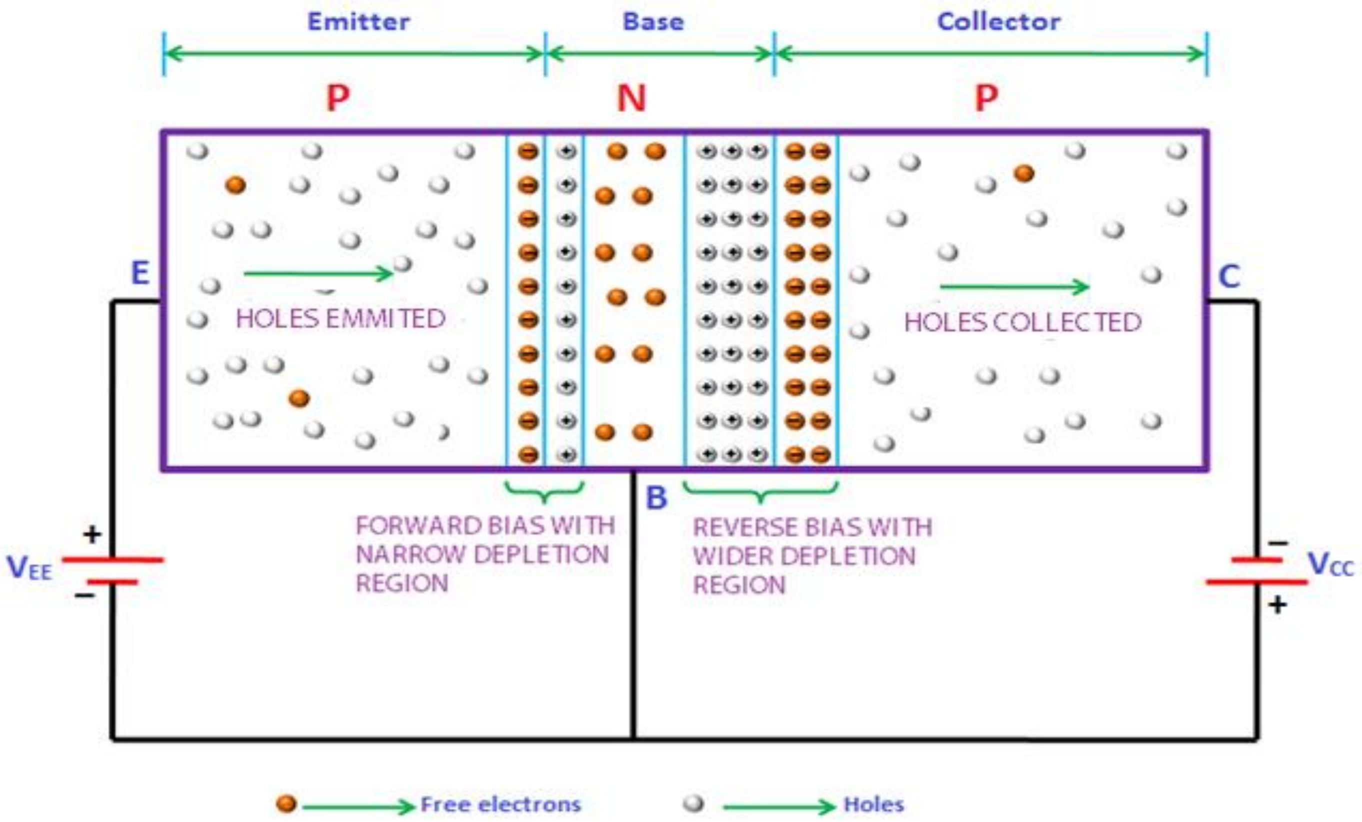



- **WORKING OF NPN TRANSISTOR**




- Here emitter base junction is forward biased and collector base junction is reverse biased. So, width of depletion region in emitter base region will be small and collector base region will be large.
- Since emitter base junction is forward biased, free electrons in N type emitter region (majority charge carrier) flows towards P type base region through emitter base junction. So, emitter current is produced
- A small number of this free electrons reached at base region combine with holes in lightly doped P-type base region. So base current is produced.
- Remaining free electrons came from emitter to base region reaches collector through collector base junction. So, collector current is produced.
- In an NPN transistor we can say that, emitter current= base current + collector current

