BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

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MODULE - I
ELECTRIC CIRCUITS,ELECTROMAGNETISM AND INSTRUMENTS

CO’s	Course outcomes
CO1	Analyze the circuits using Kirchhoff’s current and Kirchhoff’s voltage law.
CO2	Use of series-parallel concepts for simplifying circuits.
CO3	Use star delta transformation for simplifying complex circuits.
CO4	Generalize operation and principle of measuring instruments.

INTRODUCTION

- Atoms consist of three basic particles: protons, electrons, and neutrons. The nucleus (center) of the atom contains the protons (positively charged) and the neutrons (no charge). The outermost regions of the atom are called electron shells and contain the electrons (negatively charged). Atoms have different properties based on the arrangement and number of their basic particles.

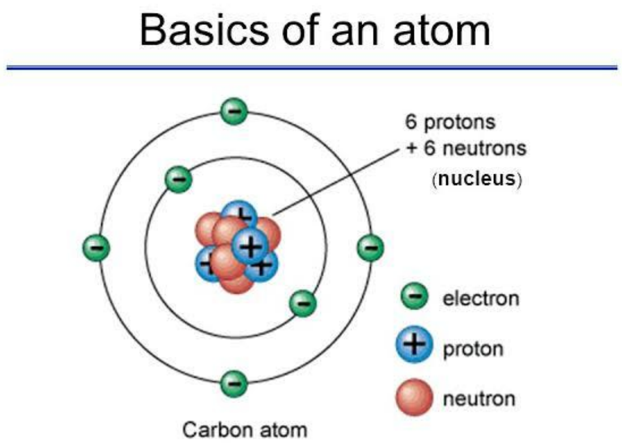


Fig 1: basic structure of atom

SYSTEMS OF UNITS

Table 1.1 shows the six units and one derived unit that are relevant to this text.

Table 1.2 shows the SI prefixes and their symbols.

Six basic SI units and one derived unit relevant to this text		
Quantity	Basic unit	symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Luminous intensity	Candela	cd
charge	coulomb	C

The SI prefixes		
Multiplier	Prefix	symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

VOLTAGE:

Voltage is the pressure from an electrical circuit's power source that pushes charged electrons (current) through a conducting loop, enabling them to do work such as illuminating a light. In brief, voltage = pressure, and it is measured in volts (V).

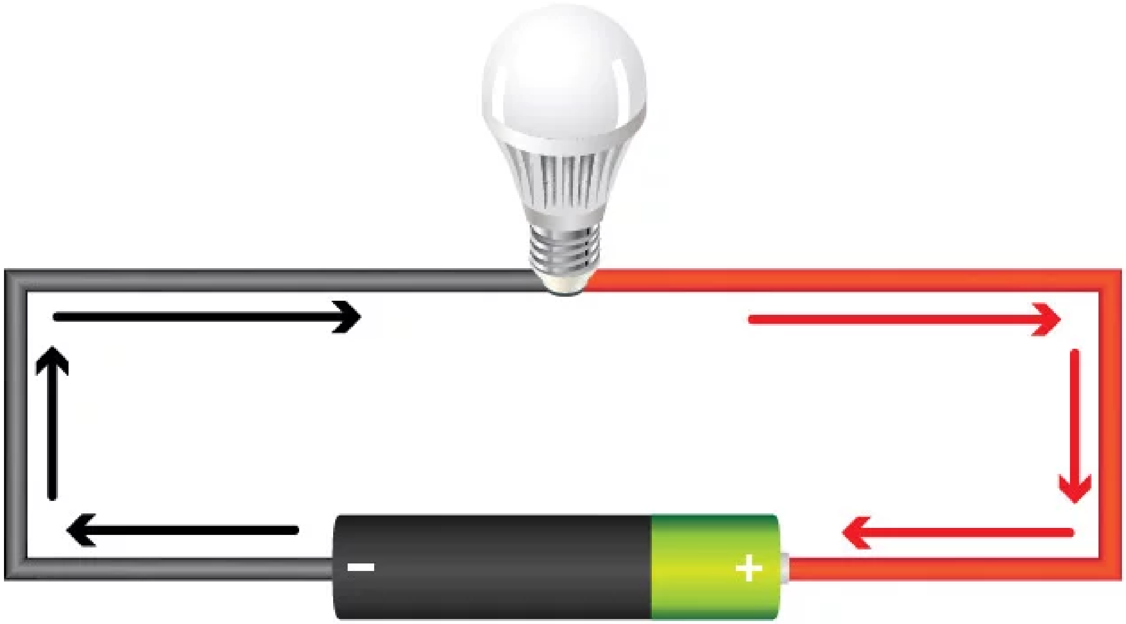
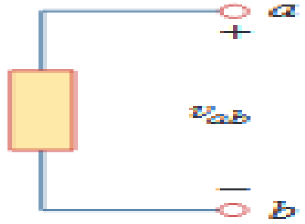


Fig 2: moment of electon when pressure is applied

VOLTAGE BETWEEN TWO POINTS

•The voltage between two points A and B in an electric circuit is the energy (or work) needed to move a unit charge from a to b; mathematically,

$$v_{ab} = \frac{dw}{dq}$$



•Where ,w is energy in joules (J) and q is charge in coulombs (C). The voltage or simply v is measured in volts (V).

1 volt=1 joule/coulomb=1 newton-meter/coulomb

•Thus, Voltage(or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).

CURRENT :

Current is the flow of electrical charge carriers like electrons. Current flows from negative to positive points. The SI unit for measuring electric current is the ampere (A).

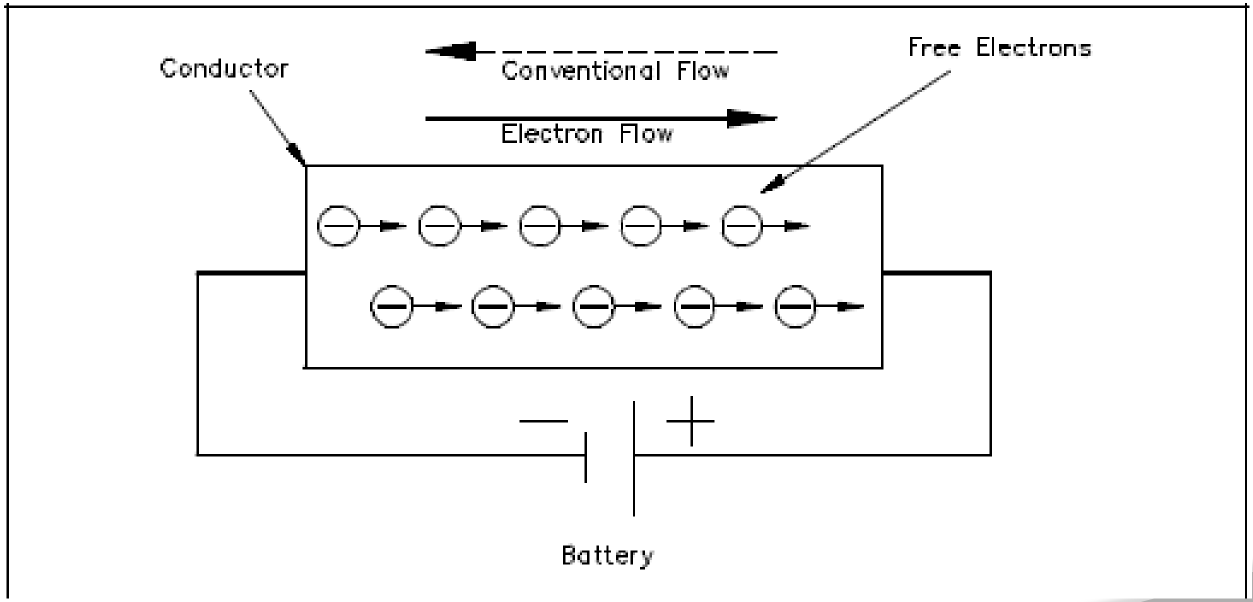


Fig 3: electron flow

TYPES OF CURRENT

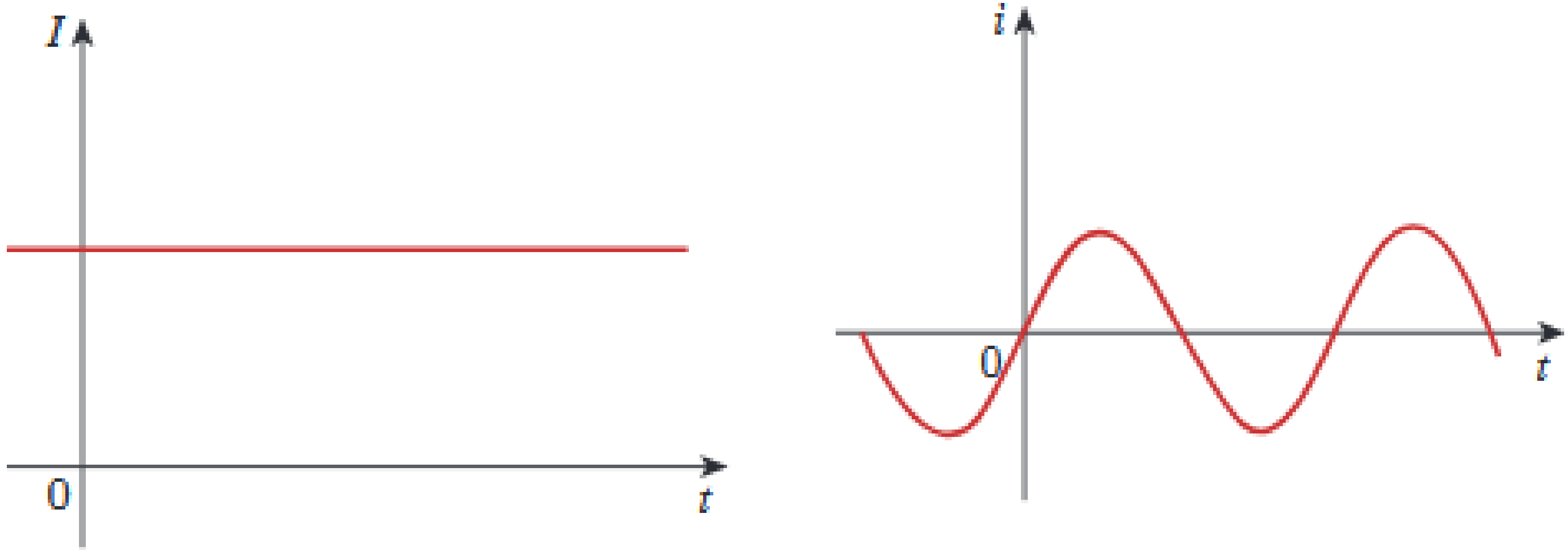


Fig 4: Two common types of current: (a) direct current (dc), (b) alternating current (ac)

POWER AND ENERGY

- Power is the time rate of expending or absorbing energy, measured in watts (W).

$$p = \frac{dw}{dt}$$

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$$

$$p = vi \ldots\ldots\ldots\ldots (1.3)$$

The power p in Eq. (1.3) is a time-varying quantity and is called the instantaneous power. Thus, the power absorbed or supplied by an element is the product of the voltage across the element and the current through it. If the power has a sign, power is being delivered to or absorbed by the element. If, on the other hand, the power has a sign, power is being supplied by the element.

TYPES OF ELECTRICAL NETWORKS

- Active and passive
- Linear and no linear
- Bilateral unilateral
- Lumped and distributed

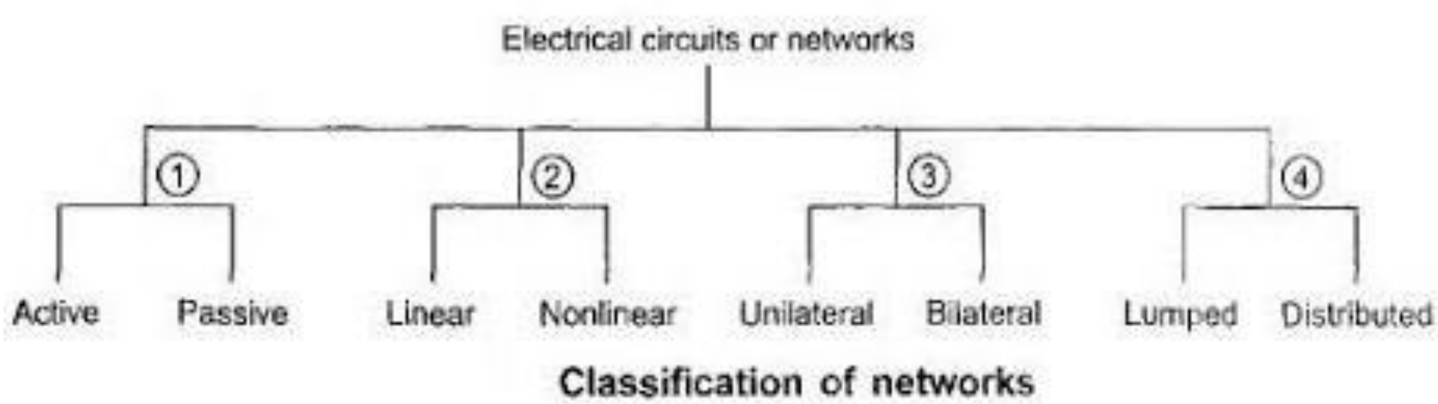


Fig 5: classification of networks

TYPES OF ELEMENTS

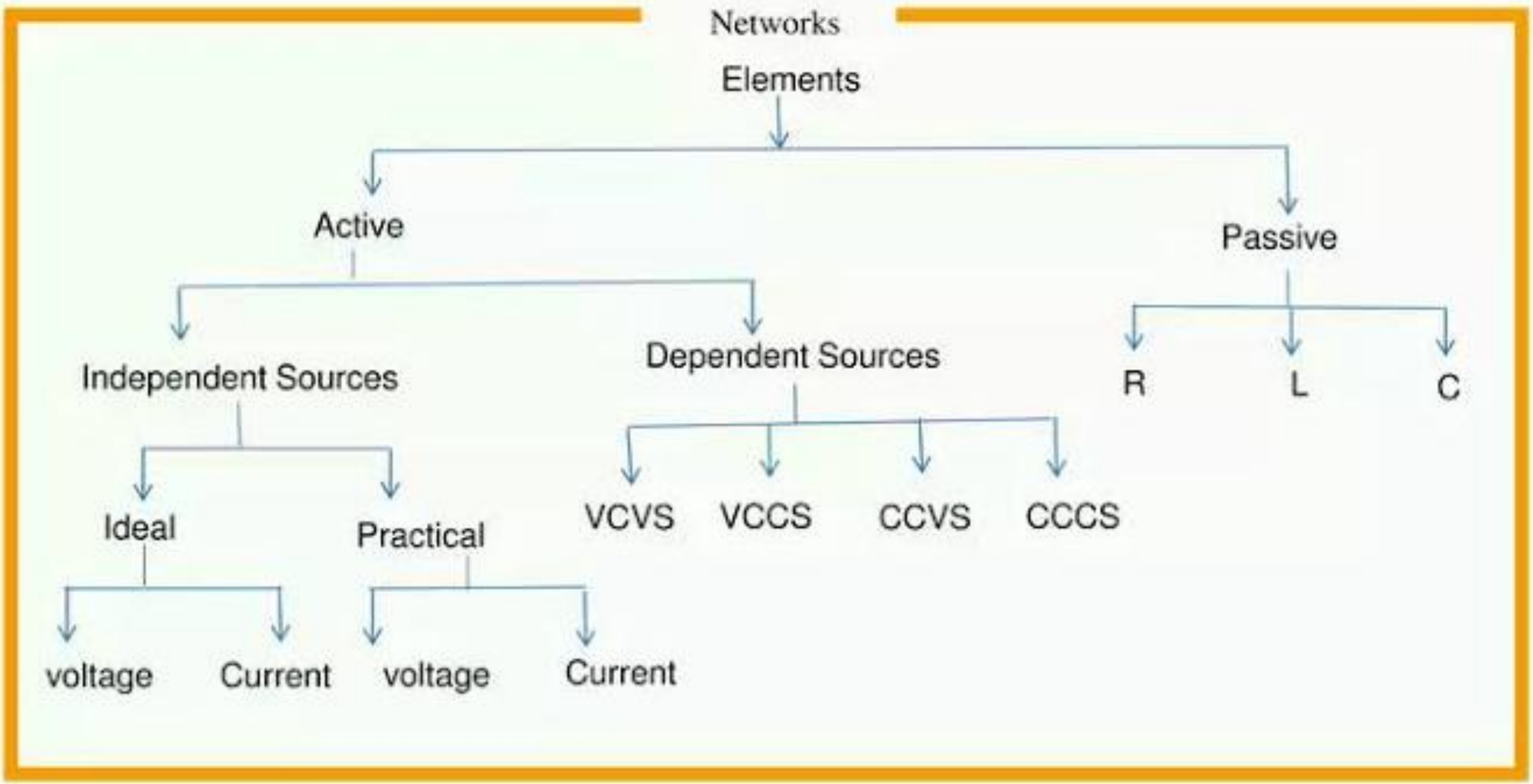
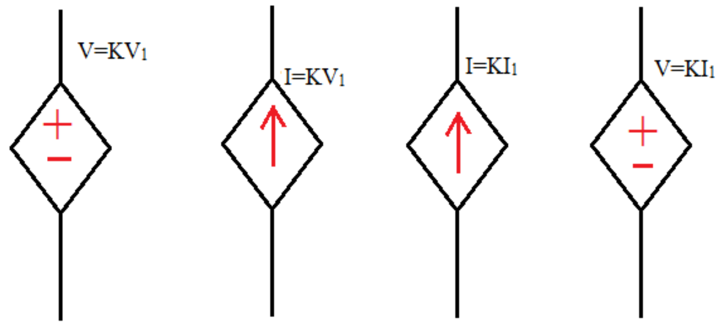


Fig 6: classification of network elements

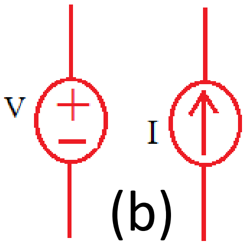
INDEPENDENT,DEPENDENT SOURCES

- The **dependent sources** depend on the voltage/current in some part of the same circuit.



(a)

- The **independent source** does not depend on voltage/current in any part of the circuit.



(b)

Fig 7: (a) dependent source ;(b) independent source

RESISTORS

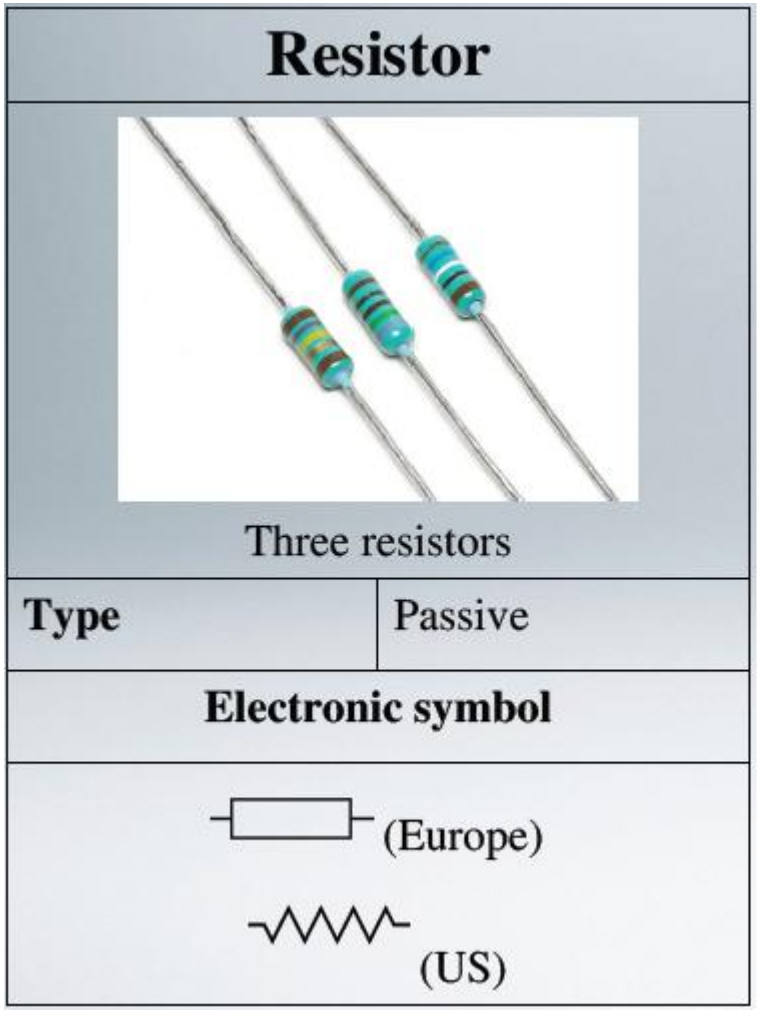


Fig 8: resistor

- Resistance (R) is the physical property of an element that impedes the flow of current . The units of resistance are Ohms (Ω)
- Resistivity (ρ) is the ability of a material to resist current flow. The units of resistivity are Ohm-meters (Ω-m)

OHMS LAW

- Georg Ohm found that, at a constant temperature, the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it, and also inversely proportional to the resistance. This relationship between the Voltage, Current and Resistance forms the basis of **Ohms Law** and is shown below.
- **Ohms Law Relationship**

$$\text{CURRENT,(I)} = \frac{\text{VOLTAGE(V)}}{\text{RESISTANCE(R)}}$$

OHMS LAW

- By knowing any two values of the Voltage, Current or Resistance quantities we can use **Ohms Law** to find the third missing value. **Ohms Law** is used extensively in electronics formulas and calculations so it is "very important to understand and accurately remember these formulas".
- **To find the Voltage, (V)**

[V = I x R] V (volts) = I (amps) x R (Ω)

- **To find the Current, (I)**

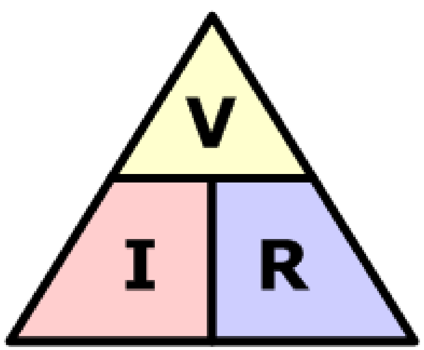
[I = V ÷ R] I (amps) = V (volts) ÷ R (Ω)

- **To find the Resistance, (R)**

[R = V ÷ I] R (Ω) = V (volts) ÷ I (amps)

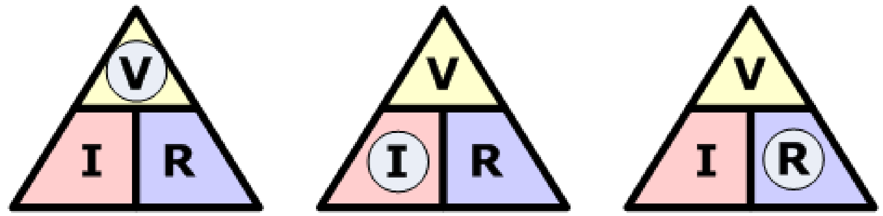
OHMS LAW

- It is sometimes easier to remember this Ohms law relationship by using pictures. Here the three quantities of V, I and R have been superimposed into a triangle (affectionately called the Ohms Law Triangle) giving voltage at the top with current and resistance below. This arrangement represents the actual position of each quantity within the Ohms law formulas.



OHM'S LAW

- Transposing the standard Ohms Law equation above will give us the following combinations of the same equation:



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

- Then by using Ohms Law we can see that a voltage of 1V applied to a resistor of 1Ω will cause a current of 1A to flow and the greater the resistance value, the less current that will flow for a given applied voltage.

CAPACITORS

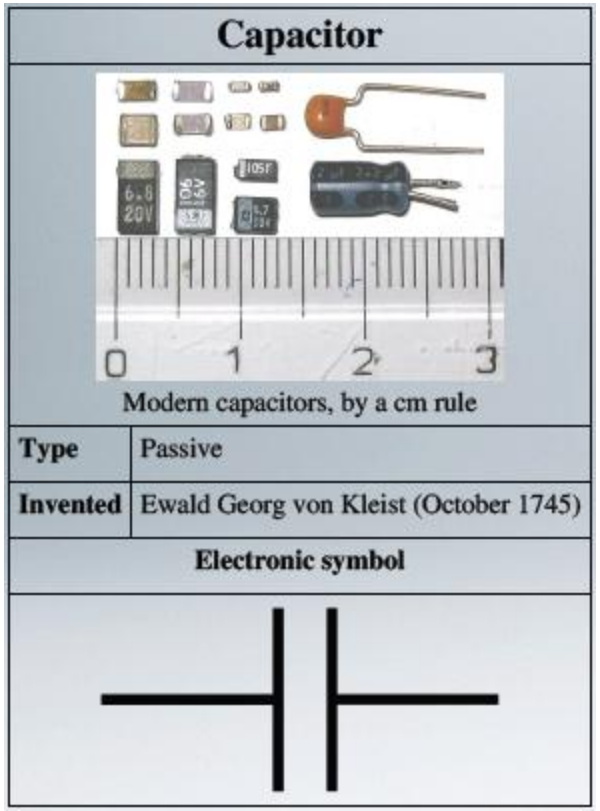


Fig 9: capacitor

- A capacitor consists of a pair of conductors separated by a dielectric (insulator).
- Electric charge is stored in the plates – a capacitor can become "charged"
- Capacitance (C) is the ability of a material to store charge in the form of separated charge or an electric field. It is the ratio of charge stored to voltage difference between two plates.
- Capacitance is measured in Farads (F)

INDUCTORS

Inductor

A selection of low-value inductors

Type	Passive
Working principle	Electromagnetic induction
First production	Michael Faraday (1831)

Electronic symbol

Fig 10: inductor

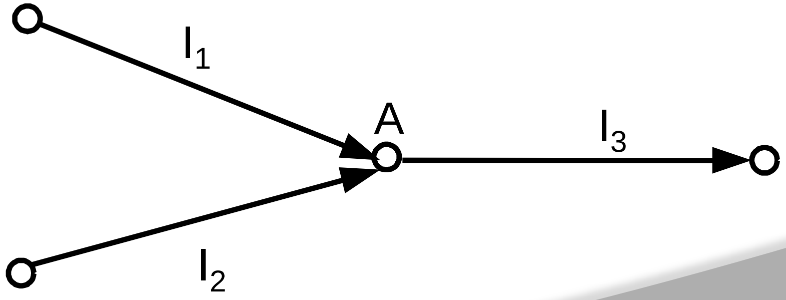
- An inductor is a two terminal element consisting of a winding of N turns capable of storing energy in the form of a magnetic field
- Inductance (L) is a measure of the ability of a device to store energy in the form of a magnetic field. It is measured in Henries (H)

- **KIRCHHOFF'S CURRENT LAW**

- Algebraic sum of all currents entering and leaving a node is zero.
- At node A:

$$I_1 + I_2 - I_3 = 0$$

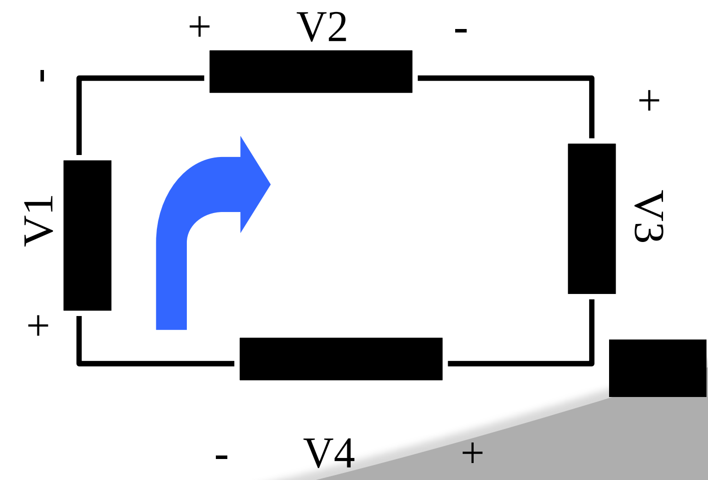
- Current entering a node is assigned positive sign. Current leaving a node is assigned a negative sign.