- **WORKING OF PNP TRANSISTOR**

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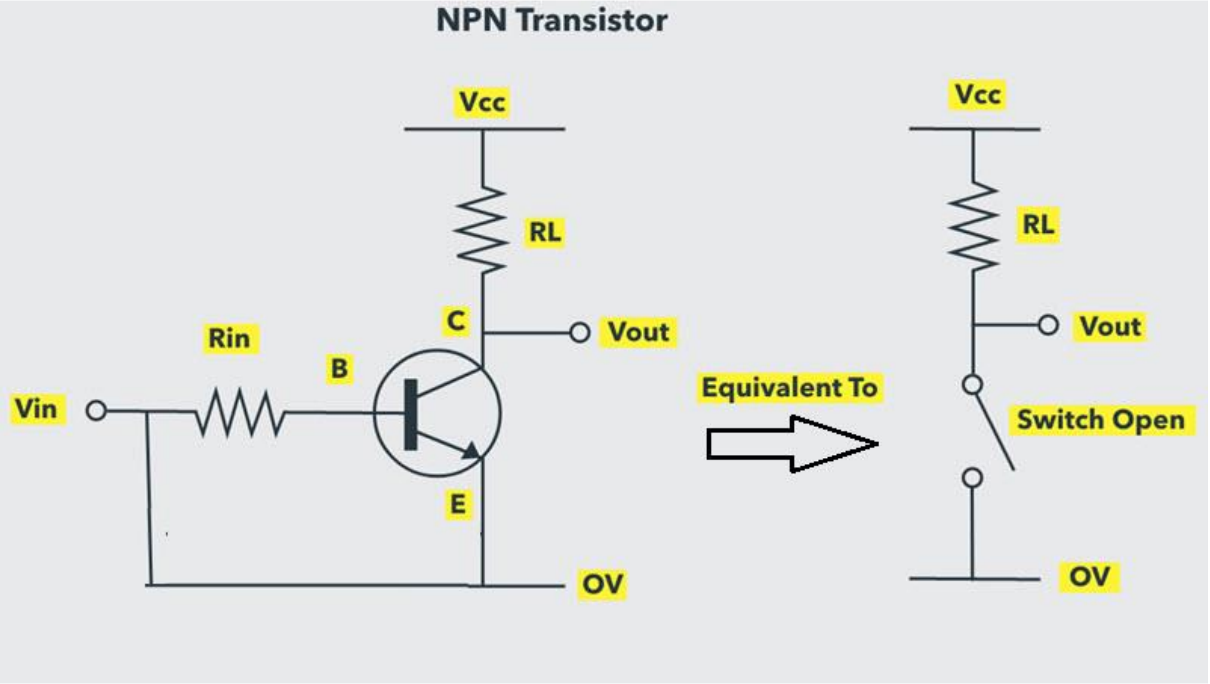
- Remaining holes came from emitter to base region reaches collector through collector base junction. So, collector current is produced. In a PNP transistor we can say that, emitter current= base current + collector current

# TRANSISTOR AS A SWITCH

- A transistor can be used for switching operation for opening or closing of a circuit. This type solid state switching offers significant reliability and lower cost when compared to conventional relays.
- Both NPN and PNP transistors can be used as switches.