KIRCHHOFF’S VOLTAGE LAW

- KIRCHHOFF’S VOLTAGE LLAW
- The algebraic sum of voltage around a loop is zero.
- Assumption:
  - Voltage drop across each passive element is in the direction of current flow.

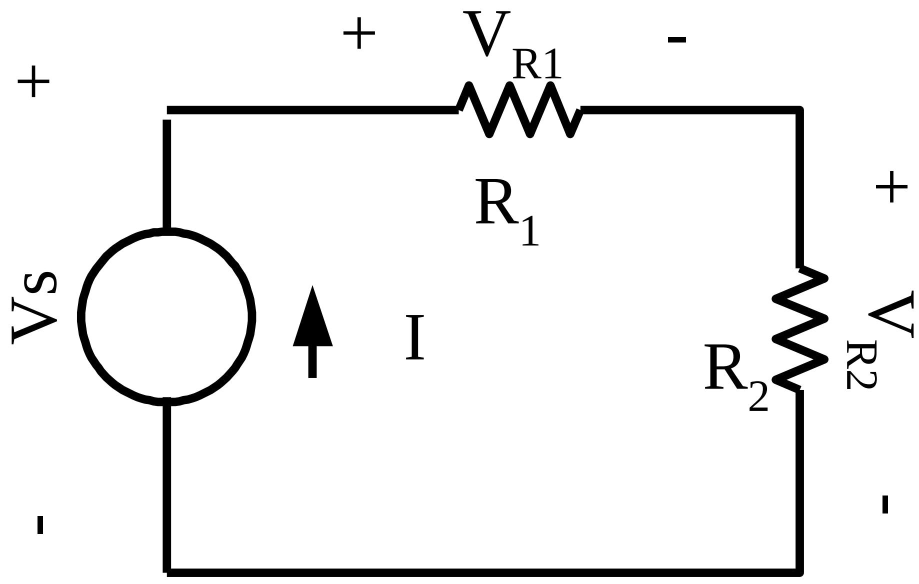
$$V_1 + V_2 + V_3 + V_4 = 0$$



LAW OF VOLTAGE DIVISION

$$V_{R_1} = \frac{R_1}{R_1 + R_2} V_s$$

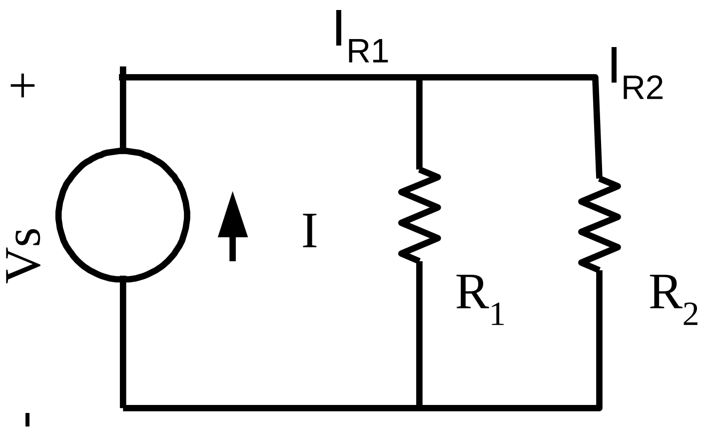
$$V_{R_2} = \frac{R_2}{R_1 + R_2} V_s$$



LAW OF CURRENT DIVISION

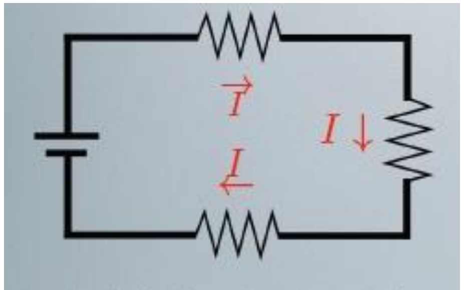
$$I_{R_1} = \frac{R_2}{R_1 + R_2} I$$

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

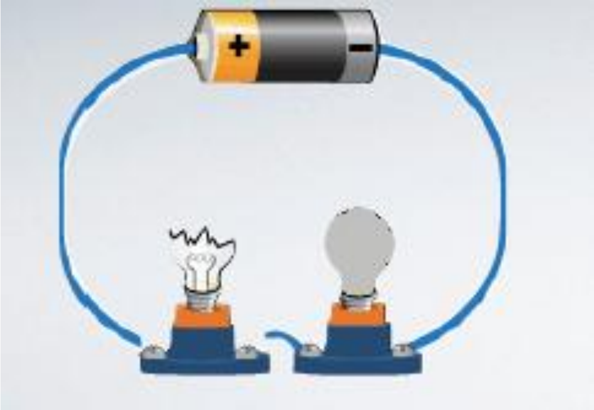


SERIES CIRCUITS

- A **series circuit** has only **one current path**

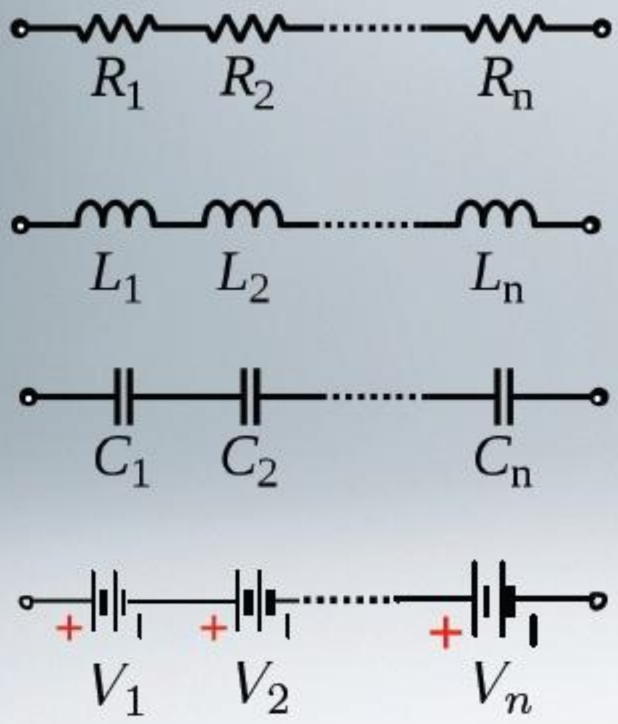


A series circuit with a voltage source (such as a battery) and 3 resistors



- Current through each component is the same
- In a series circuit, all elements must function for the circuit to be complete.

SERIES CIRCUITS



$$R_{total} = R_1 + R_2 + \ldots + R_n$$

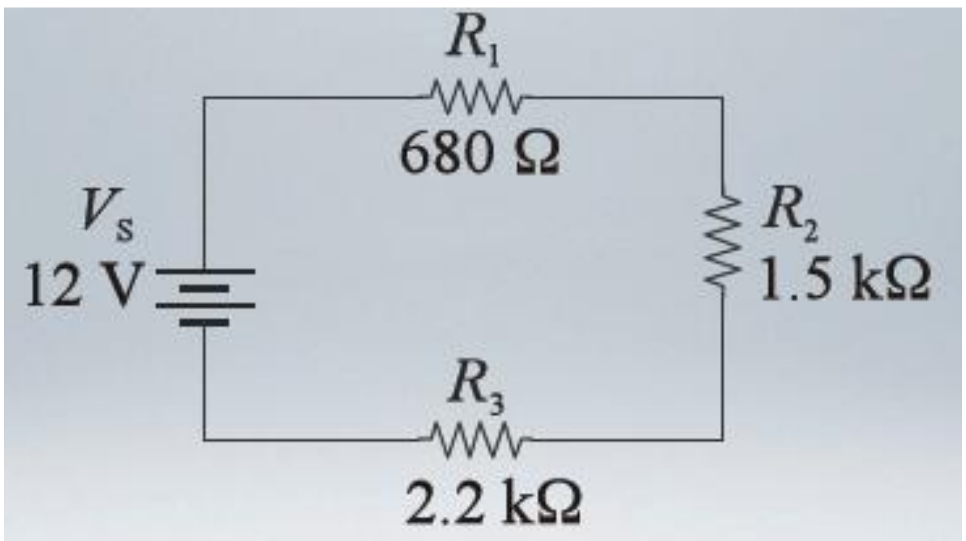
$$L_{total} = L_1 + L_2 + \ldots + L_n$$

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}$$

$$V_{total} = V_1 + V_2 + \ldots + V_n$$

EXAMPLE: RESISTORS IN SERIES

- The resistors in a series circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ. What is the total resistance?

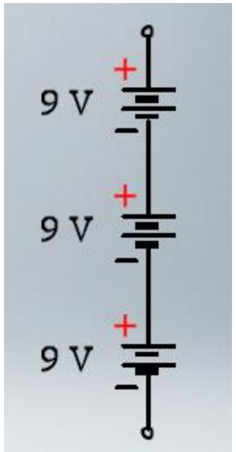


$$
\begin{aligned}
R_{total} &= R_1 + R_2 + R_3 \\
&= 680\Omega + 1500\Omega + 2200\Omega \\
&= 4380\Omega \\
&= 4.38k\Omega
\end{aligned}
$$

VOLTAGE SOURCES IN SERIES

- ✓ Find the total voltage of the sources shown

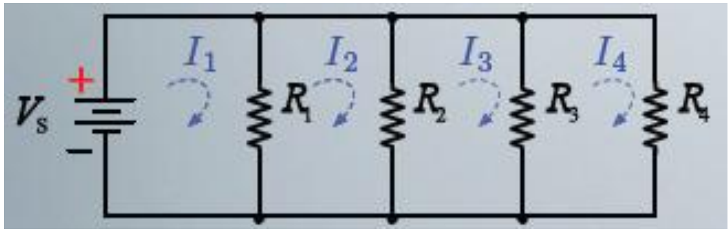
$$V_{total} = V_1 + V_2 + V_3 = 27V$$



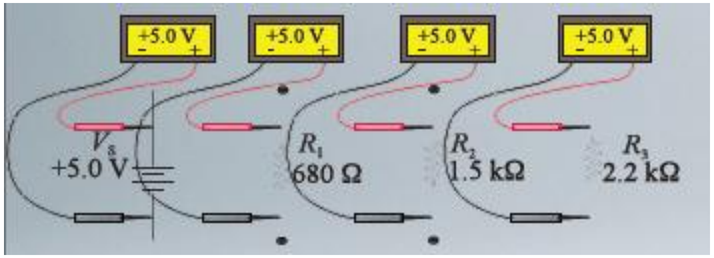
- ✓ What happens if you reverse a battery?

PARALLEL CIRCUITS

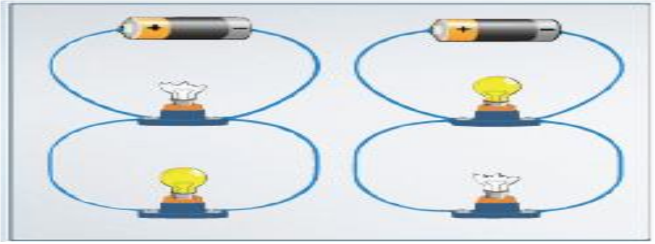
- A **parallel circuit** has **more than one current path** branching from the energy source



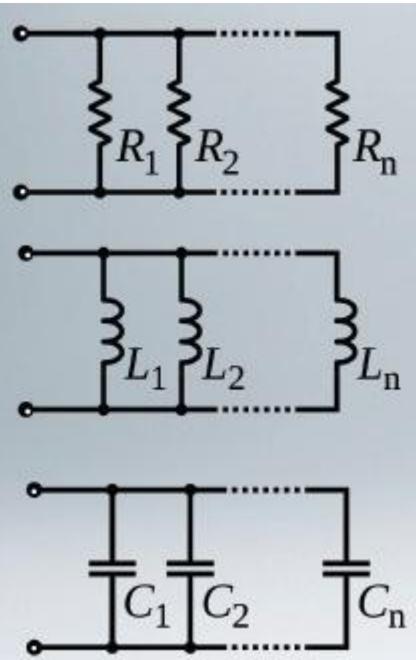
- Voltage across each pathway is the same



- In a parallel circuit, separate current paths function independently of one another



PARALLEL CIRCUITS



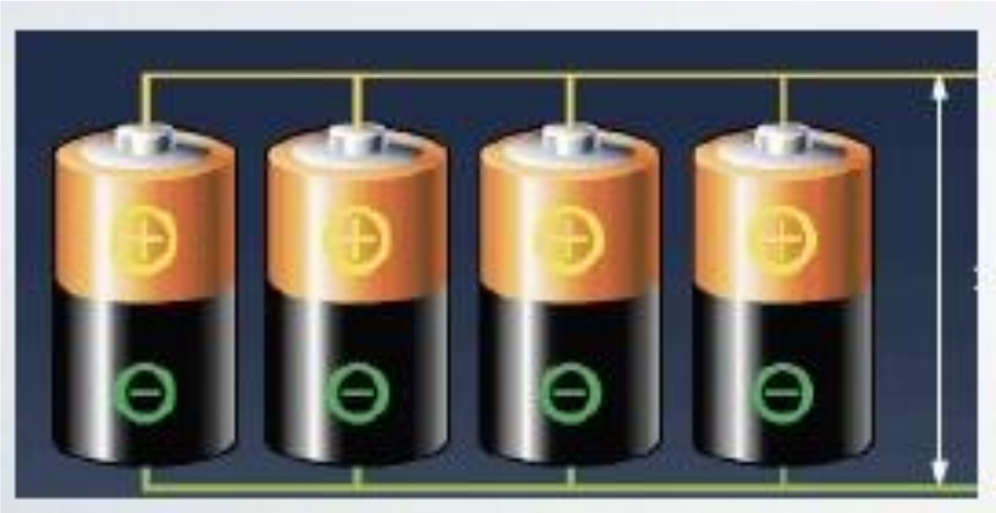
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$

$$\frac{1}{L_{total}} = \frac{1}{L_1} + \frac{1}{L_2} + \dots + \frac{1}{L_n}$$

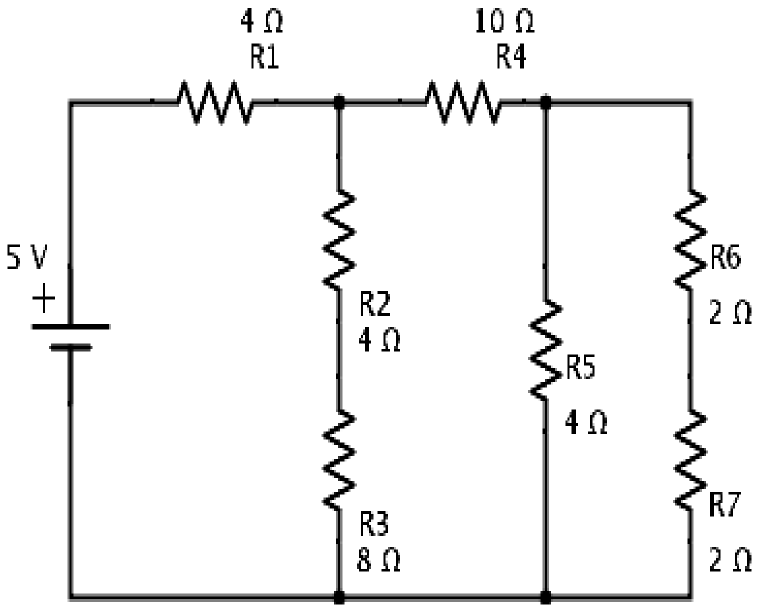
$$C_{total} = C_1 + C_2 + \dots + C_n$$

SIMPLE CIRCUIT IN PARALLEL

- For parallel voltage sources, the voltage is the same across all batteries, but the current supplied by each element is a fraction of the total current



- Calculate R_{eq} of the given circuit and also current flowing through R_4= 10ohms resistor.



STAR- CONNECTION:

- In star connection, components are connected in such a way that one end of all the resistors or components are connected to a common point.
- By the arrangement of three resistors, this star network looks like a alphabet Y hence , this network is also called as Wye or Y network.
- The equivalent of this star connection can be redrawn as T network (as a four terminal network) as shown in below figure. Most of the electrical circuits constitute this T form network.

STAR- CONNECTION

- Star network and T-network representation:

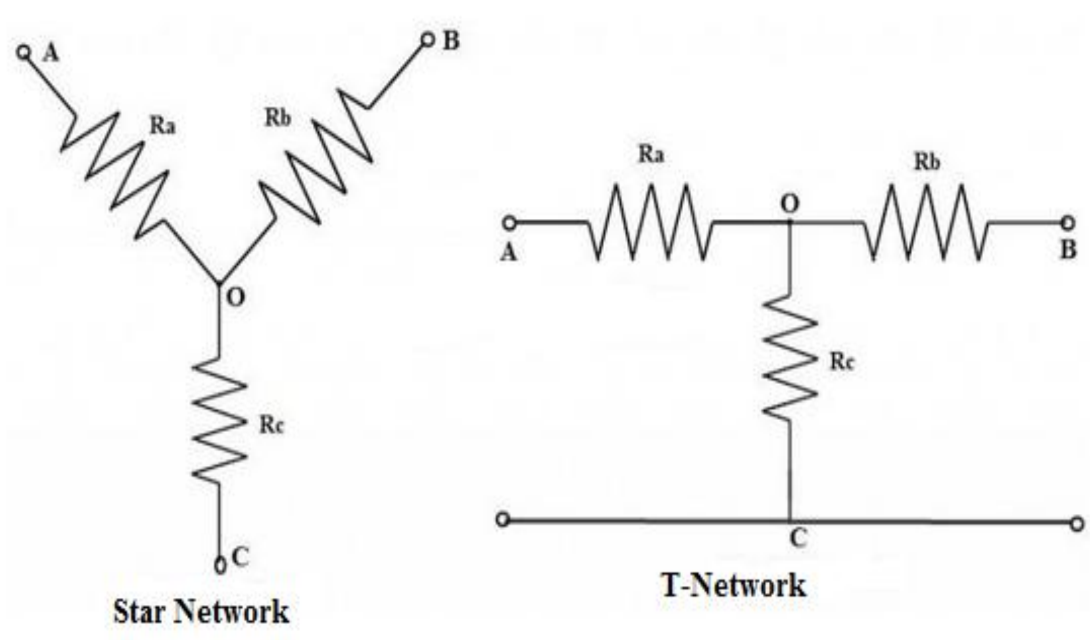


Fig 11: star network

DELTA CONNECTION

Delta Connection:

- In a delta connection, end point of each component or coil is connected to the start point of another component or coil.
- It is a series connection of three components that are connected to form a triangle. The name indicates that connection look like an alphabet delta (Δ).
- The equivalent delta network can be redrawn , to look like a symbol Pi (or four terminal network) as shown in figure. So this network can also be referred as Pi network.

DELTA CONNECTION

- Delta and PI network representation:

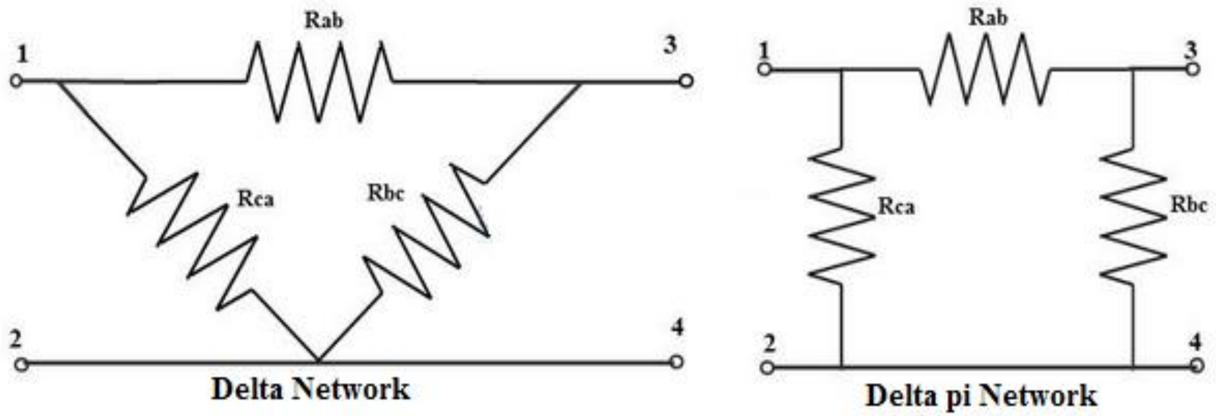
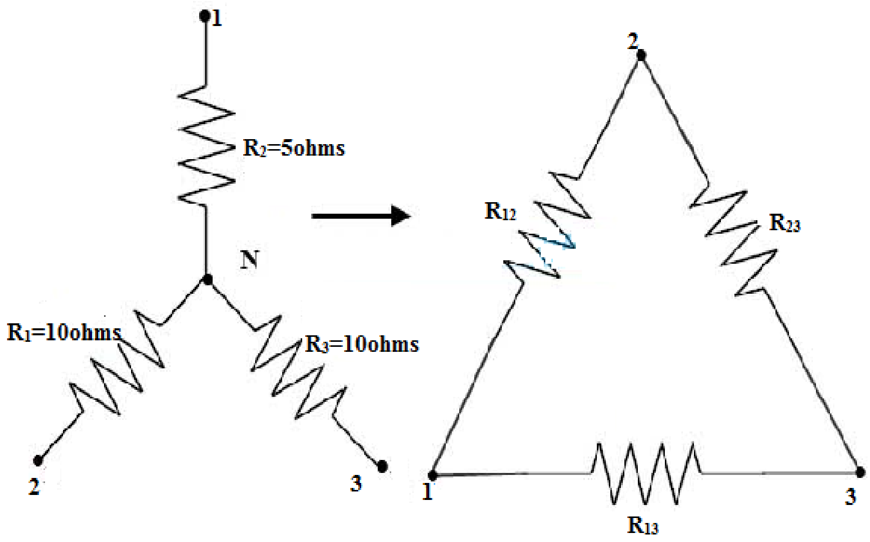


Fig 12: delta network

PROBLEMS ON STAR-DELTA TRANSFORMATIONS

- Consider the below figure to transform star or Wye to the delta circuit where the resistance values in star network are given as R_1= 10 ohms, R_2= 5 ohms and R_3 = 20 ohms.



PROBLEMS

- For star or wye to delta conversion, the equivalent resistance equations (for this problem) are

$$R_{12} = R_1 + R_2 + ((R_1R_2)/R_3)$$
$$R_{23} = R_2 + R_3 + ((R_2R_3)/R_1)$$
$$R_{31} = R_1 + R_3 + ((R_1R_3)/R_2)$$

- By simplifying the above equations we get the common numerator term as

$$R_1R_2 + R_2R_3 + R_1R_3 = 10 \text{ X } 5 + 10 \text{ X } 20 + 20 \text{ X } 5 = 350 \text{ ohms}$$

Then

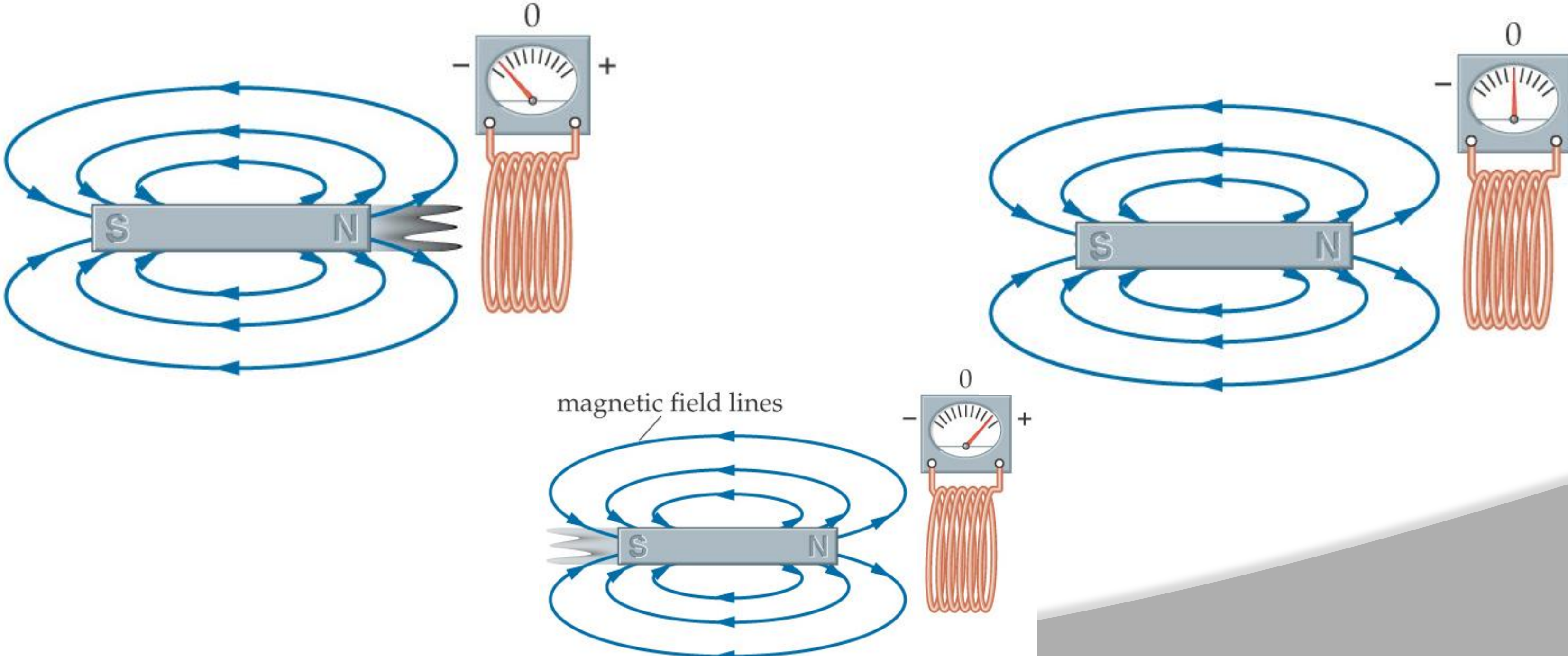
$$R_{12} = 350/\ R_3 = 350/20 = 17.5 \text{ ohms}$$
$$R_{23} = 350/\ R_1 = 350/\ 10 = 35 \text{ ohms}$$
$$R_{31} = 350/R_2 = 350\ /5 = 70 \text{ ohms}$$

FARADAYS LAWS OF ELECTROMAGNETIC INDUCTION

- In 1831, Michael Faraday, an English physicist gave one of the most basic laws of electromagnetism called Faraday's law of electromagnetic induction.
- This law explains the working principle of most of the electrical motors, generators, electrical transformers and inductors. This law shows the relationship between electric circuit and magnetic field.
- Faraday performs an experiment with a magnet and a coil. During his experiment, he found how emf is induced in the coil when flux linked with it changes.

RELATIONSHIP BETWEEN INDUCED EMF AND FLUX

- Faraday takes a magnet and a coil and connects a galvanometer across the coil. At starting, the magnet is at rest, so there is no deflection in the galvanometer i.e needle of galvanometer is at the center or zero position. When the magnet is moved towards the coil, the needle of galvanometer deflects in one direction.



INDUCED EMF

- When the magnet is held stationary at that position, the needle of galvanometer returns to zero position.
- Now when the magnet moves away from the coil, there is some deflection in the needle but opposite direction, and again when the magnet becomes stationary, at that point respect to the coil, the needle of the galvanometer returns to the zero position.
- Similarly, if the magnet is held stationary and the coil moves away, and towards the magnet, the galvanometer similarly shows deflection. It is also seen that, the faster the change in the magnetic field, the greater will be the induced emf or voltage in the coil.

FARADAYS LAWS

Faraday's First Law:

states that

"Whenever the magnetic flux linked with a circuit changes, an e.m.f. is always induced in it".

(OR)

"Whenever a conductor cuts magnetic flux, an e.m.f. is induced in that conductor"

FARADAYS LAWS

Second Law:

The magnitude of the induced e.m.f. is equal to the rate of change of flux linkages.

Emf induced is given by, $e = -N \frac{d\Phi}{dt}$

where, e is induced emf

$\frac{d\Phi}{dt}$ is rate of change in flux

MEASURING INSTRUMENTS

"The device used for comparing the unknown quantity with the unit of measurement or standard quantity is called a **Measuring Instrument**."

(OR)

"An instrument may be defined as a machine or system which is designed to maintain functional relationship between prescribed properties of physical variables & could include means of communication to human observer."

CLASSIFICATION OF INSTRUMENTS

Fig 13: measuring instruments

CLASSIFICATION OF INSTRUMENTS

- Electrical instruments may be divided into two categories, that are;
- Absolute instruments,
- Secondary instruments.
- **Absolute instruments** gives the quantity to be measured in term of instrument constant & its deflection.
- In **Secondary instruments** the deflection gives the magnitude of electrical quantity to be measured directly. These instruments are required to be calibrated by comparing with another standard instrument before putting into use.

CLASSIFICATION OF SECONDARY INSTRUMENTS

- **Indicating Instruments:**

It indicate the magnitude of an electrical quantity at the time when it is being measured. The indications are given by a pointer moving over a graduated dial.

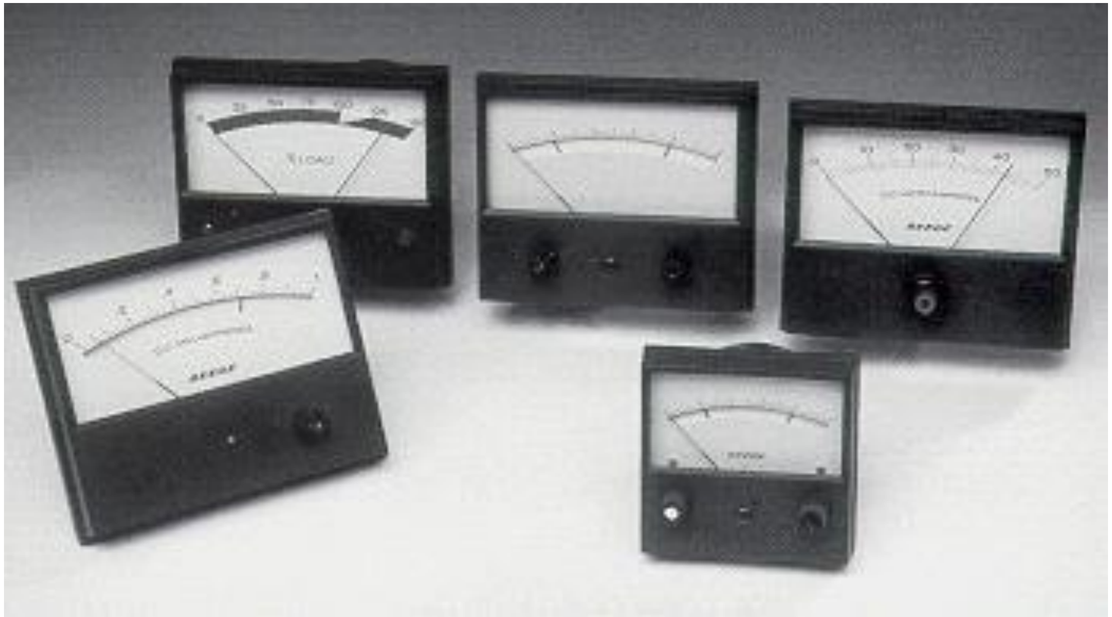


Fig 14: indicating instruments

CLASSIFICATION OF INSTRUMENTS

- **Recording Instruments:**

The instruments which keep a continuous record of the variations of the magnitude of an electrical quantity to be observed over a defined period of time.

Fig 15: recording instruments

CLASSIFICATION OF INSTRUMENTS

- **Integrating Instruments:**

The instruments which measure the total amount of either quantity of electricity or electrical energy supplied over a period of time. For example energy meters.

Fig 16: integrating instruments

ESSENTIALS OF INDICATING INSTRUMENTS

- ✓ As defined above, indicating instruments are those which indicate the value of quantity that is being measured at the time at which it is measured. Such instruments consist essentially of a pointer which moves over a calibrated scale and which is attached to a moving system pivoted in bearing. The moving system is subjected to the following three torques:

1. A deflecting (or operating) torque;
2. A controlling (or restoring) torque;
3. A damping torque.

DEFLECTING TORQUE

- The deflecting torque is produced by making one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effect of current or voltage and cause the moving system of the instrument to move from its zero position.
- The method of producing this torque depends upon the type of instrument.

CONTROLLING TORQUE

- The magnitude of the moving system would be some what indefinite under the influence of deflecting torque, unless the controlling torque existed to oppose the deflecting torque.
- It increases with increase in deflection of moving system.
- Under the influence of controlling torque the pointer will return to its zero position on removing the source producing the deflecting torque.
- Without controlling torque the pointer will swing at its maximum position & will not return to zero after removing the source.
- Controlling torque is produced either by spring or gravity control.

SPRING CONTROL

- When the pointer is deflected one spring unwinds itself while the other is twisted. This twist in the spring produces restoring (controlling) torque, which is proportional to the angle of deflection of the moving systems

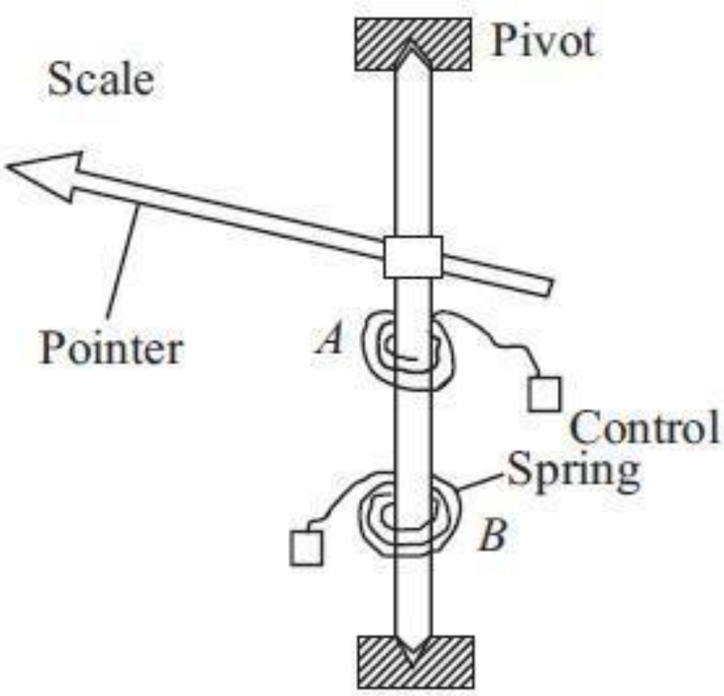


Fig 17: spring control

GRAVITY CONTROL

- In gravity controlled instruments, a small adjustable weight is attached to the spindle of the moving system such that the deflecting torque produced by the instrument has to act against the action of gravity.
- Thus a controlling torque is obtained. This weight is called the control weight. Another adjustable weight is also attached is the moving system for zero adjustment and balancing purpose. This weight is called Balance weight.

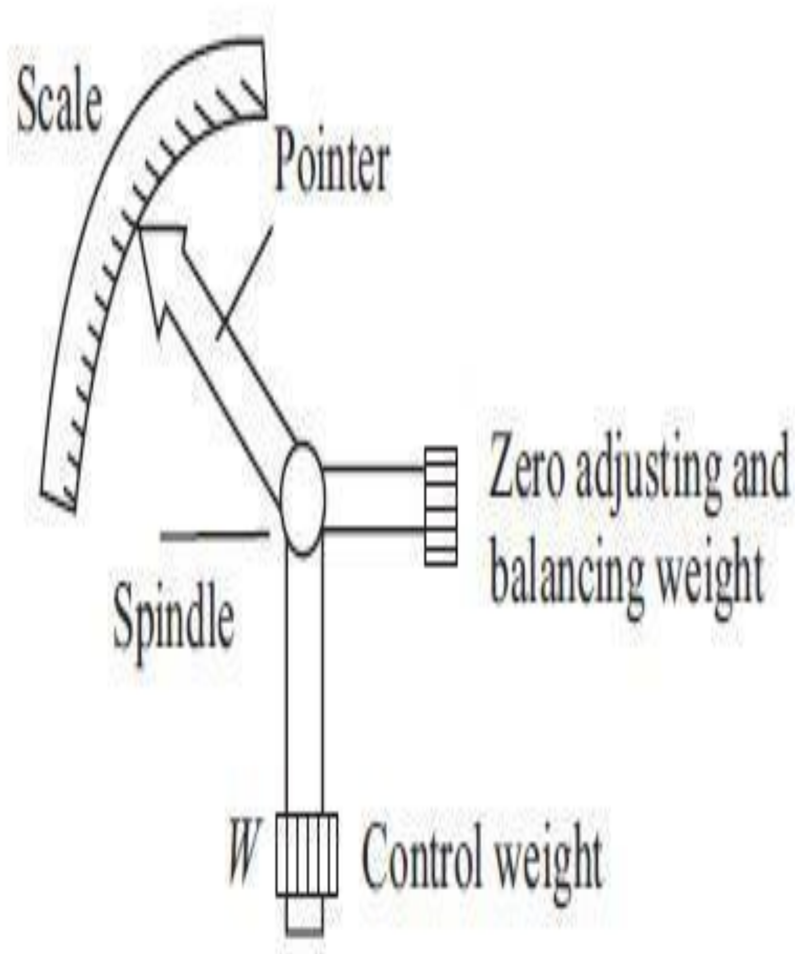


Fig 18: gravity control

DAMPING TORQUE

- We have already seen that the moving system of the instrument will tend to move under the action of deflecting torque.
- But on account of the control torque, it will try to occupy a position of rest when the two torques are equal and opposite.
- However, due to inertia of the moving system, the pointer will not come to rest immediately but oscillate about its final deflected position as shown in figure and takes appreciable time to come to steady state.
- To overcome this difficulty a damping torque is to be developed by using a damping device attached to the moving system.

MOVING-COIL INSTRUMENT

- There are two types of moving coil instruments namely, permanent magnet moving coil type which can only be used for direct current, voltage measurements.
- The dynamometer type which can be used on either direct or alternating current, voltage measurements.

PERMANENT MAGNET MOVING COIL

- “The principle operation of PMMC is based upon the principle of current carrying conductor is placed in a magnetic field it is acted upon by force which tends to move it.”

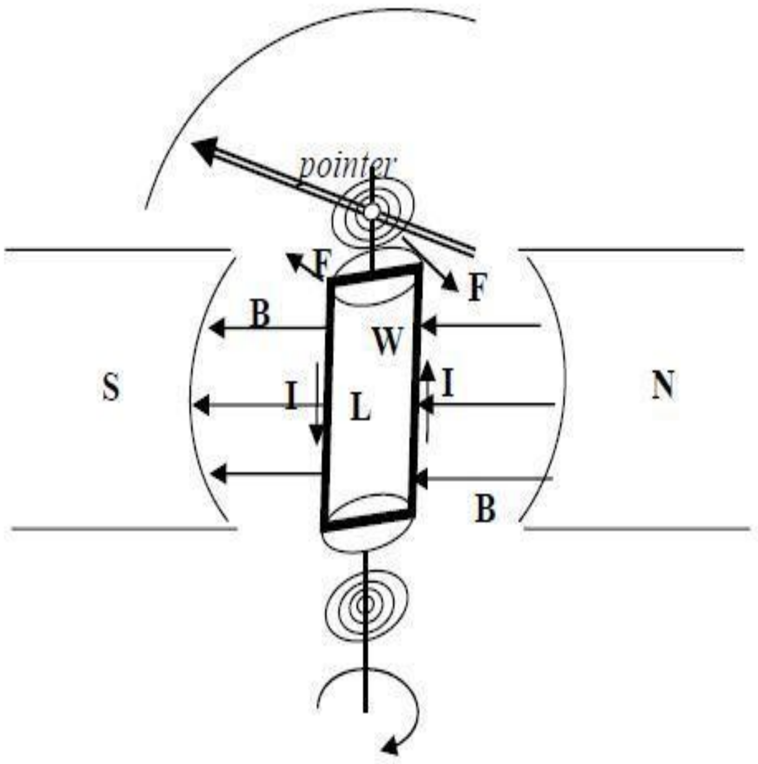


Fig 19: permanent magnet moving coil instrument

MOVING-IRON INSTRUMENT

- An attraction type of moving-iron instrument is shown diagrammatically in Figure. When current flows in the solenoid, a pivoted soft-iron disc is attracted towards the solenoid and the movement causes a pointer to move across a scale.

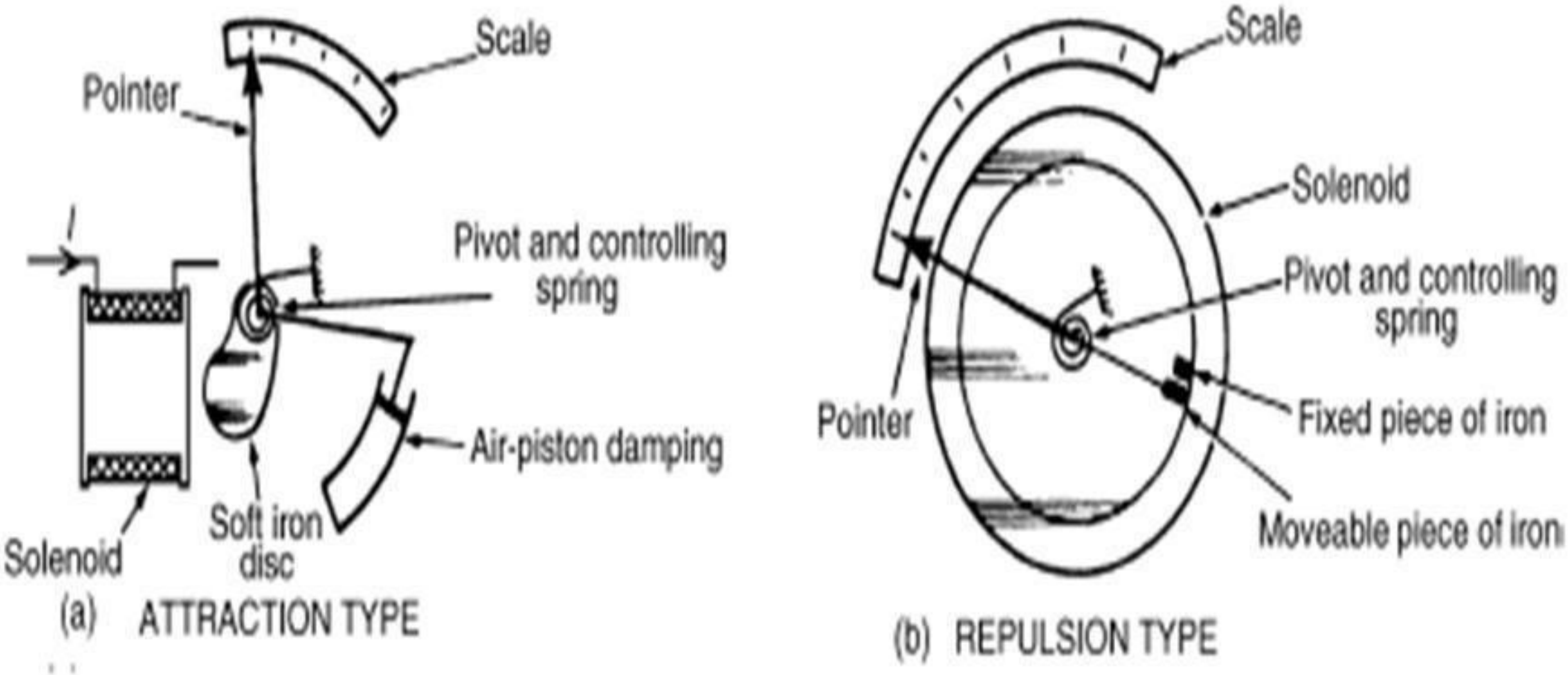


Fig 20: moving iron (a) attraction type (b) repulsion type

MODULE-II

DC MACHINES

MODULE - II

CLOs	Course Learning Outcome
CLO5	Demonstrate the working principle of DC motor, DC generator.
CLO6	Describe the construction of DC motor and DC generator.
CLO7	Classify the types of DC motor and generator with characteristics and voltage, current and power equations.
CLO8	Derive the EMF equation of DC generator, and various problems on EMF equation.
CLO9	Torque equation of DC motor and understand the purpose of three point starter.

PARTS OF DC GENERATOR

1) Yoke
2) Magnetic Poles
a) Pole core
b) Pole Shoe
3) Field Winding
4) Armature Core
5) Armature winding
6) Commutator
7) Brushes and Bearings

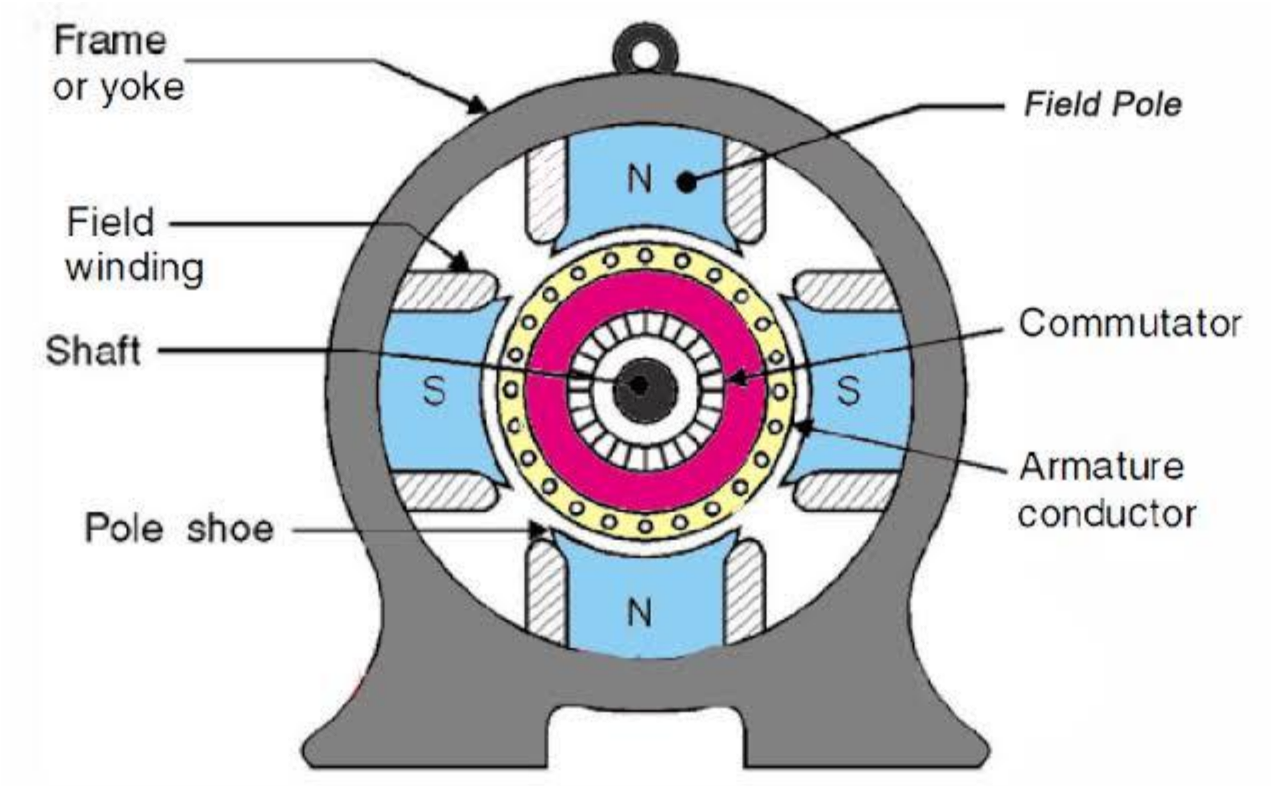


Fig 1: construction of DC machine

PARTS OF DC GENERATOR

Yoke:

1. It saves the purpose of outermost cover of the dc machine so that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO2, acidic fumes etc.
2. It provides mechanical support to the poles.
3. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux. Choice of material: To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is the cheapest. For large machines rolled steel or cast steel, is used which provides high permeability i.e., low reluctance and gives good mechanical strength

PARTS OF DC GENERATOR

Armature: It is further divided into two parts namely,
(1) Armature core (2) Armature winding.
Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

Functions:

1. Armature core provides house for armature winding i.e., armature conductors.
2. To provide a path of low reluctance path to the flux it is made up of magnetic material like cast iron or cast steel.

Choice of material: As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.
It is made up of laminated construction to keep eddy current loss as low as possible.

PARTS OF DC GENERATOR

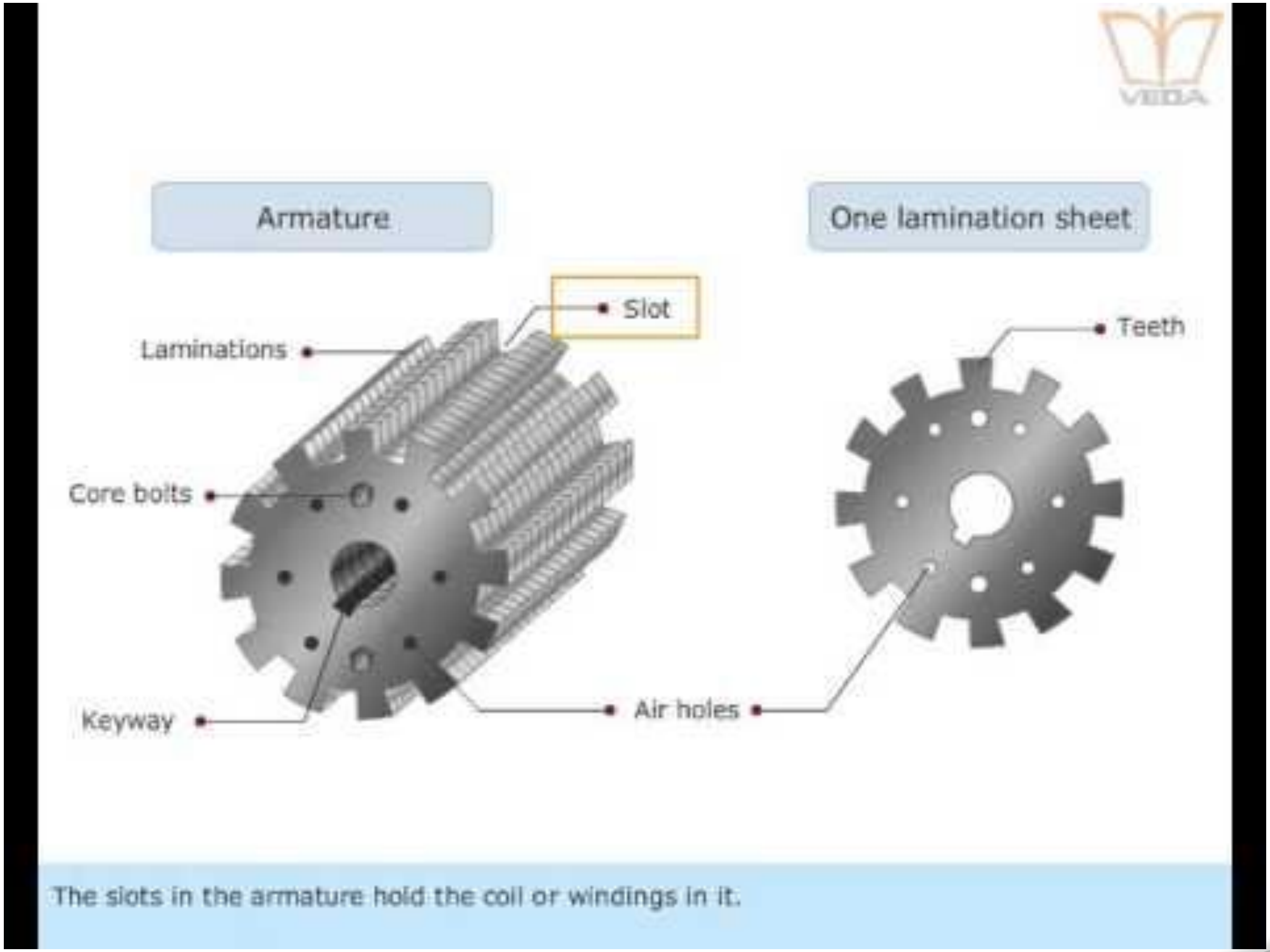


Fig 2: construction of armature

PARTS OF DC GENERATOR

Armature winding: Armature winding is nothing but the inter connection of the armature conductors, placed in the slots provided on the armature core. When the armature is rotated, in case of generator magnetic flux gets cut by armature conductors and emf gets induced in them.