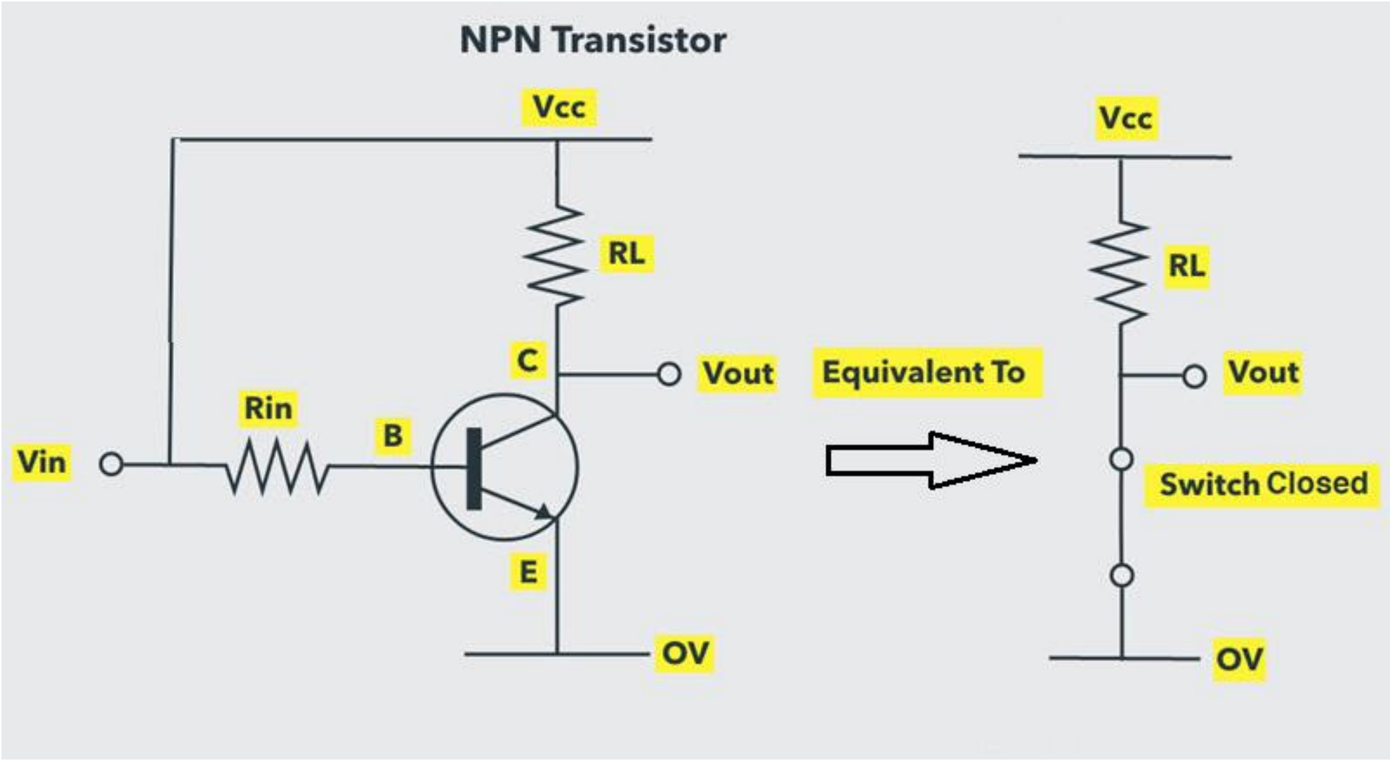



<u>TRANSISTOR AS OPEN SWITCH</u>

- both collector base junction and emitter base junction are reverse biased
- zero input base current , zero output collector current.
- maximum collector voltage which results in a large depletion layer
- So no current is flowing through the device.
- Transistor in this mode is switched OFF and is essentially an open circuit.

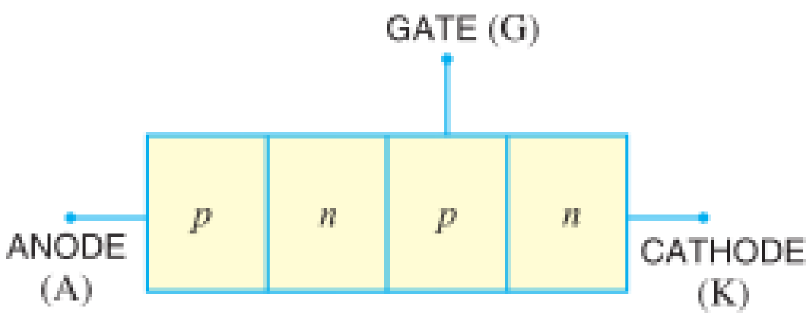
TRANSISTOR AS CLOSED SWITCH

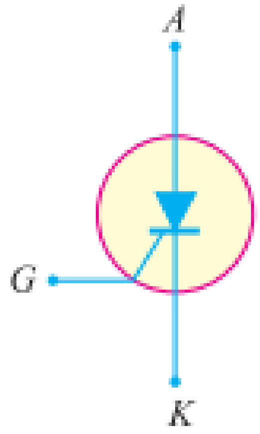
- both the emitter-base and collector-base junctions are forward biased.
- Current flows freely from collector to emitter with almost zero resistance.
- maximum amount of base current is applied, resulting in maximum collector current and then resulting in the minimum collector-emitter voltage drop.
- At this condition, the depletion layer becomes as small
- In this mode, the transistor is fully switched ON and is essentially a close circuit.



# SCR (Silicon Controlled Rectifier)

- It is a four-layer PNPN semiconductor device having three junctions.
- It has three terminals. Anode, cathode and gate
- **Working principle of SCR( or V-I characteristics of SCR)**
- it works in 3 modes .
- In normal operating conditions of SCR anode is highly positive with respect to cathode and gate is small positive with respect to cathode



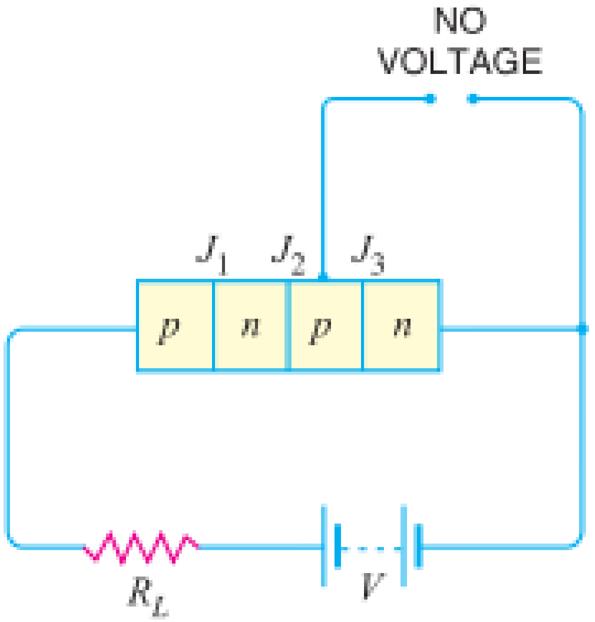
**Forward blocking mode**

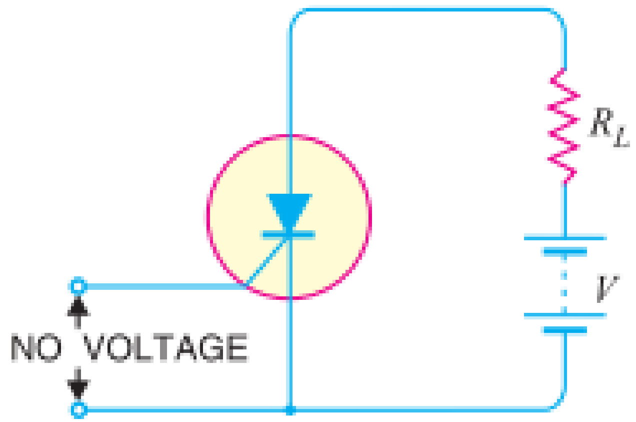
• In this mode, Anode is connected to positive terminal of input supply and cathode is connected to negative terminal of input supply. No input is given to gate terminal.