Function:

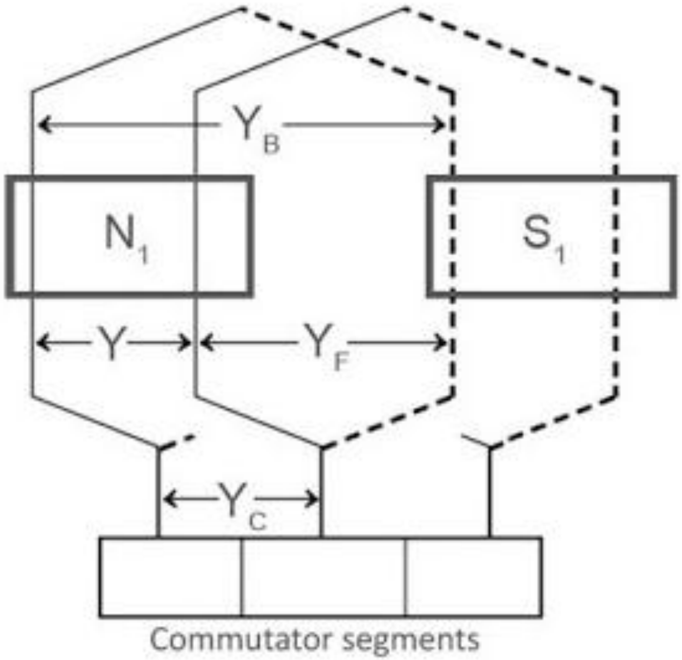
1. Generation of emf takes place in the armature winding in case of generators.
2. To carry the current supplied in case of dc motors.
3. To do the useful work it the external circuit.

Choice of material : As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

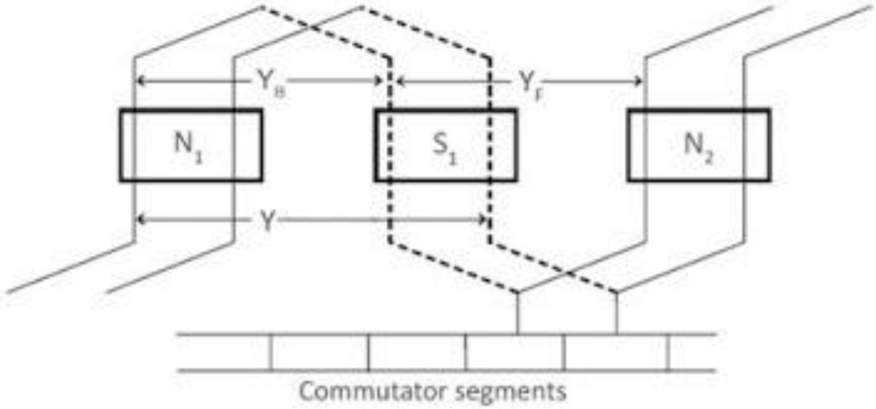
PARTS OF DC GENERATOR

- In **lap winding**, the successive coils overlap each other. In a simplex lap winding, the two ends of a coil are connected to adjacent commutator segments. The winding may be progressive or retrogressive. A progressive winding progresses in the direction in which the coil is wound. The opposite way is retrogressive.
- In **wave winding**, a conductor under one pole is connected at the back to a conductor which occupies an almost corresponding position under the next pole which is of opposite polarity. In other words, all the coils which carry emf in the same direction are connected in series.

PARTS OF DC GENERATOR



(a) Lap Winding



(b) Wave winding

Fig 3: armature windings (a) lap (b) wave

PARTS OF DC GENERATOR

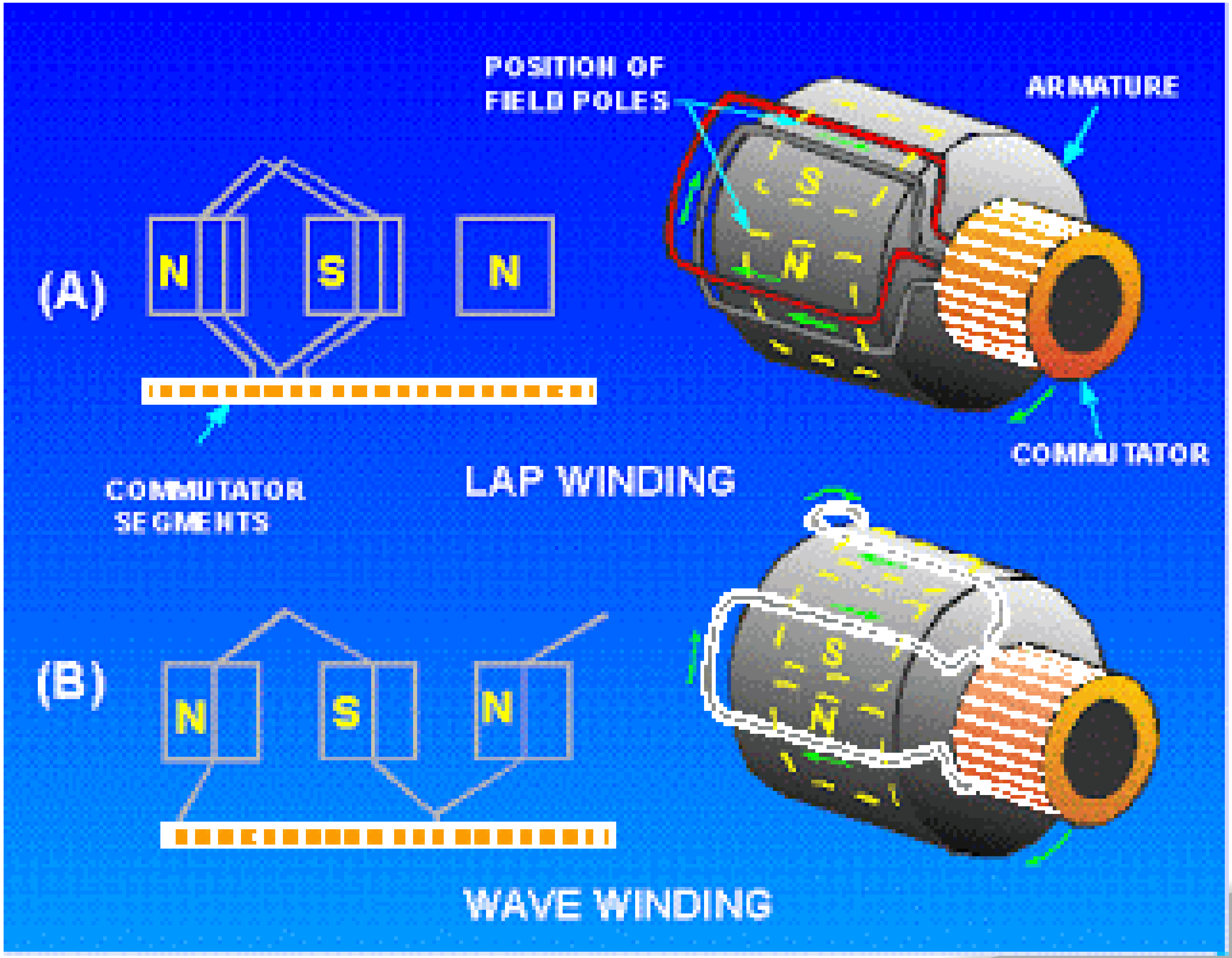


Fig 4: armature windings (a) lap (b) wave

PARTS OF DC GENERATOR

COMMUTATOR:

- The commutator, which rotates with the armature, is cylindrical in shape and is made from a number of wedge-shaped hard drawn copper bars or segments insulated from each other and from the shaft. The segments form a ring around the shaft of the armature. Each commutator segment is connected to the ends of the armature coils.

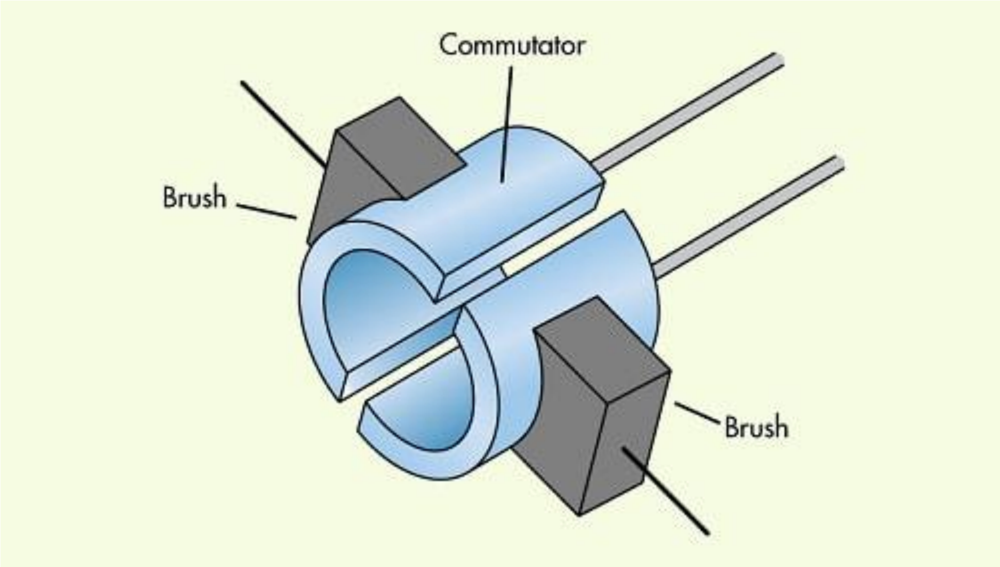


Fig 5: commutator

PARTS OF DC GENERATOR

BRUSHES:

- Carbon brushes are placed or mounted on the commutator and with the help of two or more carbon brushes current is collected from the armature winding. Each brush is supported in a metal box called a **brush box** or **brush holder**. The brushes are pressed upon the commutator and form the connecting link between the armature winding and the external circuit.

SHAFT:

- The shaft is made of mild steel with a maximum breaking strength. The shaft is used to transfer mechanical power from or to the machine. The rotating parts like armature core, commutator, cooling fans, etc. are keyed to the shaft.

INTRODUCTION OF DC GENERATOR

- The electrical machines deals with the energy transfer either from mechanical to electrical form or from electrical to mechanical form, this process is called electromechanical energy conversion.
- An electrical machine which converts mechanical energy into electrical energy is called an electric generator while an electrical machine which converts electrical energy into the mechanical energy is called an electric motor.
- A DC generator is built utilizing the basic principle that emf is induced in a conductor when it cuts magnetic lines of force.
- A DC motor works on the basic principle that a current carrying conductor placed in a magnetic field experiences a force.

WORKING PRINCIPLE

- According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field (OR a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor. The magnitude of induced emf can be calculated from the emf equation of dc generator. If the conductor is provided with a closed path, the induced current will circulate within the path. In a DC generator, field coils produce an electromagnetic field and the armature conductors are rotated into the field. Thus, an electromagnetically induced emf is generated in the armature conductors. The direction of induced current is given by Fleming's right hand rule.

WORKING PRINCIPLE

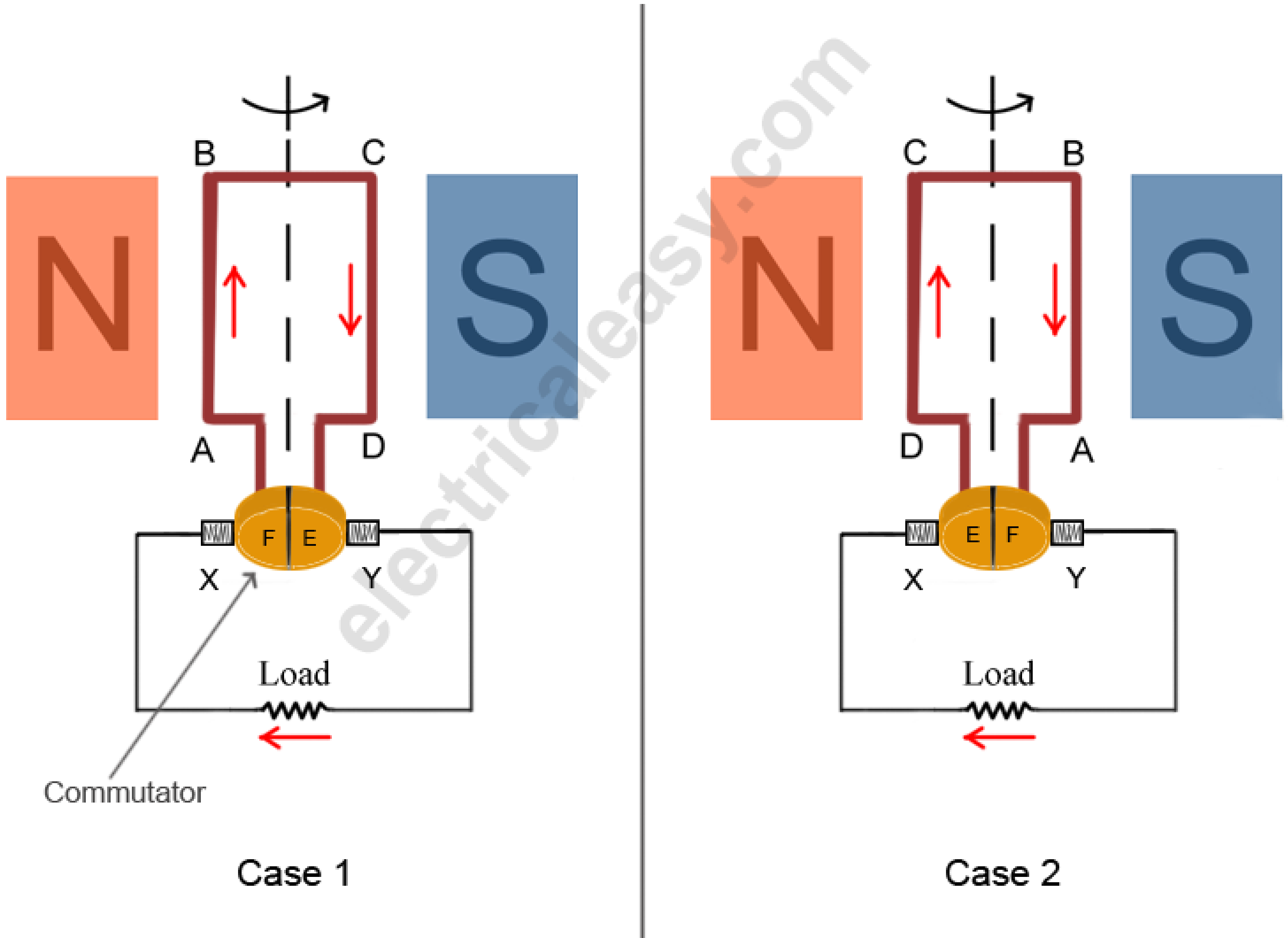


Fig 6: working of generator

FLEMINGS RIGHT HAND RULE

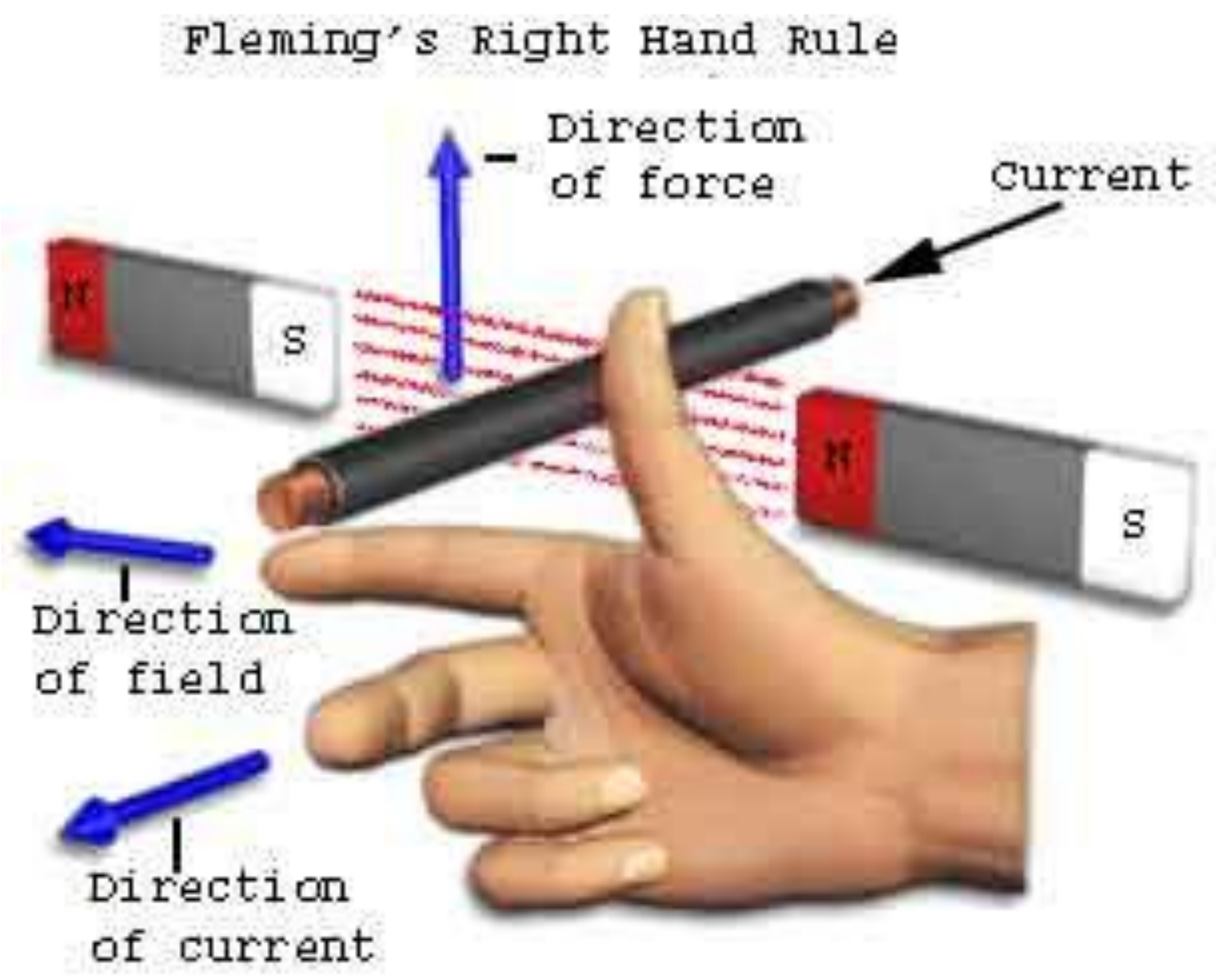


Fig 7: fleming right hand rule

EMF EQUATION OF DC GENERATOR

P = number of poles

Ø = flux/pole in webers

Z = total number of armature conductors

= number of slots x number of conductors/slot

N = armature rotation in revolutions (speed for armature) per minute (rpm)

A = No. of parallel paths into which the ‘z’ no. of conductors are divided

E = emf induced in any parallel path

Eg = emf generated in any one parallel path in the armature

Average emf generated/conductor = dØ/dt volt

Flux current/conductor in one revolution

dt = d x p

EMF EQUATION OF DC GENERATOR

In one revolution, the conductor will cut total flux produced by all poles = d x p

No. of revolutions/second = N/60

Therefore, Time for one revolution, dt = 60/N second

According to Faraday's laws of Electromagnetic Induction, emf generated/conductor = dØx p x N / 60 volts

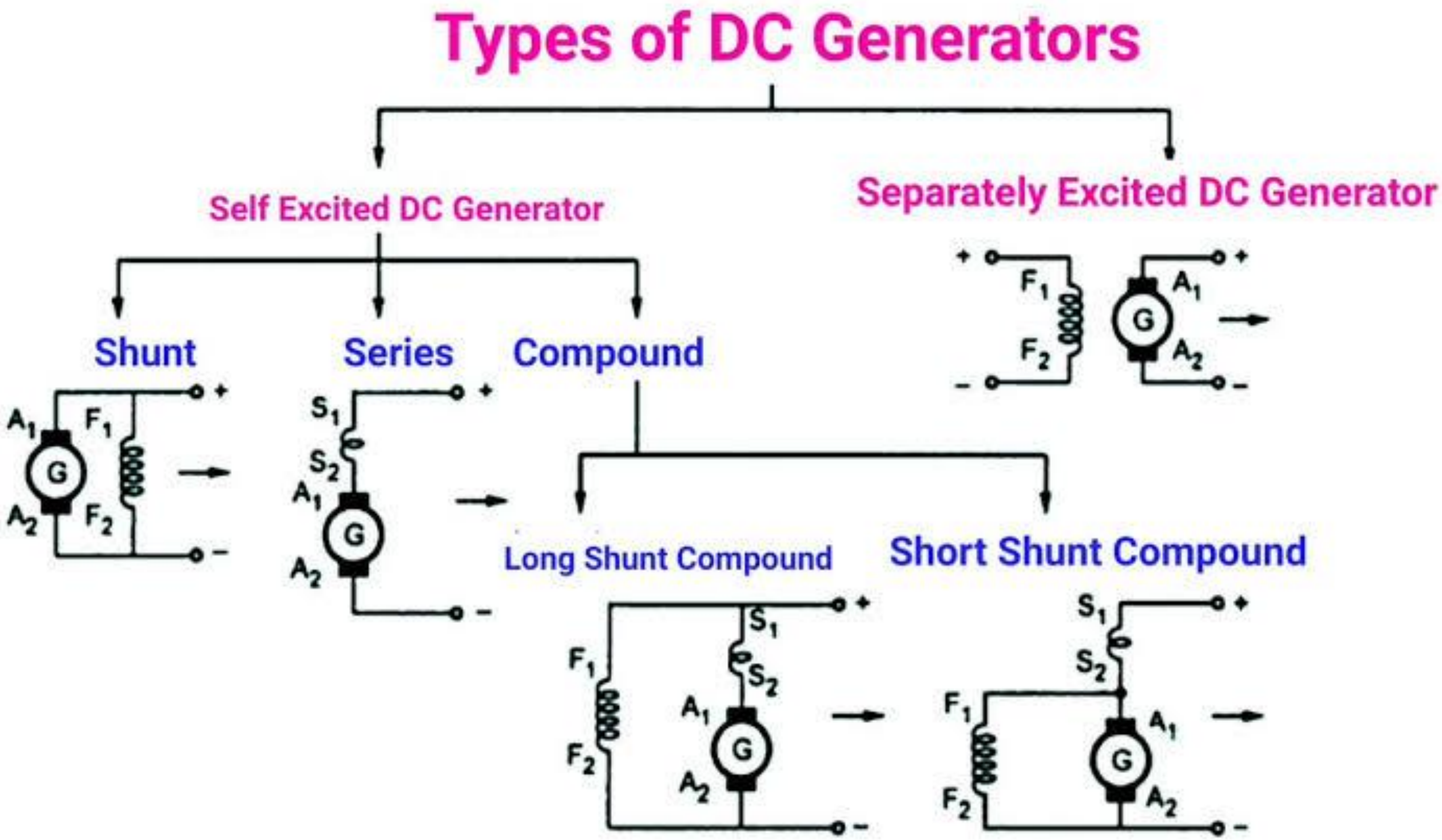
This is emf induced in one conductor.

For a simplex wave-wound generator No. of parallel paths = 2

No. of conductors in (series)in one path = Z/2

EMF generated/path = ØPN/60 x Z/2 = ØZPN/120 volt

TYPES OF DC GENERATOR



Separately Excited DC Generator

•These are the generators whose field magnets are energized by some external dc source such as battery .

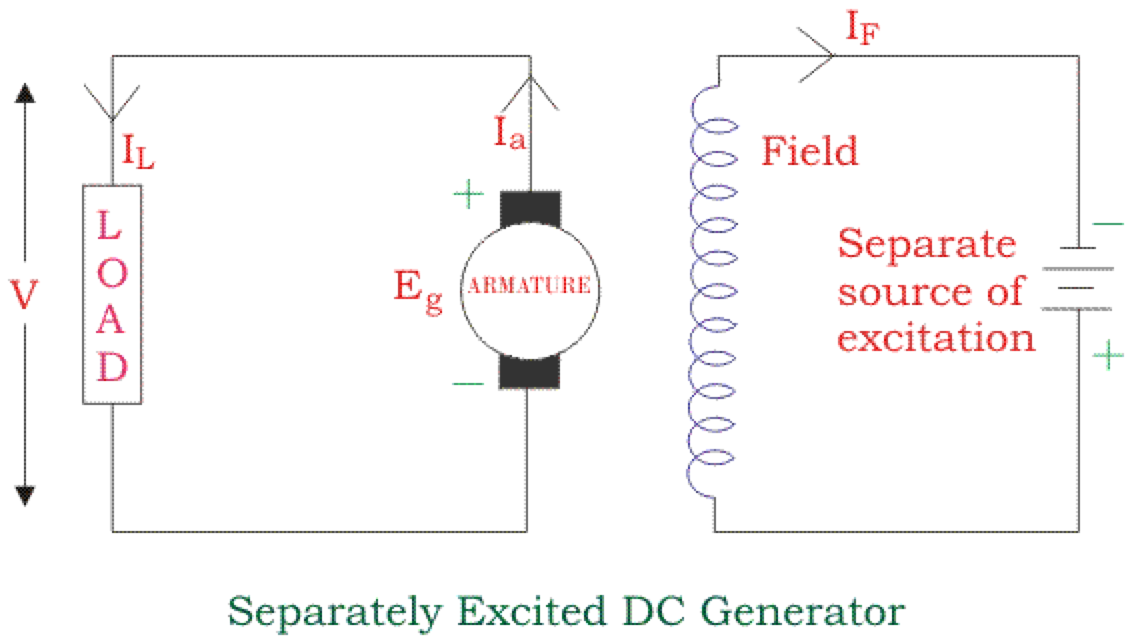


Fig 8: seperatly excited DC generator

TYPES OF DC GENERATOR

Self-excited DC Generators

- These are the generators whose field magnets are energized by the current supplied by themselves.
- In these type of machines field coils are internally connected with the armature. Due to residual magnetism some flux is always present in the poles. When the armature is rotated some emf is induced. Hence some induced current is produced.

Series Wound Generator

- In these type of generators, the field windings are connected in series with armature conductors as shown in figure below.
- So, whole current flows through the field coils as well as the load.

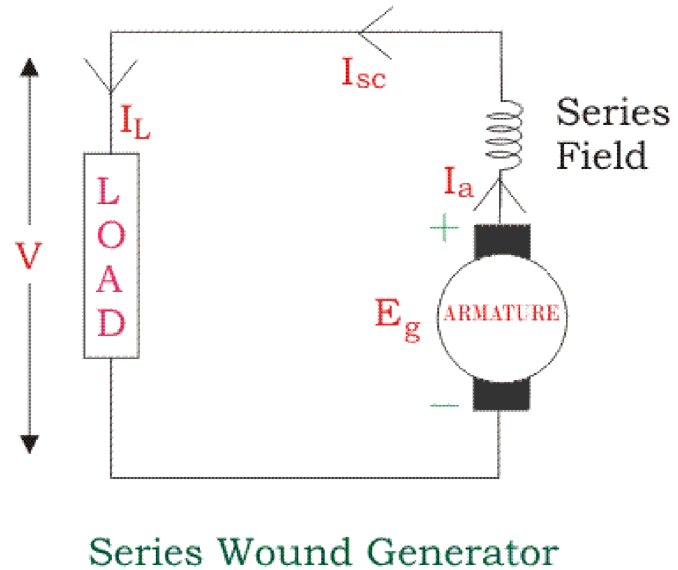


Fig 9: series wound generator

Shunt Wound DC Generators

•In these type of DC generators the field windings are connected in parallel with armature conductors as shown in figure below.

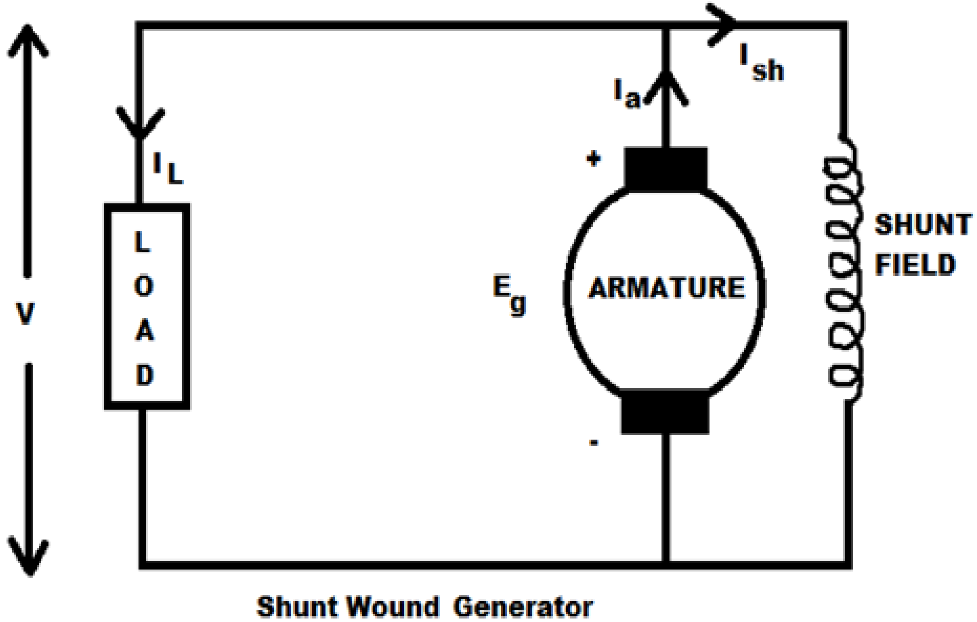
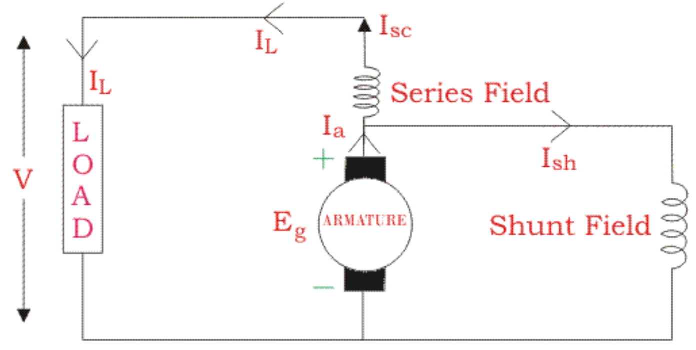


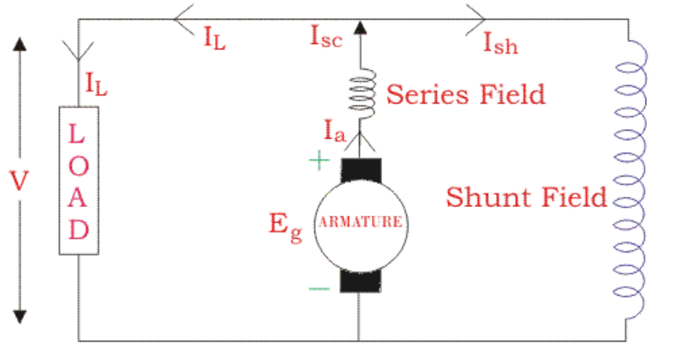
Fig 10: shunt wound generator

TYPES OF DC GENERATORS

- Short Shunt Compound Wound DC Generators are generators where only the shunt field winding is in parallel with the armature winding, as shown in the figure below.
- Long Shunt Compound Wound DC Generator are generators where the shunt field winding is in parallel with both series field and armature winding, as shown in the figure below.



Short Shunt Compound Wound Generator



Long Shunt Compound Wound Generator

Fig 11: compound generator

CHARACTERISTICS OF DC GENERATOR

OPEN CIRCUIT CHARACTERISTIC

- Open circuit characteristic is also known as magnetic characteristic or no-load saturation characteristic. This characteristic shows the relation between generated emf at no load (E0) and the field current (If) at a given fixed speed. The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators.

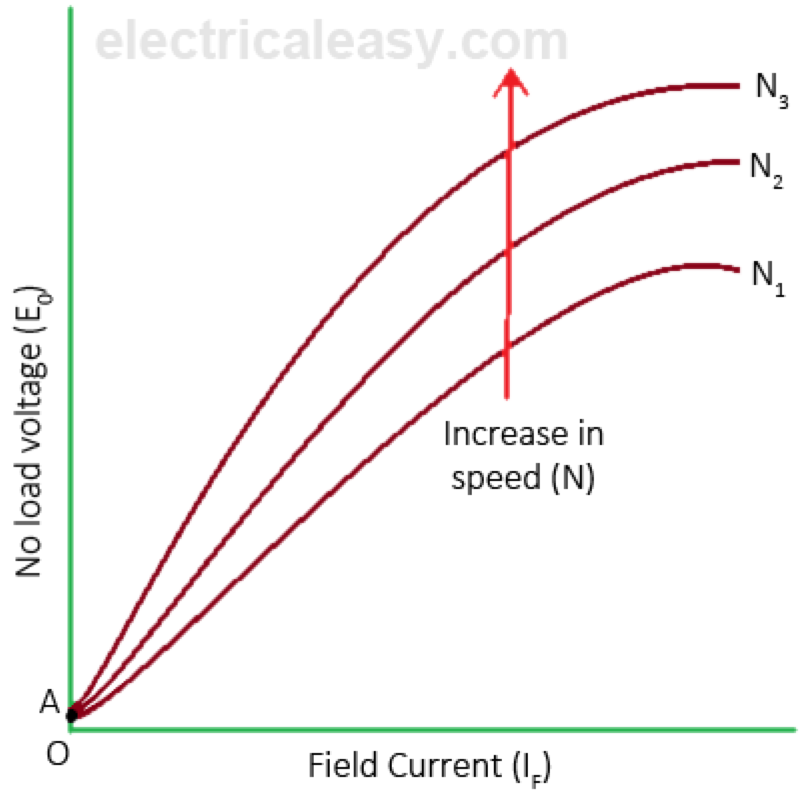


Fig 12: Open Circuit Characteristic (O.C.C.)

CHARACTERISTICS OF DC GENERATOR

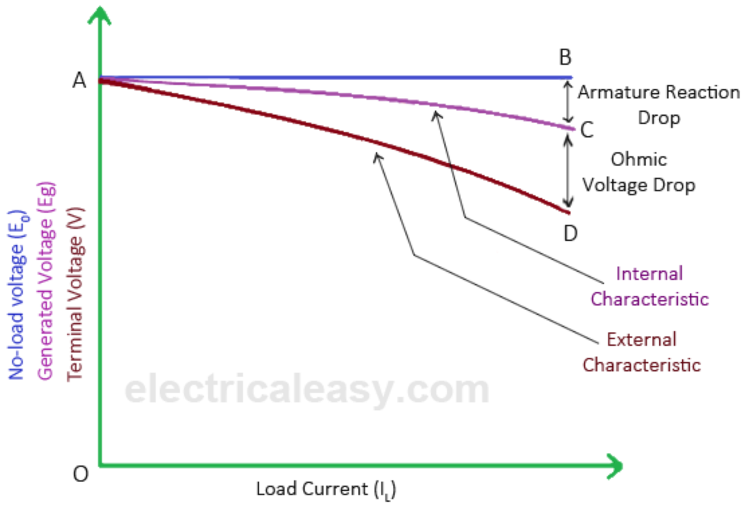
INTERNAL CHARACTERISTICS:

An internal characteristic curve shows the relation between the on-load generated emf (Eg) and the armature current (I_a). The on-load generated emf Eg is always less than E_0 due to the armature reaction. Eg can be determined by subtracting the drop due to demagnetizing effect of armature reaction from no-load voltage E_0. Therefore, internal characteristic curve lies below the O.C.C. curve.

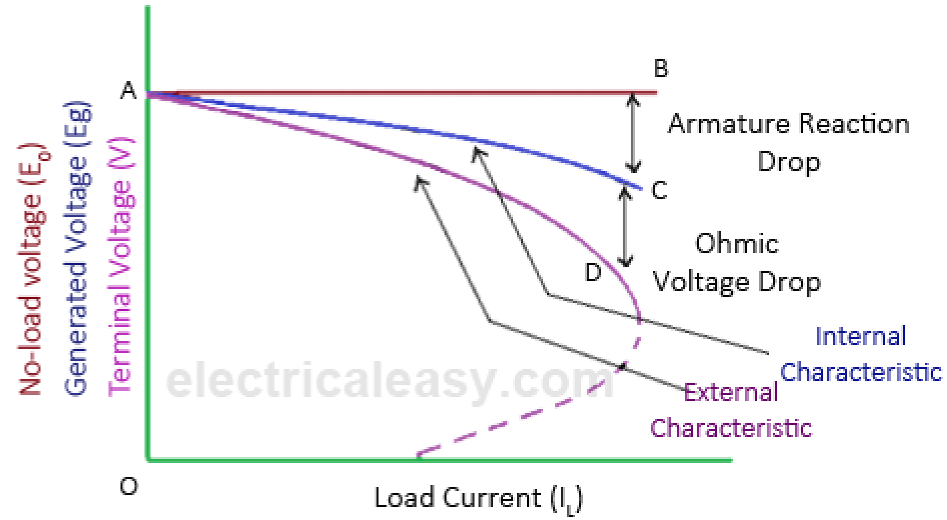
EXTERNAL CHARACTERISTICS:

An external characteristic curve shows the relation between terminal voltage (V) and the load current (I_L). Terminal voltage V is less than the generated emf Eg due to voltage drop in the armature circuit. Therefore, external characteristic curve lies below the internal characteristic curve. External characteristics are very important to determine the suitability of a generator for a given purpose. Therefore, this type of characteristic is sometimes also called as **performance characteristic** or **load characteristic**.

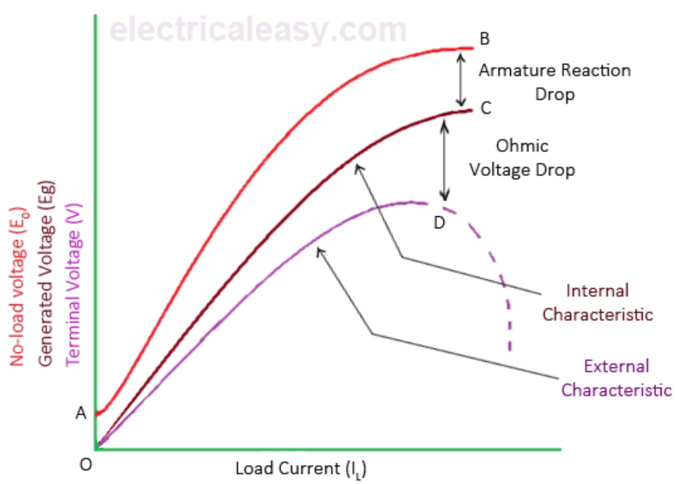
CHARACTERISTICS OF DC GENERATOR



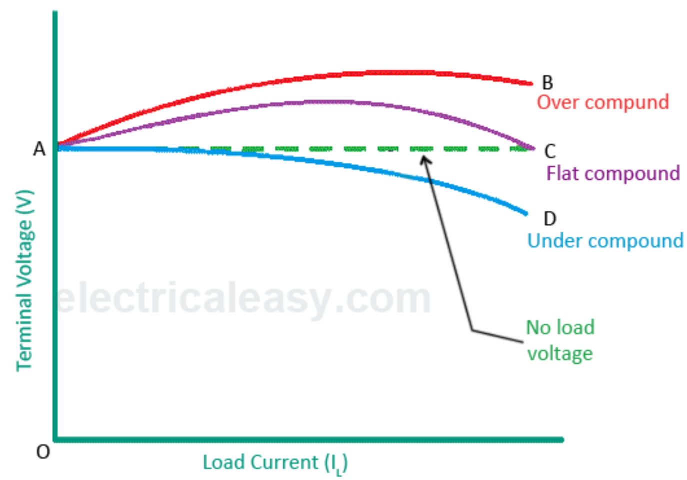
Characteristics of separately excited DC generator



Characteristics of DC shunt generator



Characteristics of DC series generator



External characteristic of DC compound generator

Fig 13: characteristics of DC generator

PRINCIPLE OF DC MOTOR

- A machine which transforms the DC power into mechanical power is called as a DC motor. Its operation relies on the principle that once a current carrying conductor is placed in a very magnetic field, the conductor experiences a mechanical force. The direction of this force is given by Fleming’s left hand rule and magnitude is given by;

$$F = BIl \text{ newtons}$$

- Fundamentally, there's no constructional distinction between a DC motor and a DC generator. The same DC motor will be run as a generator or motor.

WORKING PRINCIPLE OF DC MOTOR

- A DC motor in simple words is a device that converts electrical energy (direct current system) into mechanical energy. It is of vital importance for the industry today and is equally important for engineers to look into the working principle of DC motor in details that we have discussed in this article. To understand the operating principle of DC motor we need to first look into its constructional feature.

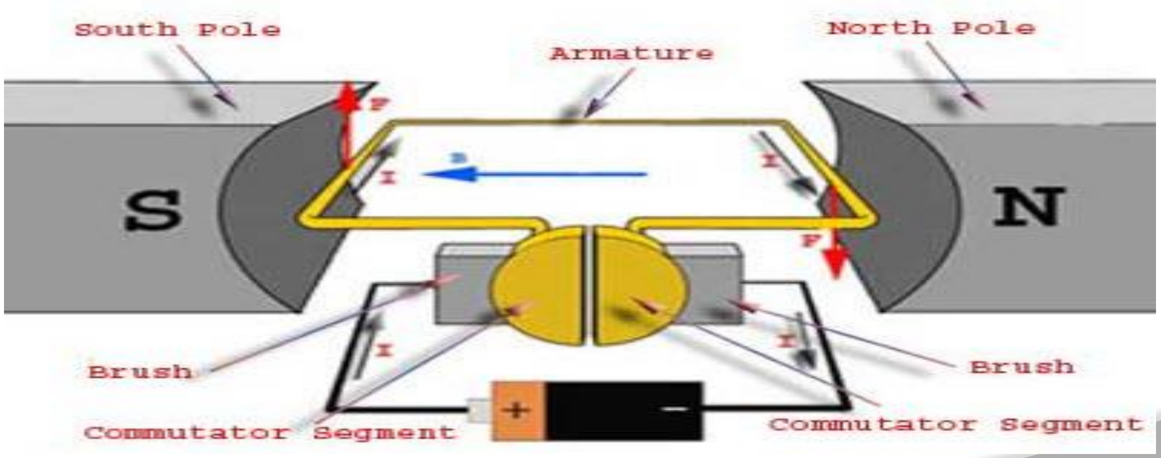


Fig 14: principle of DC motor

FLEMINGS LEFT HAND RULE

- To go into the details of the operating principle of DC motor it's important that we have a clear understanding of Fleming's left-hand rule to determine the direction of the force acting on the armature conductors of DC motor.

FLEMING'S LEFT-HAND RULE

- If a current carrying conductor is placed in a magnetic field perpendicularly, then the conductor experiences a force in the direction mutually perpendicular to both the direction of field and the current carrying conductor. Fleming's Left-Hand Rule can determine the direction of rotation of the motor. We extend the index finger, middle finger and thumb of our left-hand perpendicular to each other. The middle finger is in the direction of current in the conductor, and index finger is along the direction of magnetic field, i.e. north to south pole, then thumb indicates the direction of the created mechanical force.

FLEMINGS LEFT HAND RULE

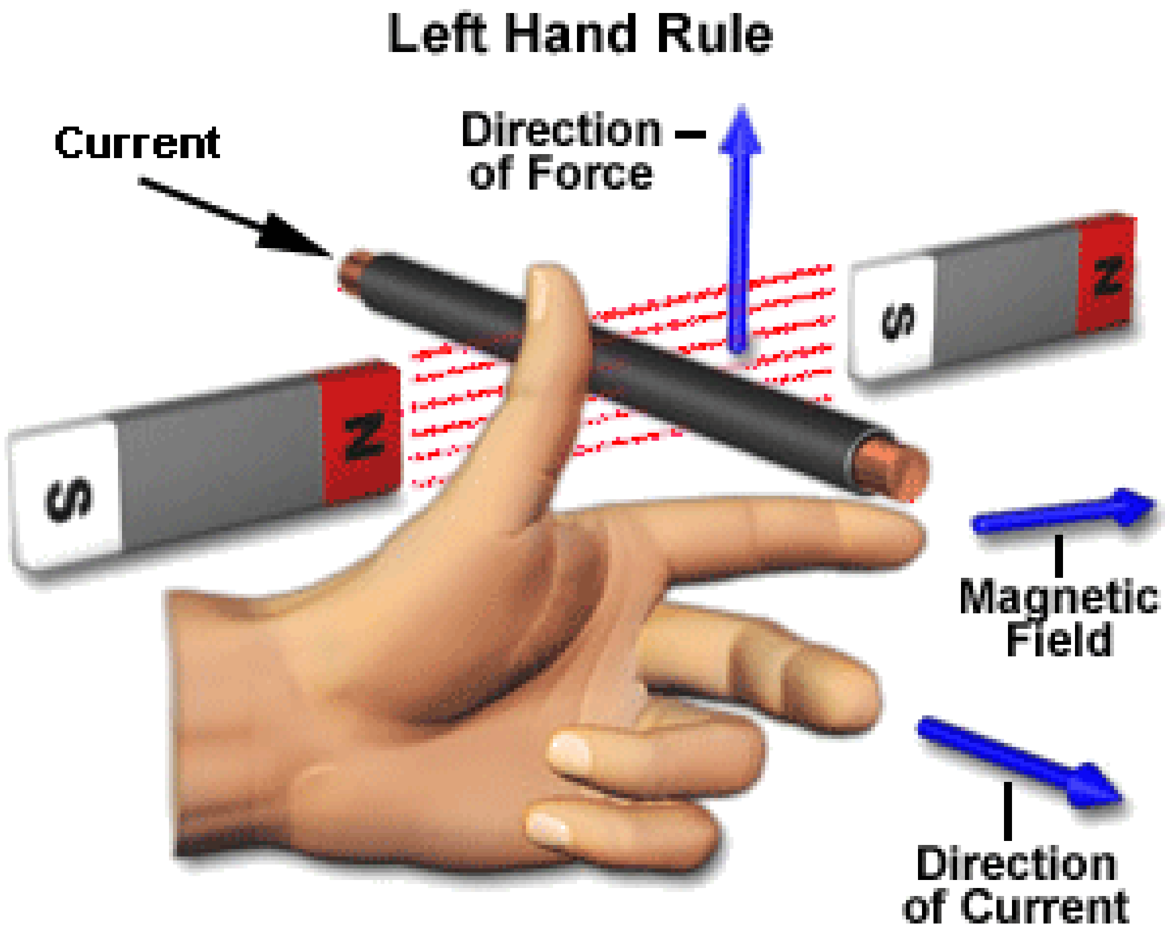
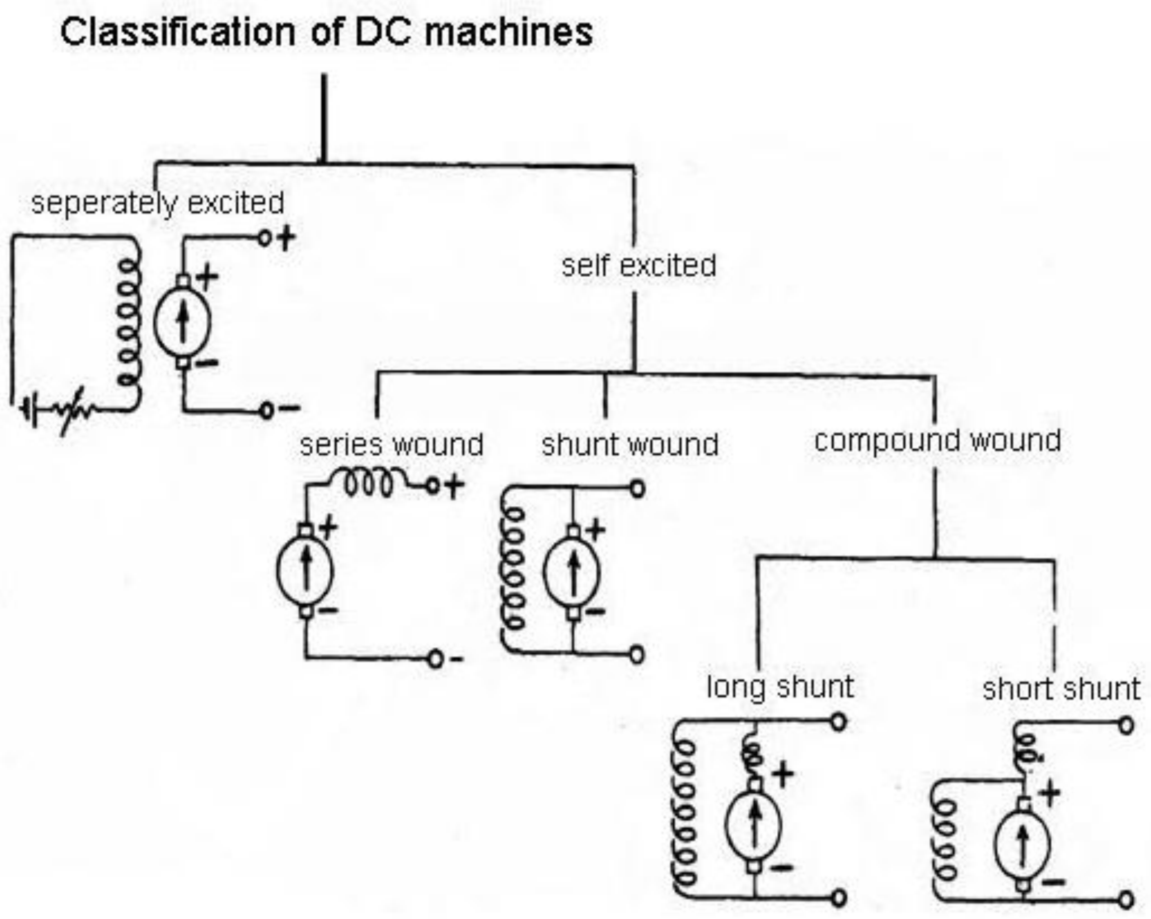


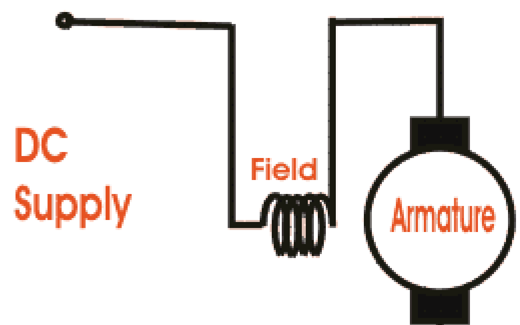
Fig 15: Fleming left hand rule

TYPES OF DC MOTOR



SERIES MOTOR:

- In case of a series wound self excited DC motor or simply series wound DC motor, the entire armature current flows through the field winding as its connected in series to the armature winding. The series wound self excited DC motor is diagrammatically represented

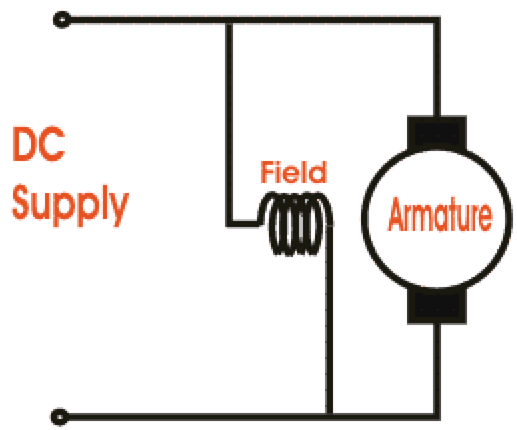


Series Excited DC Motor

TYPES OF DC MOTOR

SHUNT MOTOR:

- In case of a shunt wound DC motor or more specifically shunt wound self excited DC motor, the field windings are exposed to the entire terminal voltage as they are connected in parallel to the armature winding as shown in the figure below.