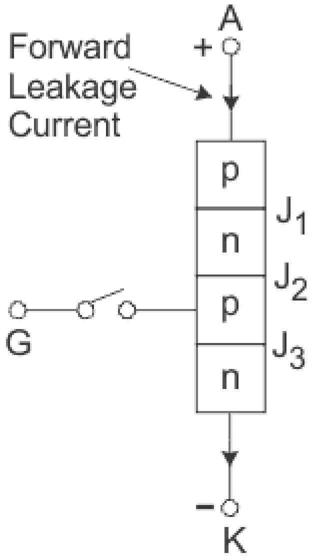
• So, junction J1 and J3 of SCR becomes forward biased and Junction J2 becomes reverse biased.

• So only very small current flows from anode to cathode.

• If we increase the voltage between anode and cathode above a certain limit, a breakdown will happen. This voltage at which breakdown of SCR takes place is called forward breakover voltage( VBO)



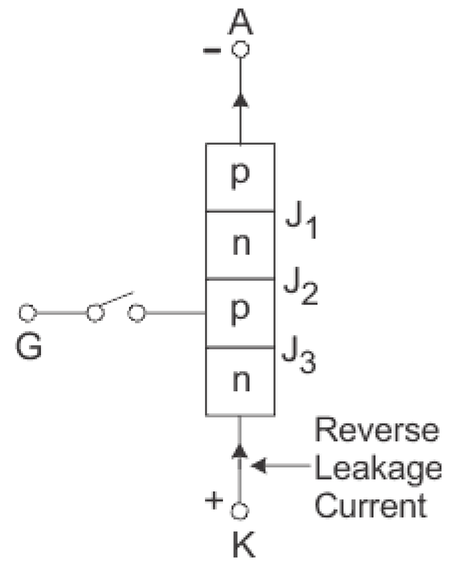




Forward Biased Condition

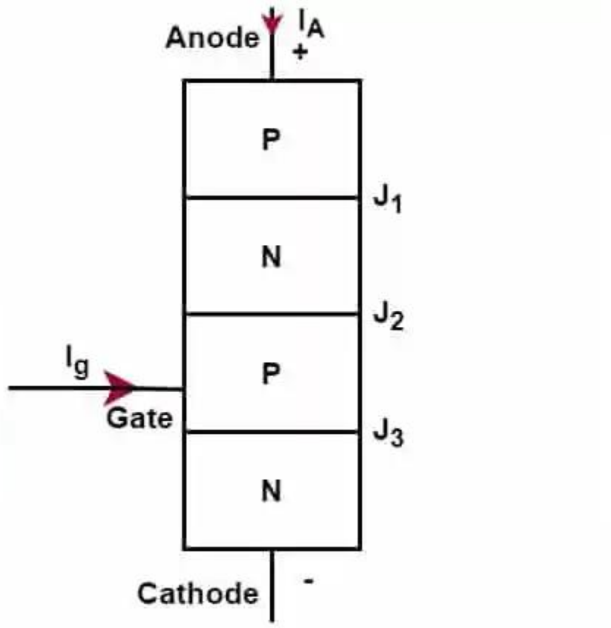
**Reverse blocking mode**

- In this mode, Anode is connected to negative terminal of input supply and cathode is connected to positive terminal of input supply. No input is given to gate terminal.
- So, junction J1 and J3 of SCR becomes reverse biased and Junction J2 becomes biased.
- So only very small current flows. It is due to minority charge carriers from cathode to anode. This current is called reverse leakage current.
- If we increase the voltage between anode and cathode above a certain limit, a breakdown will happen. This voltage at which breakdown of SCR takes place is called reverse breakdown voltage( VBR)