Shunt Excited DC Motor

TYPES OF DC MOTOR

- If the shunt field winding is only parallel to the armature winding and not the series field winding then its known as short shunt DC motor or more specifically short shunt type compound wound DC motor.
- If the shunt field winding is parallel to both the armature winding and the series field winding then it's known as long shunt type compounded wound DC motor or simply long shunt DC motor.

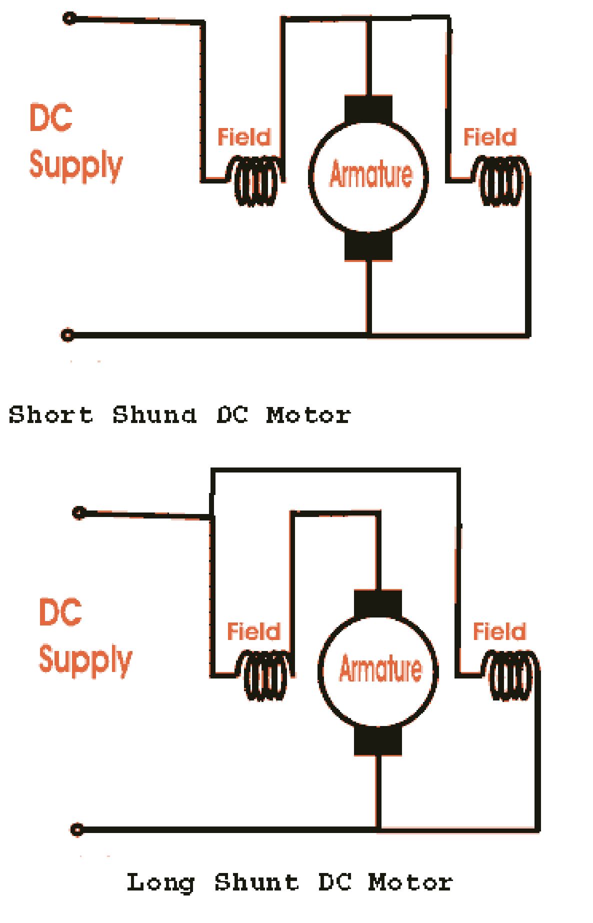


Fig 16: compound motor

CHARACTERISTICS OF DC SHUNT MOTOR

Torque Vs. Armature Current (Ta-Ia)

- In case of DC shunt motors, we can assume the field flux ϕ to be constant. Though at heavy loads, ϕ decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux ϕ, we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin.
- **Speed Vs. Armature Current (N-Ia)**
- As flux ϕ is assumed to be constant, we can say $N \propto Eb$. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor**.

CHARACTERISTICS OF DC SHUNT MOTOR

- **Torque Current Characteristic of DC shunt motor**

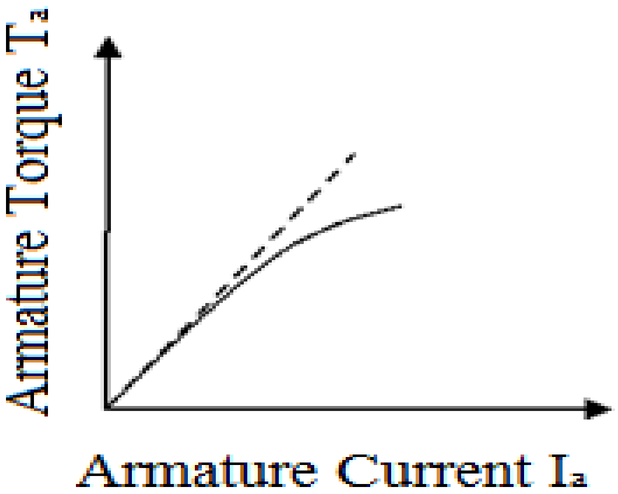


Fig. 17 Torque Current Characteristic of DC shunt motor

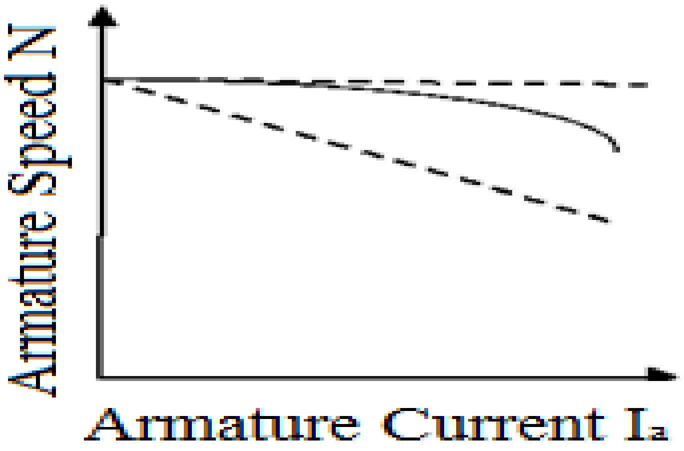


Fig. 18 Speed vs armature current characteristics of DC shunt motor

CHARACTERISTIC OF DC SERIES MOTOR

- We know that torque is directly proportional to the product of armature current and field flux, $T_a \propto \phi . I_a$. In DC series motors, field winding is connected in series with the armature, i.e. $I_a = I_f$. Therefore, before magnetic saturation of the field, flux ϕ is directly proportional to Ia. Hence, before magnetic saturation $Ta \; \alpha \; Ia^2$. Therefore, the Ta-Ia curve is parabola for smaller values of Ia.
- After magnetic saturation of the field poles, flux ϕ is independent of armature current Ia. Therefore, the torque varies proportionally to Ia only, $T \propto Ia$. Therefore, after magnetic saturation, Ta-Ia curve becomes a straight line.
- The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses. Hence, the curve Tsh vs Ia lies slightly lower.
- In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required.

- **Characteristics of DC series motors**

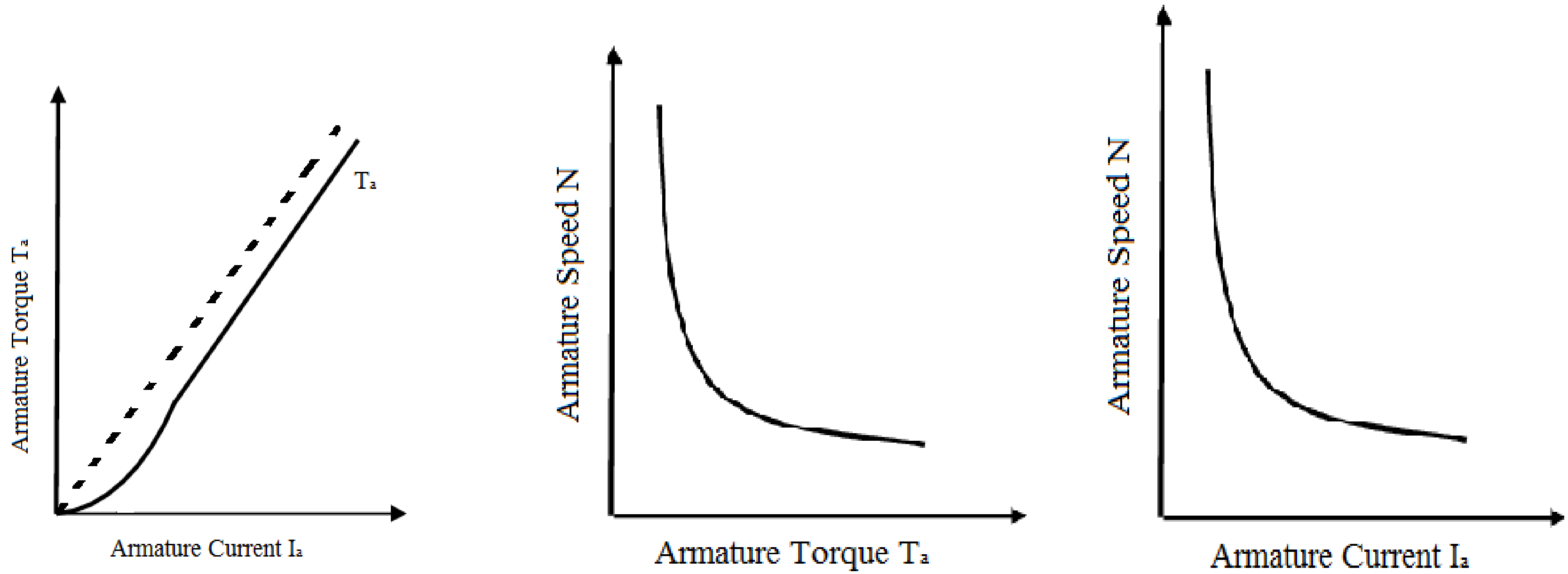


Fig 19: Characteristics of DC series motors

CHARACTERISTICS OF DC COMPOUND MOTOR

Characteristic of dc compound motor

- DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded.

(a) Cumulative compound motor

- Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel.

CHARACTERISTICS OF DC COMPOUND MOTOR

(b) Differential compound motor

Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load ($N \propto E_b/\phi$). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.

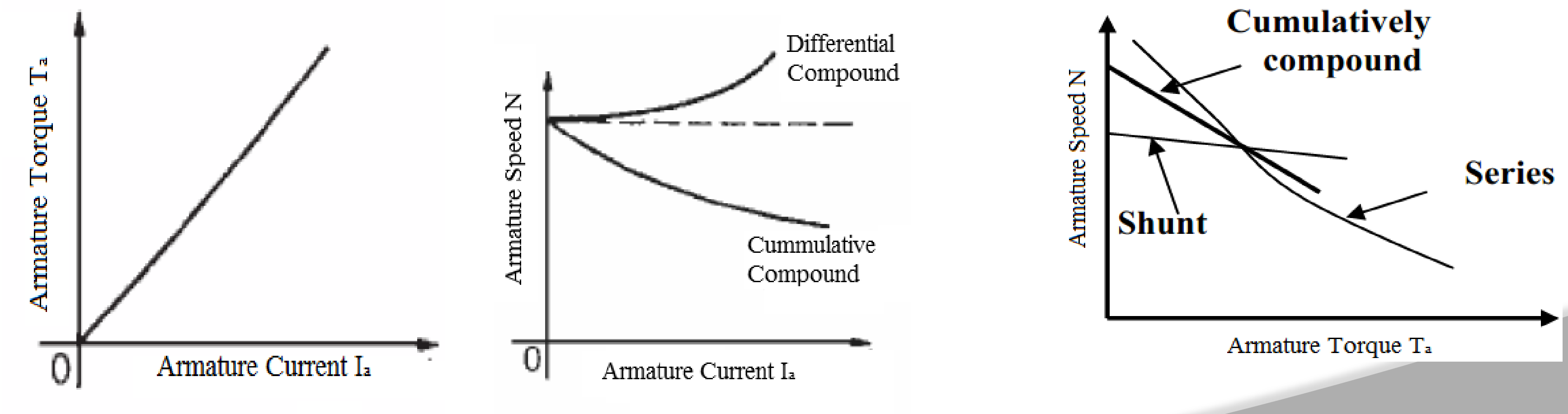


Fig 20: Characteristics of DC compound motors

LOSSSES IN DC MACHINE

COPPER LOSSES

This loss generally occurs due to current in the various windings on of the machine. The different winding losses are;

- Armature copper loss = $I^2_a R_a$
- Shunt field copper loss = $I^2_{sh} R_{sh}$
- Series field copper loss = $I^2_{se} R_{se}$

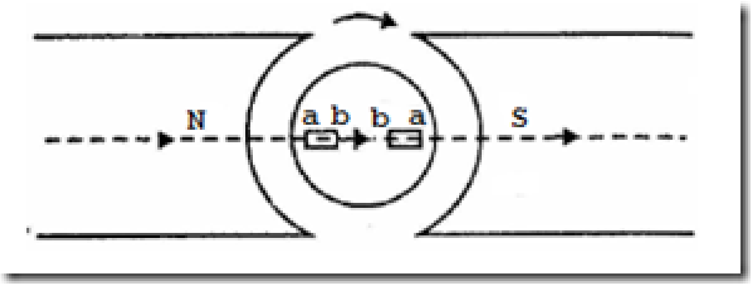
IRON LOSSES

This loss occurs within the armature of a d.c. machine and are attributable to the rotation of armature within the magnetic field of the poles. They're of 2 sorts viz.,

- Hysteresis loss
- eddy current loss.

LOSSSES IN DC MACHINE

HYSTERESIS LOSS:



Hysteresis loss $P_h = \eta B^{16}_{max}\, fV$ watts

Where,

η = Steinmetz hysteresis co-efficient

B_{max} = Maximum flux Density in armature

F = Frequency of magnetic reversals

= NP/120 (N is in RPM)

V = Volume of armature in m^3

EDDY CURRENT LOSS

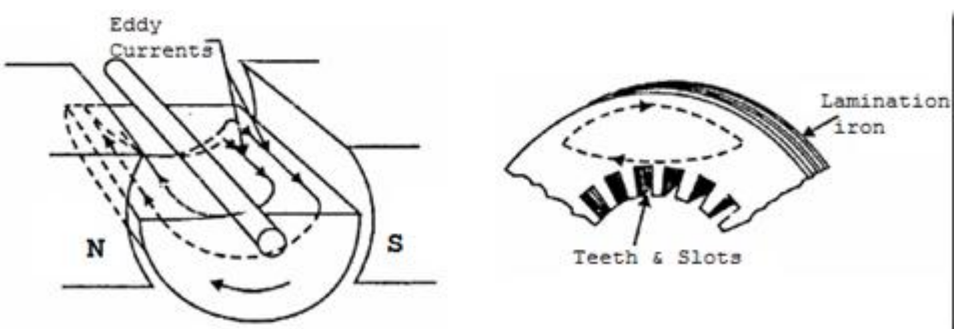


Fig 21: iron losses

Eddy Current loss $P_e = K_e B^2_{max} f^2 t^2 V$ Watts

Where,

k_e = constant

B_{max} = Maximum flux density in wb/m^2

T = Thickness of lamination in m

V = Volume of core in m^3

LOSSSES IN DC MACHINE

MECHANICAL LOSSES:

These losses are attributable to friction and windage.

- Friction loss occurs due to the friction in bearing, brushes etc.
- windage loss occurs due to the air friction of rotating coil.

These losses rely on the speed of the machine. Except for a given speed, they're much constant.

THREE POINT STARTER

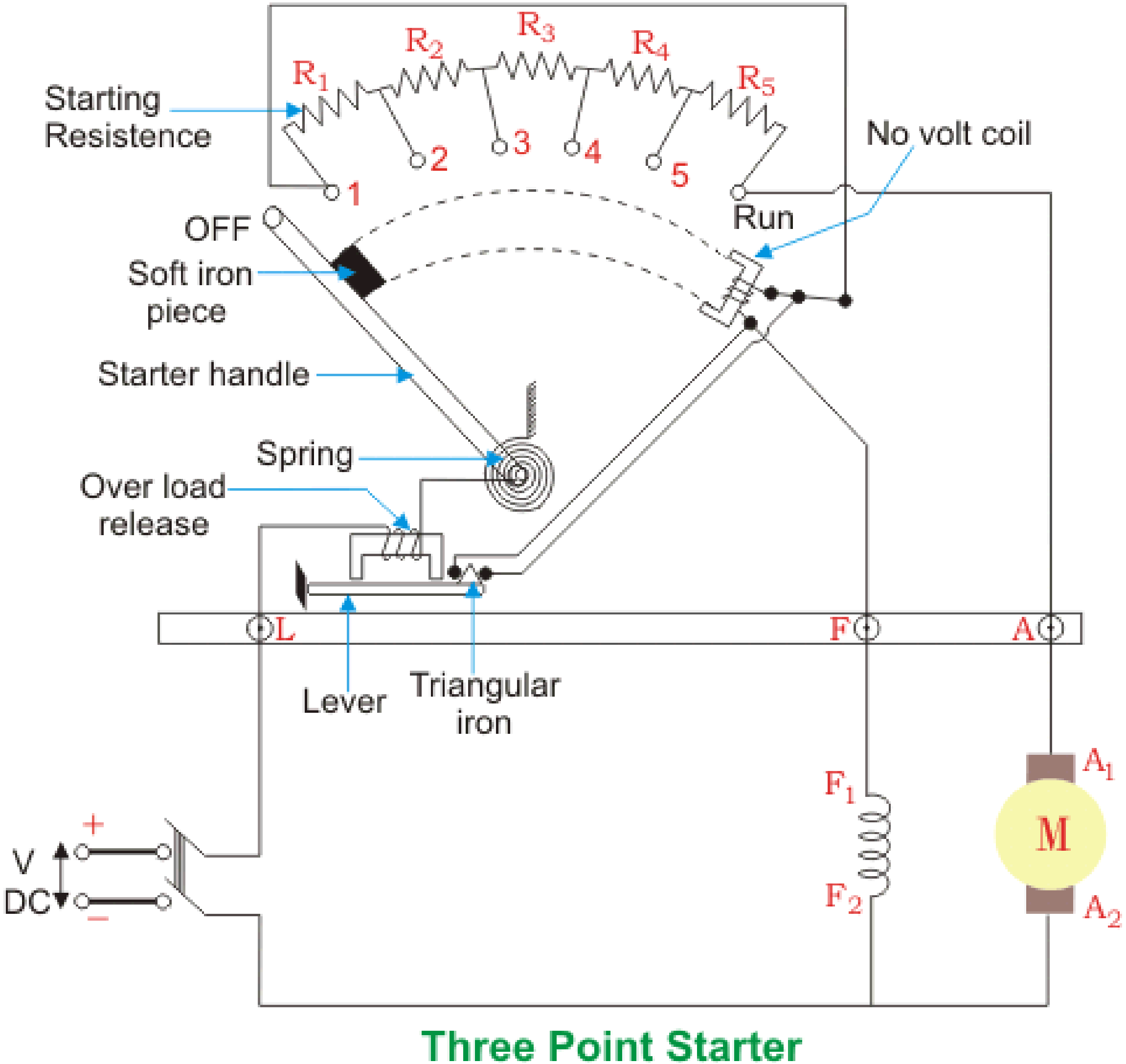


Fig 22: three point starter

THREE POINT STARTER

- The supply to the field winding is derived through no voltage coil. So when field current flows, the NVC is magnetized. Now when the handle is in the ‘RUN’ position, a soft iron piece is connected to the handle and gets attracted by the magnetic force produced by NVC, because of flow of current through it. The NVC is designed in such a way that it holds the handle in ‘RUN’ position against the force of the spring as long as supply is given to the motor. Thus NVC holds the handle in the ‘RUN’ position and hence also called **hold on coil**.

THREE POINT STARTER

- Now when there is any kind of supply failure, the current flow through NVC is affected and it immediately loses its magnetic property and is unable to keep the soft iron piece on the handle, attracted. At this point under the action of the spring force, the handle comes back to OFF position, opening the circuit and thus switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problem. Thus it also acts as a protective device safeguarding the motor from any kind of abnormality.

MODULE-III

ALTERNATING QUANTITIES AND AC MACHINES

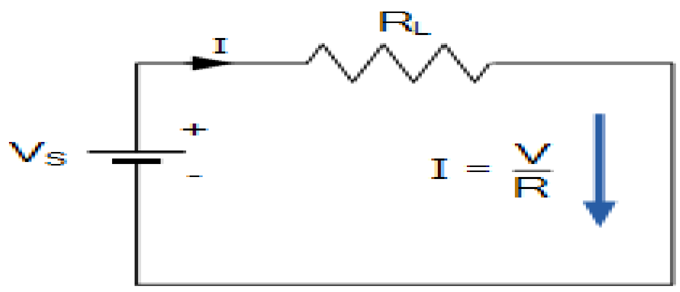
MODULE - III

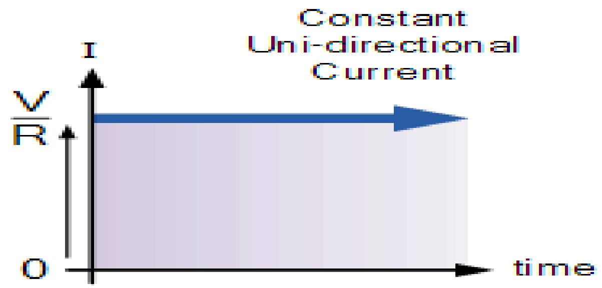
CLOs	Course Learning Outcome
CLO 10	List out various alternating quantities such as Sinusoidal AC voltage, average and RMS values, form and peak factor, and understand concept of three phase alternating quantity.
CLO 11	Discuss the principle of operation of induction motor.
CLO 12	Explain the construction and characteristics of alternator.
CLO 13	Explain the construction and characteristics of 3-phase induction motor.
CLO 14	Explain the principle and construction of Transformer.

ANALYSIS OF AC CIRCUITS

- **Direct Current** or **D.C.** as it is more commonly called, is a form of electrical current or voltage that flows around an electrical circuit in one direction only, making it a “Uni-directional” supply.
- Generally, both DC currents and voltages are produced by power supplies, batteries, dynamos and solar cells to name a few. A DC voltage or current has a fixed magnitude (amplitude) and a definite direction associated with it. For example, +12V represents 12 volts in the positive direction, or -5V represents 5 volts in the negative direction.
- We also know that DC power supplies do not change their value with regards to time, they are a constant value flowing in a continuous steady state direction. In other words, DC maintains the same value for all times and a constant uni-directional DC supply never changes or becomes negative unless its connections are physically reversed. An example of a simple DC or direct current circuit is shown below

DC CIRCUIT AND WAVEFORM





- An alternating function or **AC Waveform** on the other hand is defined as one that varies in both magnitude and direction in more or less an even manner with respect to time making it a “Bi-directional” waveform. An AC function can represent either a power source or a signal source with the shape of an *AC waveform* generally following that of a mathematical sinusoid being defined as: $A(t) = A_{max}*\sin(2\pi ft)$.

- The Period, (T) is the length of time in seconds that the waveform takes to repeat itself from start to finish. This can also be called the *Periodic Time* of the waveform for sine waves, or the *Pulse Width* for square waves.
- The Frequency, (f) is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ($f = 1/T$) with the unit of frequency being the *Hertz*, (Hz).
- The Amplitude (A) is the magnitude or intensity of the signal waveform measured in volts or amps.

TYPES OF PERIODIC WAVEFORM

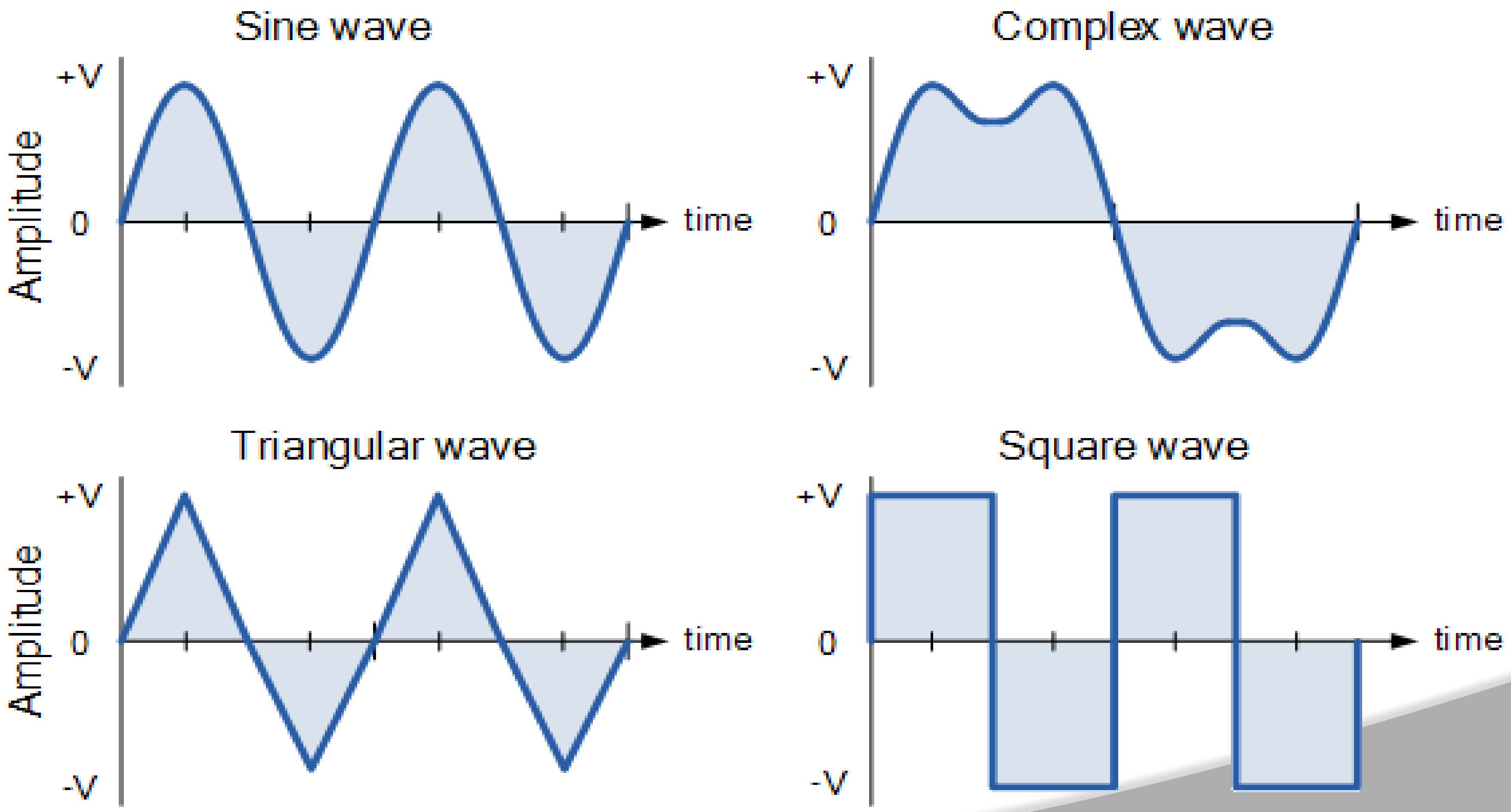


Fig 1: types of periodic waveforms

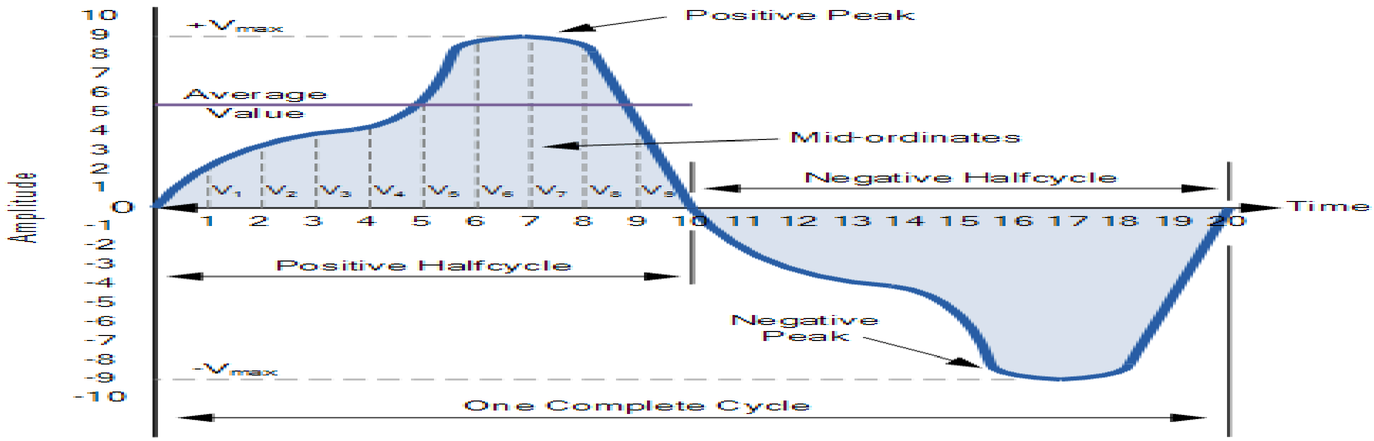
ANALYSIS OF AC CIRCUITS

- The time taken for an **AC Waveform** to complete one full pattern from its positive half to its negative half and back to its zero baseline again is called a **Cycle** and one complete cycle contains both a positive half-cycle and a negative half-cycle.
- The time taken by the waveform to complete one full cycle is called the **Periodic Time** of the waveform, and is given the symbol "T".
- The number of complete cycles that are produced within one second (cycles/second) is called the **Frequency**, symbol ƒ of the alternating waveform. Frequency is measured in **Hertz**, (Hz) named after the German physicist Heinrich Hertz.
- Relationship between frequency and periodic time
  - Frequency(f)=1/T Hz
  - Time period(T)=1/f Sec

THE AVERAGE VALUE OF AN AC WAVEFORM

- The average or mean value of a continuous DC voltage will always be equal to its maximum peak value as a DC voltage is constant. This average value will only change if the duty cycle of the DC voltage changes. In a pure sine wave if the average value is calculated over the full cycle, the average value would be equal to zero as the positive and negative halves will cancel each other out. So the average or mean value of an AC waveform is calculated or measured over a half cycle only and this is shown below.

AVERAGE VALUE OF A NON-SINUSOIDAL WAVEFORM



- To find the average value of the waveform we need to calculate the area underneath the waveform using the mid-ordinate rule, trapezoidal rule or the Simpson's rule found commonly in mathematics. The approximate area under any irregular waveform can easily be found by simply using the mid-ordinate rule.

AVERAGE VALUE OF AN AC WAVEFORM

$$V_{AVG} = \frac{V_1 + V_2 + V_3 + \dots\dots\dots + V_n}{n}$$

- Where: n equals the actual number of mid-ordinates used.
- For a pure sinusoidal waveform this average or mean value will always be equal to $0.637 * V_{max}$ and this relationship also holds true for average values of current.

RMS VALUE OF AN AC WAVEFORM

$$V_{rms} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + \ldots\ldots + V_{n1}^2}{n}}$$

- Where: n equals the number of mid-ordinates.
- For a pure sinusoidal waveform this effective or R.M.S. value will always be equal too: $1/\sqrt{2}*V_{max}$ which is equal to $0.707*V_{max}$ and this relationship holds true for RMS values of current. The RMS value for a sinusoidal waveform is always greater than the average value except for a rectangular waveform. In this case the heating effect remains constant so the average and the RMS values will be the same.

FORM FACTOR AND CREST FACTOR

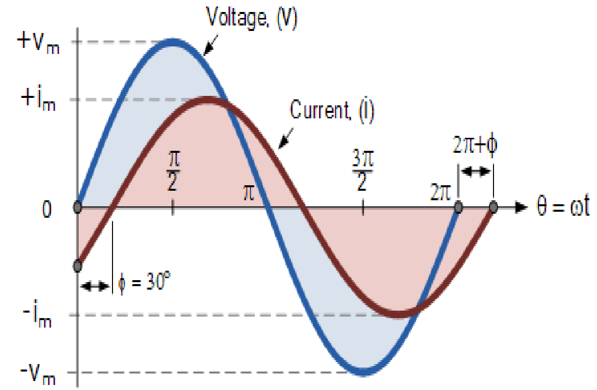
- Although little used these days, both Form Factor and Crest Factor can be used to give information about the actual shape of the AC waveform. Form Factor is the ratio between the average value and the RMS value and is given as.

$$FormFactor = \frac{\text{R.M.S Value}}{\text{Average Value}} = \frac{0.707 \times V_{\max}}{0.637 \times V_{\max}}$$

- For a pure sinusoidal waveform the Form Factor will always be equal to 1.11. Crest Factor is the ratio between the R.M.S. value and the Peak value of the waveform and is given as.

$$CrestFactor = \frac{\text{Peak Value}}{\text{R.M.S Value}} = \frac{V_{\max}}{0.707 \times V_{\max}}$$

PHASE DIFFERENCE OF A SINUSOIDAL WAVEFORM



- The generalised mathematical expression to define these two sinusoidal quantities will be written as:
- The current, i is lagging the voltage, v by angle Φ and in our example above this is 30°. So the difference between the two phasors representing the two sinusoidal quantities is angle Φ and the resulting phasor diagram will be.

$$v_{(t)} = V_m \sin(\omega t)$$

$$i_{(t)} = I_m \sin(\omega t - \phi)$$

INTRODUCTION OF TRANSFORMER

INTRODUCTION

- A transformer is a device that changes ac electric power at one voltage level to ac electric power at another voltage level through the action of a magnetic field.
- There are two or more stationary electric circuits that are coupled magnetically.
- It involves interchange of electric energy between two or more electric systems Transformers provide much needed capability of changing the voltage and current levels easily.
- They are used to step-up generator voltage to an appropriate voltage level for power transfer.

PRINCIPLE OF TRANSFORMER

- According to Faraday's law of electromagnetic induction, there will be an EMF induced in the second winding. If the circuit of this secondary winding is closed, then a current will flow through it. This is the basic working principle of a transformer. Let us use electrical symbols to help visualize this. The winding which receives electrical power from the source is known as the 'primary wind
- The winding which gives the desired output voltage due to mutual induction is commonly known as the 'secondary winding'.

PRINCIPLE OF TRANSFORMER

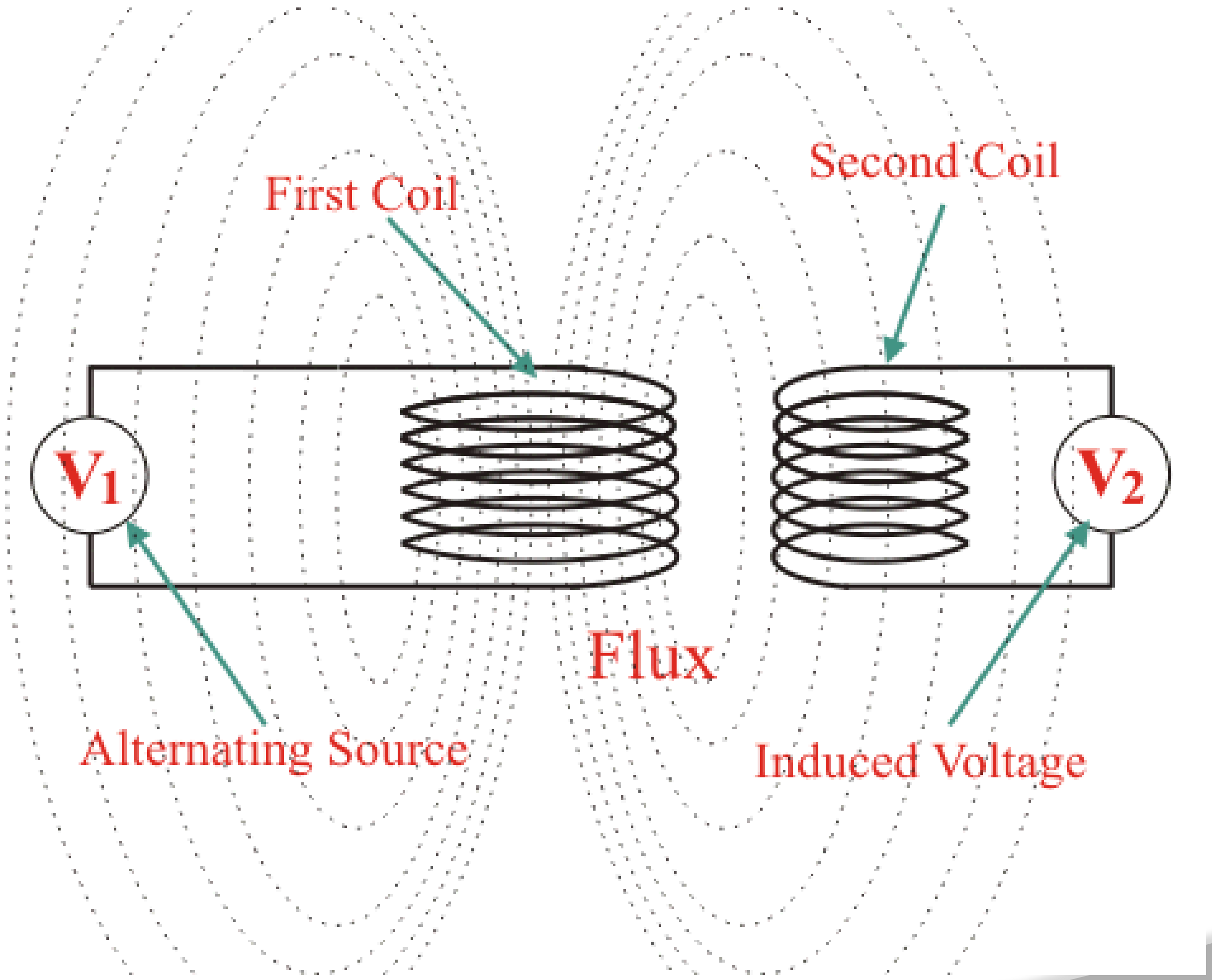


Fig 2: principle of transformer

CONSTRUCTION OF TRANSFORMER

STRUCTURE OF TRANSFORMER

- The transformer two inductive coils ,these are electrical separated but linked through a common magnetic current circuit
- These two coils have a high mutual induction One of the two coils is connected of alternating voltage .this coil in which electrical energy is fed with the help of source called primary winding (P) shown in fig. The other winding is connected to a load the electrical energy is transformed to this winding drawn out to the load .this winding is called secondary winding(S) shown in fig.

CONSTRUCTION OF TRANSFORMER

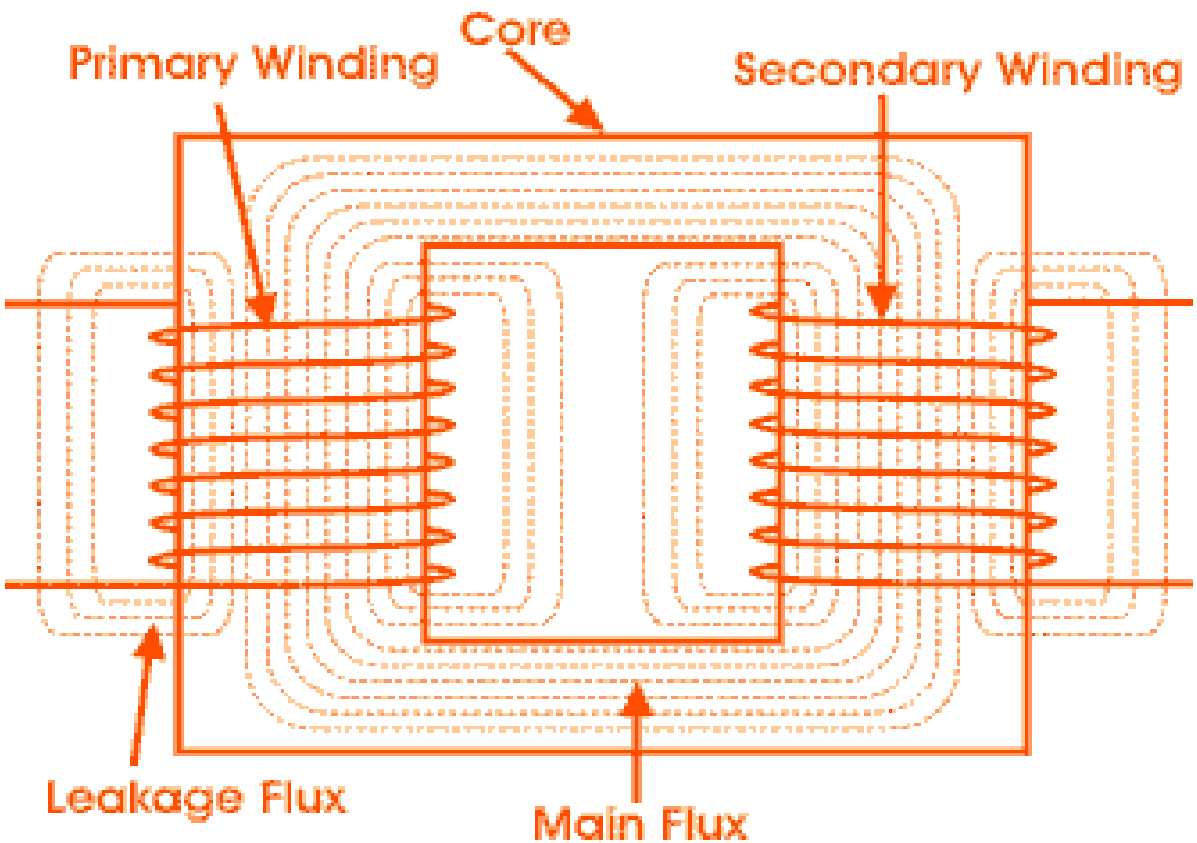
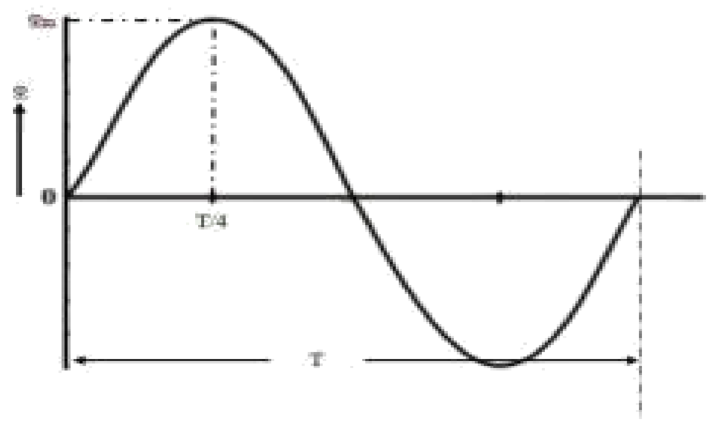


Fig 3: working of transformer

EMF EQUATION OF A TRANSFORMER

- N1 =Primary turns
- N2 = Secondary turns
- Φm = Maximum flux in the core
- Φm = Bm × A webers
- f= frequency of ac input in hertz (Hz)



$$E1 = 4.44 f \phi m \times N1 = 4.44 f Bm \times A \times N1$$

Similarly;

$$E2 = 4.44 f \phi m \times N2 = 4.44 f Bm \times A \times N2$$

LOSSES IN TRANSFORMER

Copper losses :

•It is due to power wasted in the form of I2Rdue to resistance of primary and secondary.

•The magnitude of copper losses depend upon the current flowing through these coils.

•The iron losses depend on the supply voltage while the copper depends on the current .

•The losses are not dependent on the phase angle between current and voltage .

•Hence the rating of the transformer is expressed as a product o f voltage and current called VA rating of transformer.

• It is not expressed in watts or kilowatts. Most of the timer, is rating is expressed in **KVA**

LOSSES

Hysteresis loss :

During magnetization and demagnetization ,

due to hysteresis effect some energy losses in the core called hysteresis loss

$$P_h = K\eta B_{max}^{1.6} f V \quad \text{watts}$$

Eddy current loss :

The leakage magnetic flux generates the E.M.F in the core produces current is called of eddy current loss.

$$P_e = K_e B_m^2 t^2 f^2 V \qquad \text{watts}$$

EQUIVALENT CIRCUIT OF TRANSFORMER

- The equivalent circuit diagram of any device can be quite helpful in predetermination of the behavior of the device under the various condition of operation. It is simply the circuit representation of the equation describing the performance of the device.

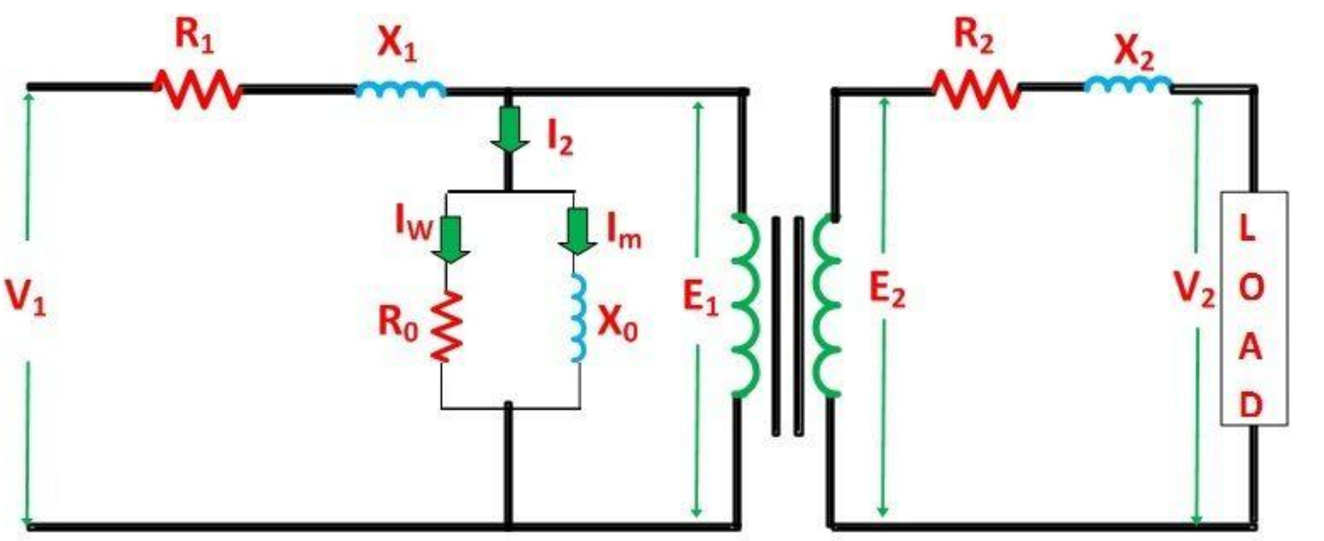
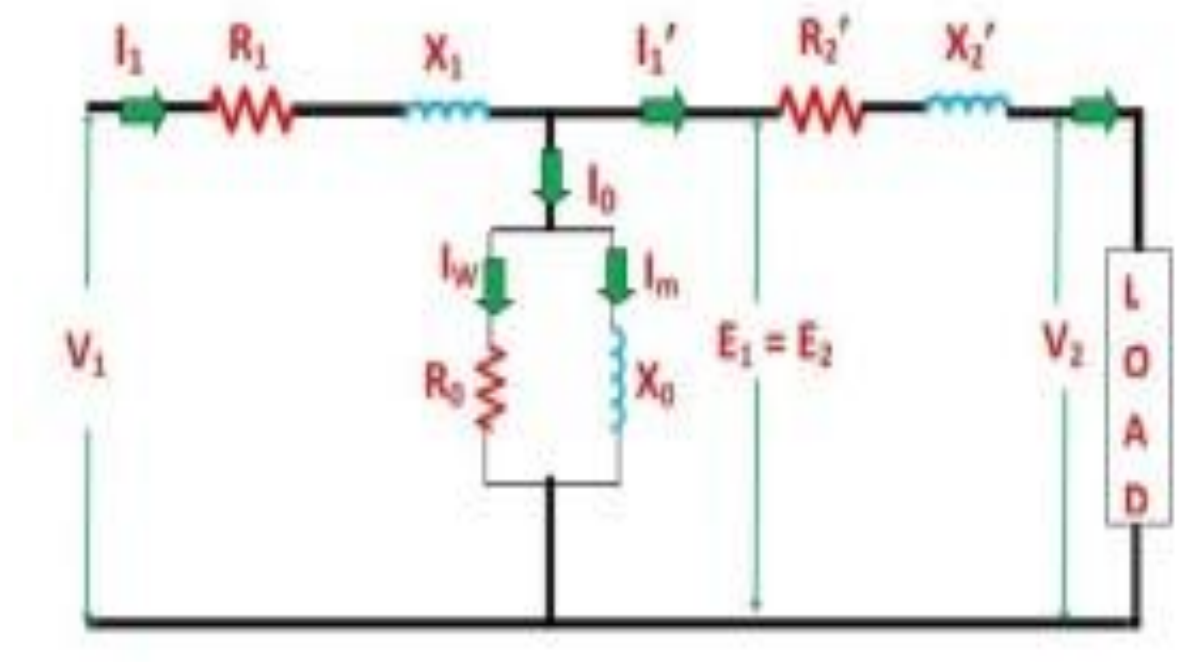


Fig 4: equivalent circuit of transformer

EQUIVALENT CIRCUIT REFERRED TO PRIMARY



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

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

$$R_{ep} = R_1 + R_2'$$

$$X_{ep} = X_1 + X_2'$$

Fig 5: equivalent circuit referred to primary

EQUIVALENT CIRCUIT REFFERED TO SECONDARY

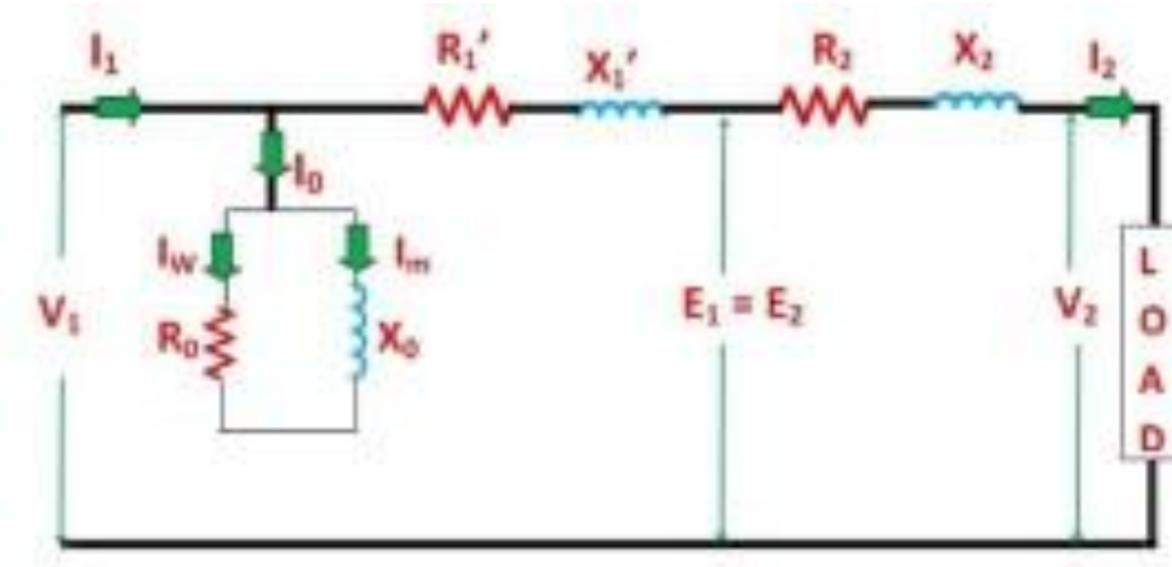


Fig 6: equivalent circuit referred to secondary

$$R_1' = K^2 R_1$$

$$R_{es} = R_2 + R_1'$$

$$X_1' = K^2 X_1$$

$$X_{eq} = X_2 + X_I'$$

OPEN CIRCUIT AND SHORT CIRCUIT TEST ON TRANSFORMER

- The purpose of the open circuit test is to determine the no-load current and losses of the transformer because of which their no-load parameter are determined. This test is performed on the primary winding of the transformer. The wattmeter, ammeter and the voltage are connected to their primary winding. The nominal rated voltage is supplied to their primary winding with the help of the ac source