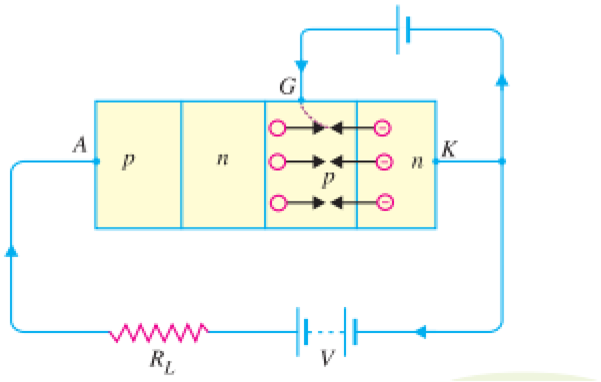


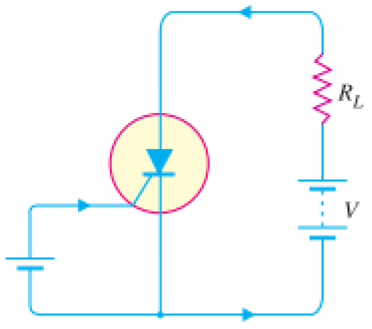

Reverse Blocking Mode

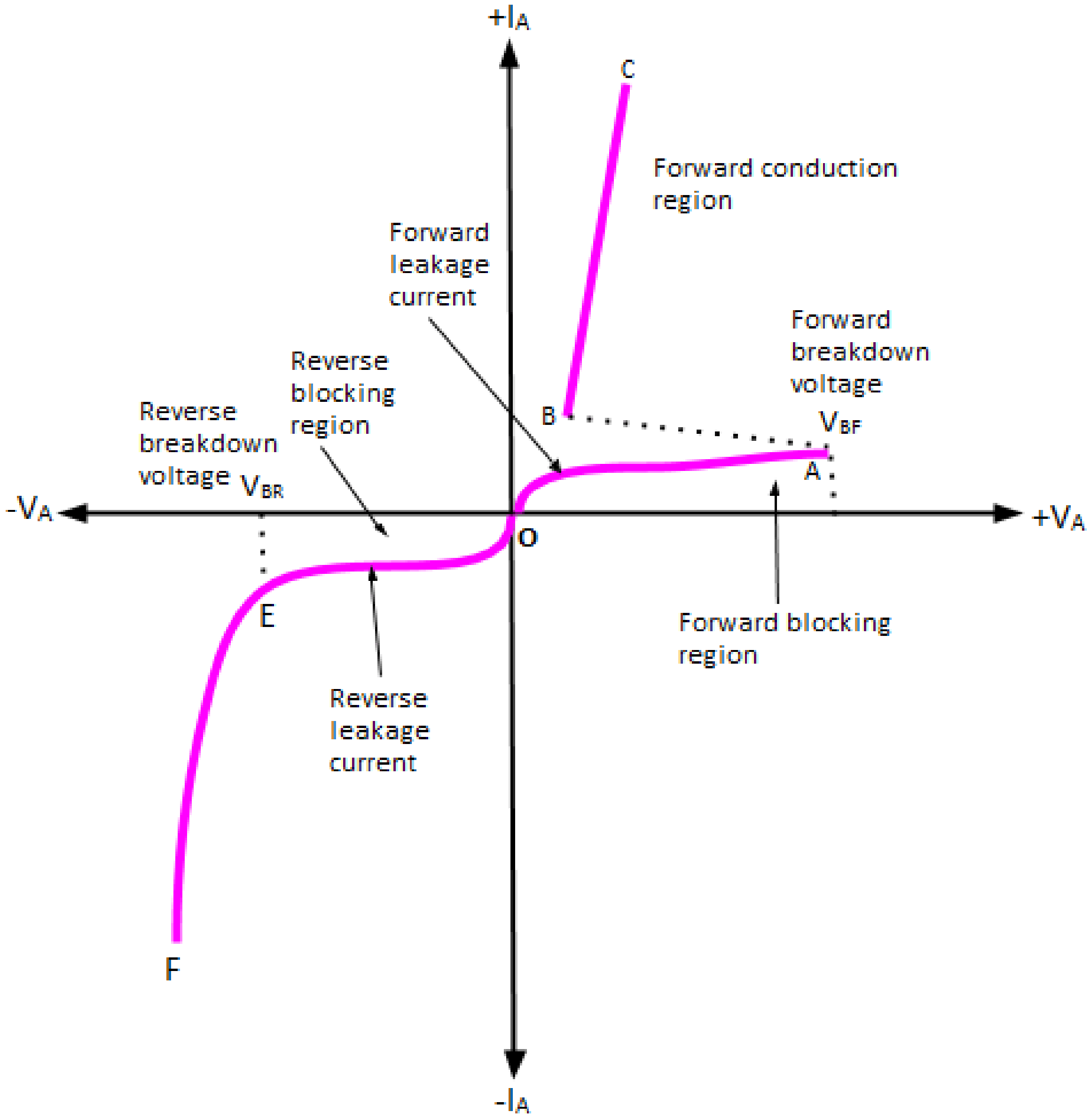
- **Forward conduction mode**
- In this mode, Anode is connected to positive terminal of input supply and cathode is connected to negative terminal of input supply.
- So, junction J1 and J3 of SCR becomes forward biased
- In this mode of operation, a positive input is given to gate terminal. So, junction J2 also becomes forward biased. So, a current flow from anode to cathode. Now SCR conducts
- These three modes of operation of SCR is shown in V-I characteristics




Forward Conduction Mode Of SCR



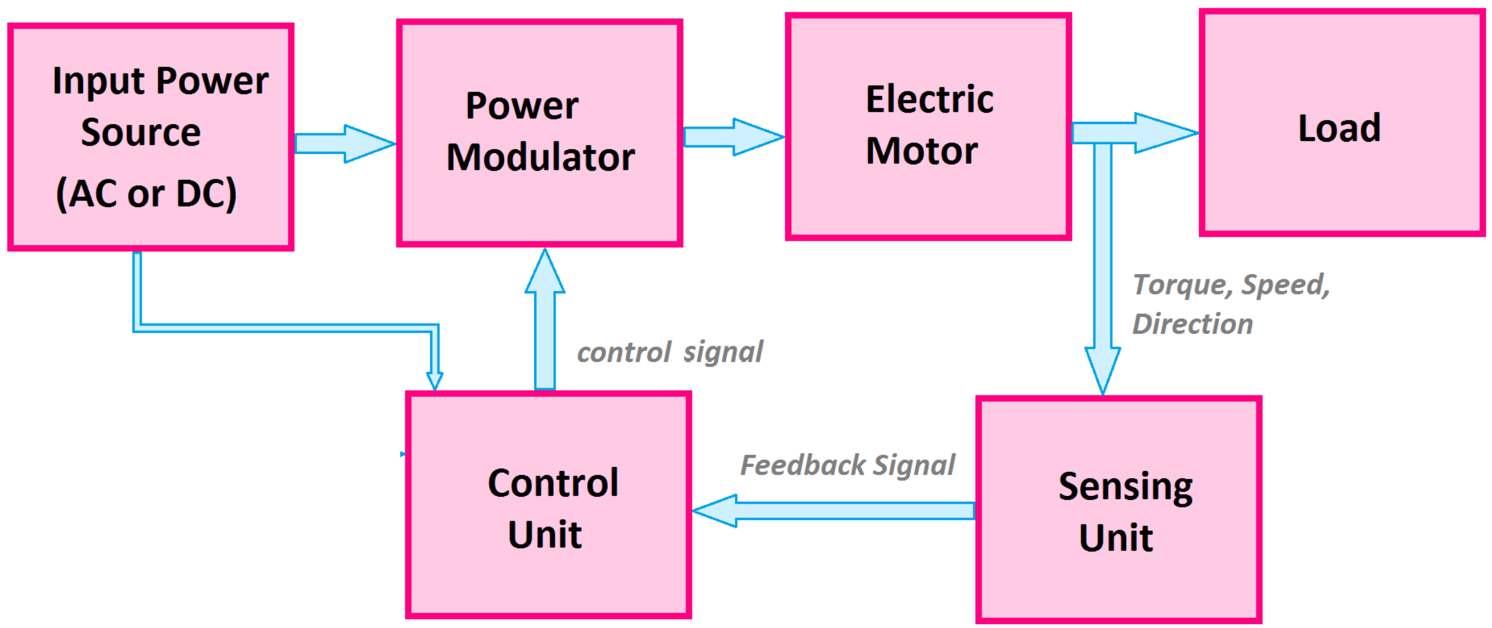




V-I Characteristics of SCR

# APPLICATION OF SCR

- 1. For controlled AC to DC conversion
- 2. Speed control of DC and AC motors
- 3. As rectifier for conversion of AC into DC
- 3. As inverter for conversion of DC into AC
- 4. As chopper for converting fixed DC into variable DC.
- 3. In DC circuit breaker
- 4. In battery charging circuit
- 5. In automobiles
- 6. in overvoltage protection circuits

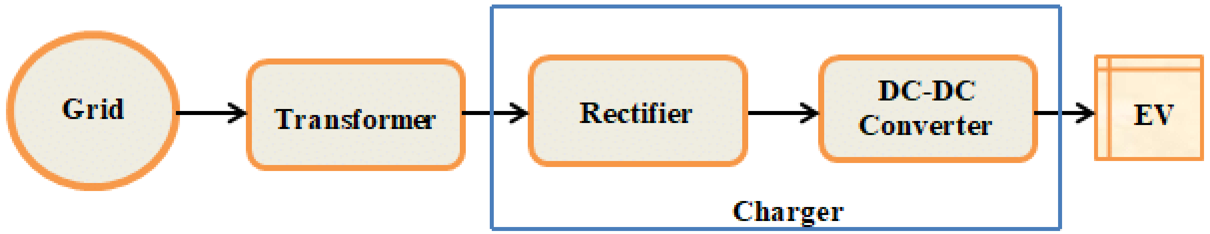
# ELECTRIC DRIVES




*Electrical Drive System Block Diagram*

- Electric Drive is a system with the combination of electric motors and their speed or motion controlling circuits.
- The main function of the input power circuit of an electrical drive system is to provide power to the power modulator and keep regulating the voltage means the output of the power circuit always be constant even the power fluctuation or voltage changes in the input of the system.
- The power modulator converts the input AC into pulsed DC signals to provide the motor.
- The sensing unit is connected to different types of sensors. It senses and measures the speed, torque, direction of the motor rotation. It generates the feedback signal and provides it to the control unit.
- The control unit takes the both feedback signal from the sensing unit and the reference signal from the input device and generates a controlled signal to provide it to the power modulator. The Control unit is built with electronic circuits, programming devices, etc.
- **Applications of Electric Drive System**
- Electrical drive used in industrial motor controls, pump controls, lift control, etc.
- An electric drive system is used in transportation systems such as electric vehicles.

# EV CHARGING SYSTEM




$$\text{Charging Time (h)} = \frac{\text{Battery capacity (kWh)}}{\text{Charging power (kW)}}$$

- In EV Charging system the grid supplies the power in the form of AC signal .the step down transformer increases current available to the system by reducing voltage .rectifier circuit helps converting AC to DC . Batteries can only be charged with direct current (DC) electric power, while most electricity is delivered from the power grid as alternating current (AC). For this reason, most electric vehicles have a built-in AC-to-DC converter, commonly known as the "onboard charger". At an AC charging station, AC power from the grid is supplied to this onboard charger, which produces DC power to charge the battery. DC chargers facilitate higher power charging (which requires much larger AC-to-DC converters) by building the converter into the charging station instead of the vehicle to avoid size and weight restrictions.