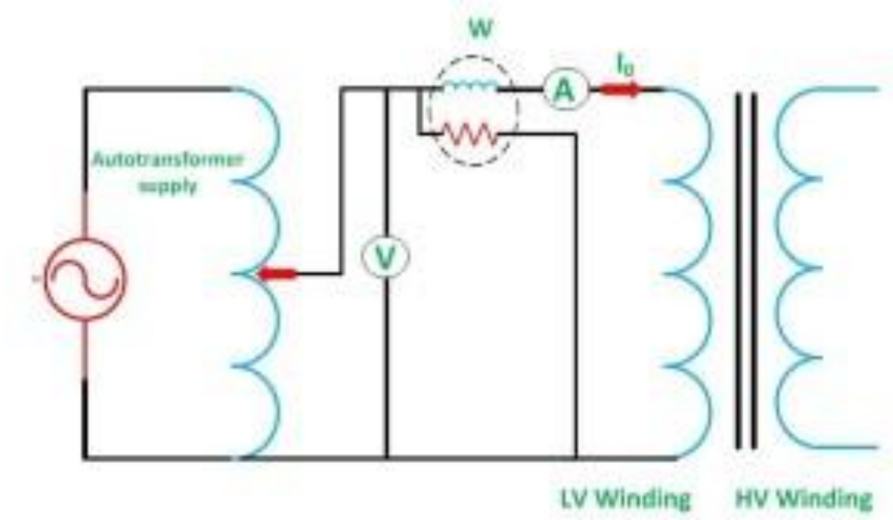


Fig 7: OC test on transformer

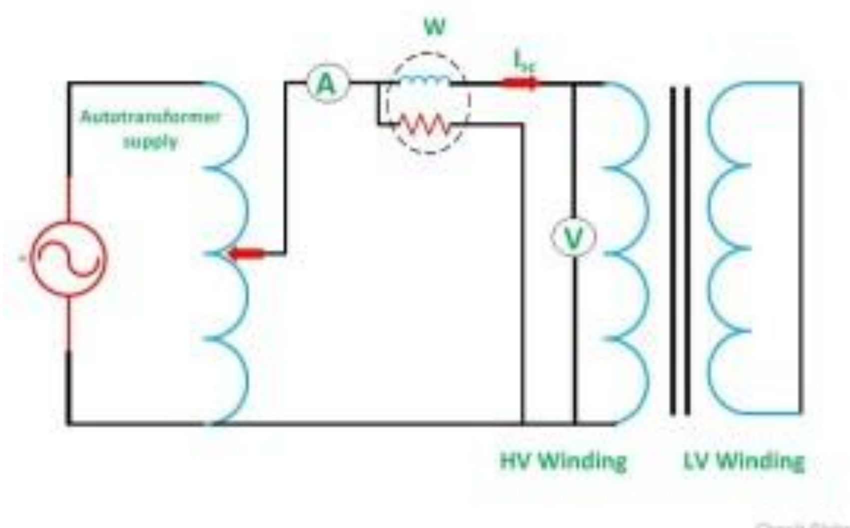
$$W_0 = V_1 I_0 \cos\varphi_0 \; ; \quad \cos\varphi_0 = \frac{W_0}{V_1 I_0}$$

$$I_w = \frac{W_0}{V_1} \; ; \quad I_w = I_0 \cos\varphi_0$$

$$I_m = \sqrt{I_0^2 - I_w^2}$$

$$R_0 = \frac{V_1}{I_w} \qquad X_0 = \frac{V_1}{I_m}$$

- The short circuit test is performed on the secondary or high voltage winding of the transformer. The measuring instrument like wattmeter, voltmeter and ammeter are connected to the High voltage winding of the transformer. Their primary winding is short circuited by the help of thick strip or ammeter which is connected to their terminal.



$$P_c = \left(\frac{I_{2fl}}{I_{2sc}}\right)^2 W_c \quad \text{And} \quad R_{es} = \frac{W_c}{I_{2sc}^2}$$

$$Z_{es} = \frac{V_{2sc}}{I_{2sc}} \qquad X_{es} = \sqrt{(Z_{es})^2 - (R_{es})^2}$$

Fig 8: SC test on transformer

VOLTAGE REGULATION OF TRANSFORMER

- The voltage regulation is defined as the change in the magnitude of receiving and sending the voltage of the transformer. The voltage regulation determines the ability of the transformer to provide the constant voltage for variable loads.

$$\text{Voltage Regulation} = \frac{E_2 - V_2}{E_2}$$

$$\%\ \text{Voltage Regulation} = \frac{E_2 - V_2}{E_2} \times 100$$

VOLTAGE REGULATION OF TRANSFORMER

INDUCTIVE LOAD

$$E_2 = I_2R_{02}Cos\varphi_2 + I_2X_{02}Sin\varphi_2 + V_2$$

OR

$$E_2 - V_2 = I_2R_{02}Cos\varphi_2 + I_2X_{02}Sin\varphi_2$$

OR

$$\frac{E_2 - V_2}{E_2} \times 100 = \frac{I_2R_{02}}{E_2} \times 100\ Cos\varphi_2 + \frac{I_2X_{02}}{E_2} \times 100\ Sin\varphi_2$$

CAPACITIVE LOAD

$$E_2 = I_2R_{02}Cos\varphi_2 - I_2X_{02}Sin\varphi_2 + V_2$$

OR

$$E_2 - V_2 = I_2R_{02}Cos\varphi_2 - I_2X_{02}Sin\varphi_2$$

OR

$$\frac{E_2 - V_2}{E_2} \times 100 = \frac{I_2R_{02}}{E_2} \times 100\ Cos\varphi_2 - \frac{I_2X_{02}}{E_2} \times 100\ Sin\varphi_2$$

PRINCIPLE OF INDUCTION MOTOR

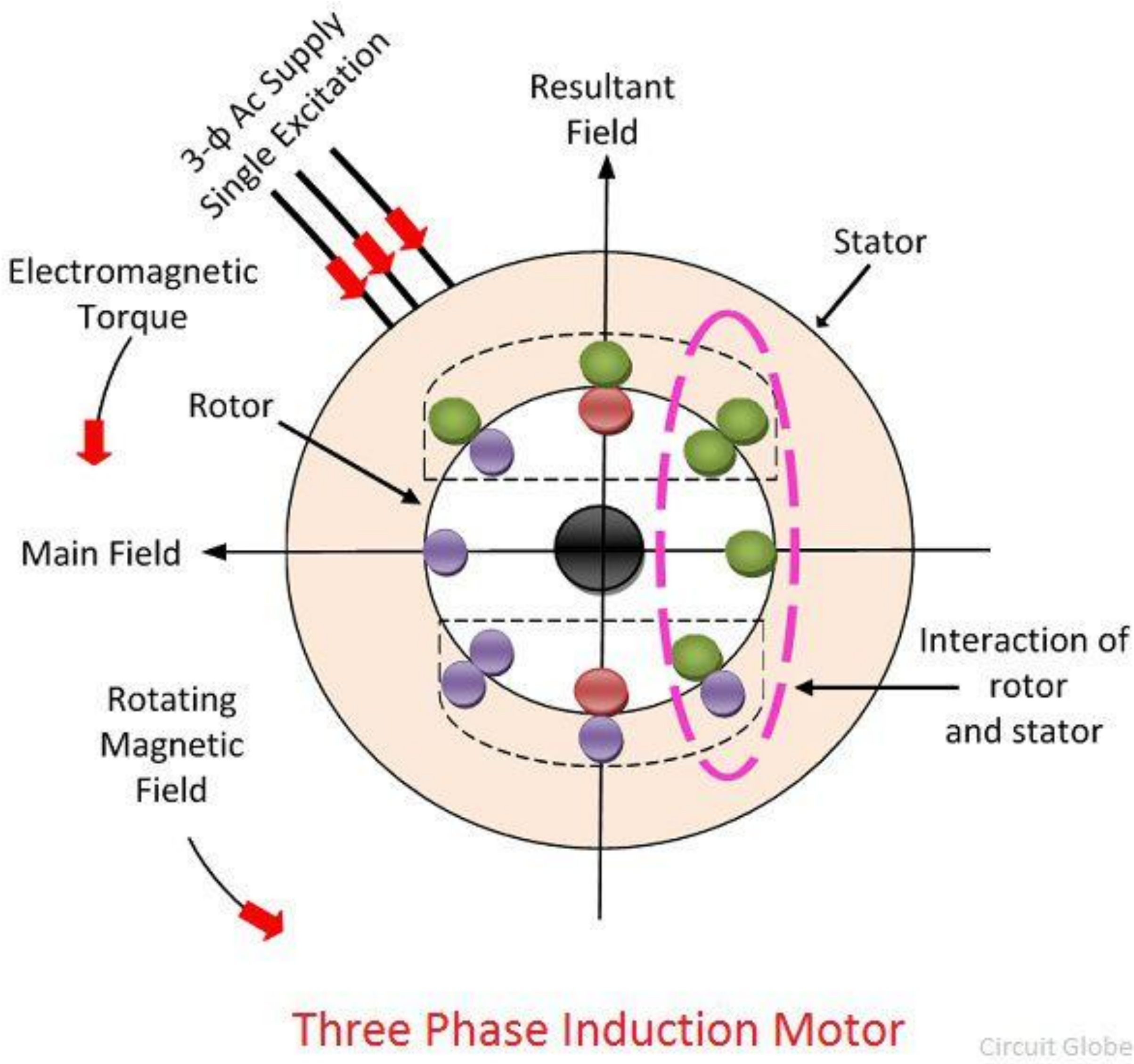
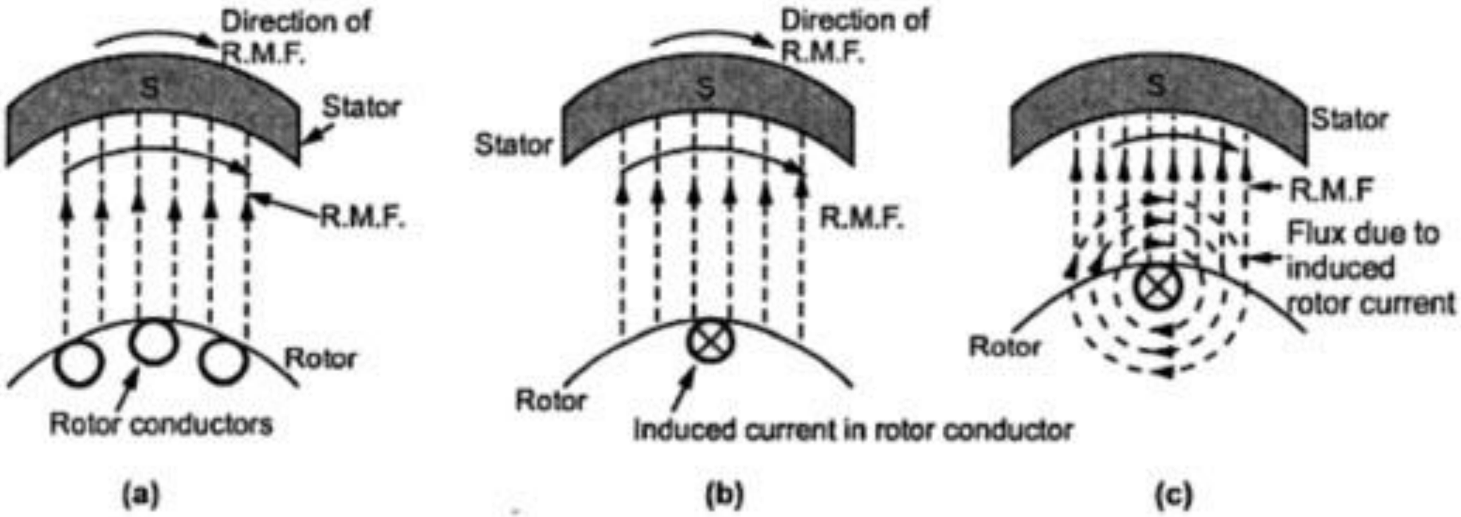


Fig 9: Principle of induction motor

PRINCIPLE OF INDUCTION MOTOR



When the three phase supply is given to the stator, the rotating magnetic field produced on it. The conductors of the rotor are stationary. This stationary conductor cut the rotating magnetic field of the stator, and because of the electromagnetic induction, the EMF induces in the rotor. This EMF is known as the rotor induced EMF, and it is because of the electromagnetic induction phenomenon. Now we have two fluxes one because of the rotor and another because of the stator. These fluxes interact each other. On one end of the conductor the fluxes cancel each other, and on the other end, the density of the flux is very high. Thus, the high-density flux tries to push the conductor of rotor towards the low-density flux region. This phenomenon induces the torque on the conductor, and this torque is known as the electromagnetic torque.

ROTATING MAGNETIC FIELD

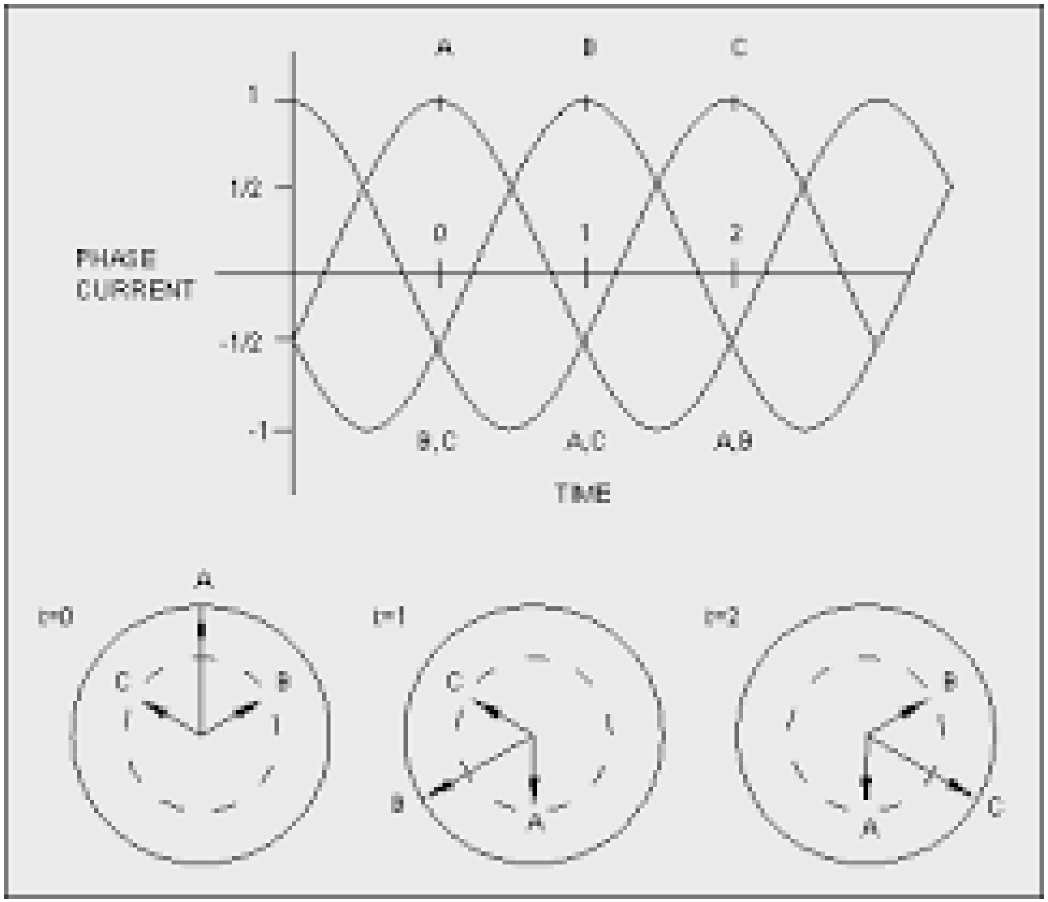


Fig 10: Rotating magnetic field

WORKING OF INDUCTION MOTOR

- Alternating flux is produced around the stator winding due to AC supply. This alternating flux revolves with synchronous speed. The revolving flux is called as "Rotating Magnetic Field" (RMF).
- The relative speed between stator RMF and rotor conductors causes an induced emf in the rotor conductors, according to the Faraday's law of electromagnetic induction. The rotor conductors are short circuited, and hence rotor current is produced due to induced emf. That is why such motors are called as induction motors.
- (This action is same as that occurs in transformers, hence induction motors can be called as rotating transformers.)

WORKING OF INDUCTION MOTOR

- Now, induced current in rotor will also produce alternating flux around it. This rotor flux lags behind the stator flux. The direction of induced rotor current, according to Lenz's law, is such that it will tend to oppose the cause of its production.
- As the cause of production of rotor current is the relative velocity between rotating stator flux and the rotor, the rotor will try to catch up with the stator RMF. Thus the rotor rotates in the same direction as that of stator flux to minimize the relative velocity. However, the rotor never succeeds in catching up the synchronous speed. This is the **basic working principle of induction motor** of either type, single phase of 3 phase.

SYNCHRONOUS SPEED:

- The rotational speed of the rotating magnetic field is called as synchronous speed.

$$Ns = \frac{120 \times f}{P} \quad (RPM)$$

where, f = frequency of the spply
P = number of poles

WORKING OF INDUCTION MOTOR

- Rotor tries to catch up the synchronous speed of the stator field, and hence it rotates. But in practice, rotor never succeeds in catching up. If rotor catches up the stator speed, there wont be any relative speed between the stator flux and the rotor, hence no induced rotor current and no torque production to maintain the rotation. However, this won't stop the motor, the rotor will slow down due to lost of torque, the torque will again be exerted due to relative speed. That is why the rotor rotates at speed which is always less the synchronous speed.
- The difference between the synchronous speed (N_s) and actual speed (N) of the rotor is called as slip.

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

CONSTRUCTION

- An induction motor has two main parts
- **stator**
  - consisting of a steel frame that supports a hollow, cylindrical core
  - core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding

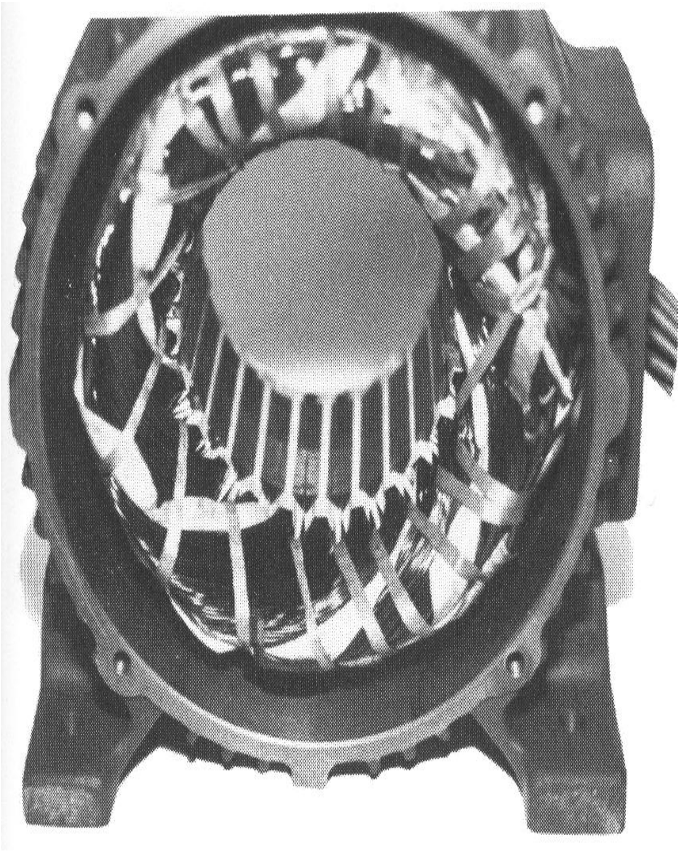


Fig 11: stator

CONSTRUCTION

Rotor

- composed of punched laminations, stacked to create a series of rotor slots, providing space for the rotor winding
- one of two types of rotor windings
- conventional 3-phase windings made of insulated wire (wound-rotor) » similar to the winding on the stator
- aluminum bus bars shorted together at the ends by two aluminum rings, forming a squirrel-cage shaped circuit (squirrel-cage)

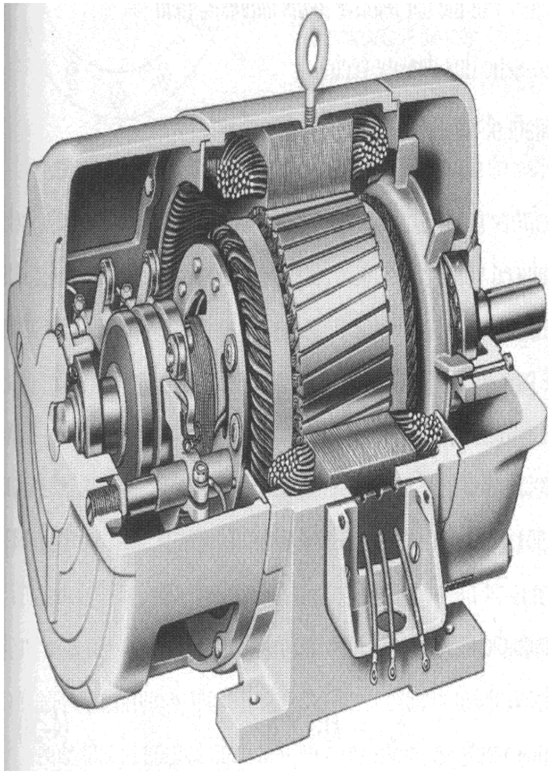


Fig 12: rotor

CONSTRUCTION

- Two basic design types depending on the rotor design
  - squirrel-cage.
  - wound-rotor or wound rotor

SQUIRREL CAGE

This rotating magnetic field induces the voltage in rotor bars and hence short-circuit currents start flowing in the rotor bars. These rotor currents generate their self-magnetic field which will interact with the field of the stator. Now the rotor field will try to oppose its cause, and hence rotor starts following the rotating magnetic field.

CONSTRUCTION

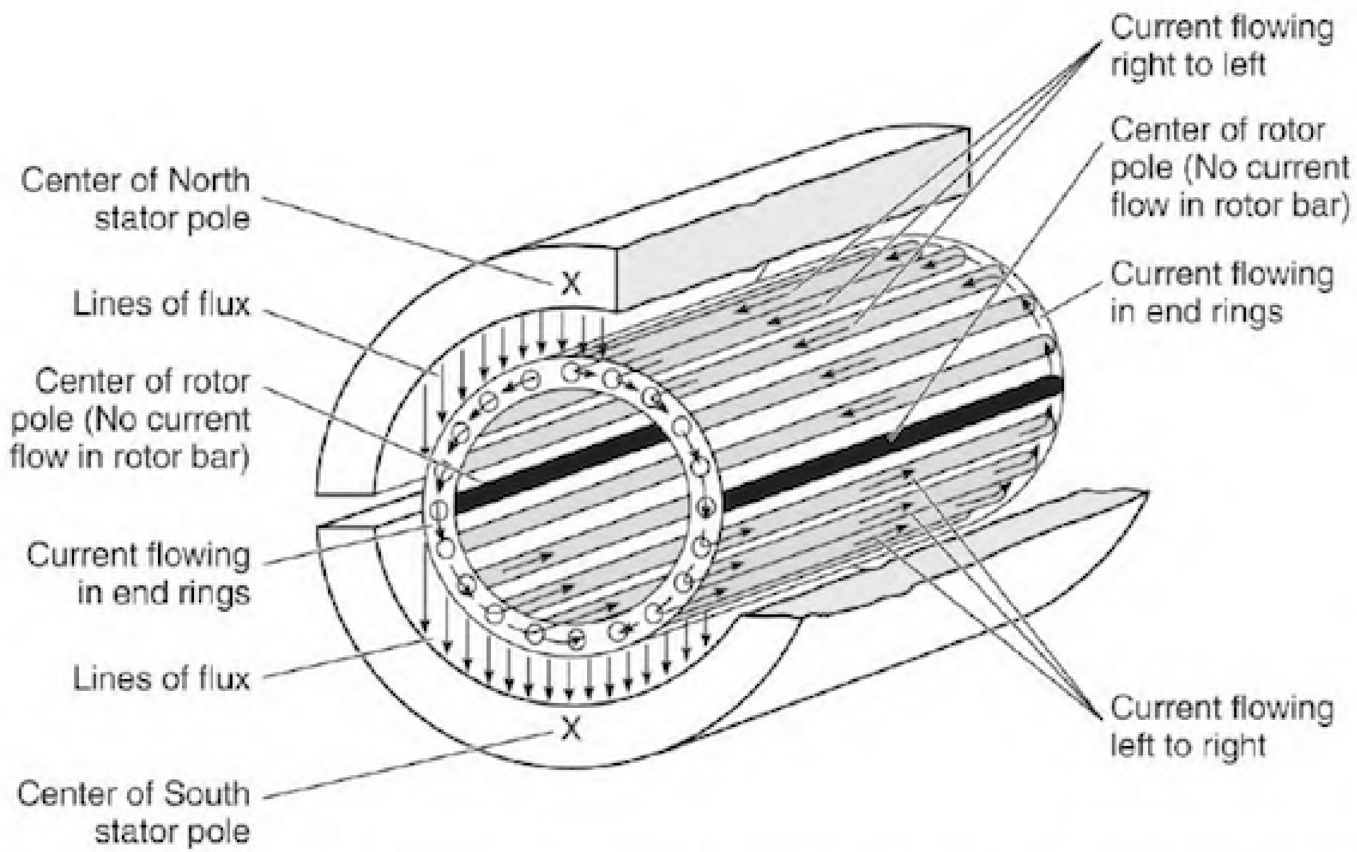


Fig 13: squirrel cage induction motor

CONSTRUCTION

- SLIP RING OR WOUND ROTOR:

A wound rotor induction motor has a stator like a squirrel cage induction motor, but a rotor with insulated windings brought out via slip rings and brushes. However, no power is applied to the slip rings. Their sole purpose is to allow resistance to be placed in series with the rotor windings while starting (figure below). This resistance is shorted out once the motor is started to make the rotor look electrically like the squirrel cage counterpart.

CONSTRUCTION

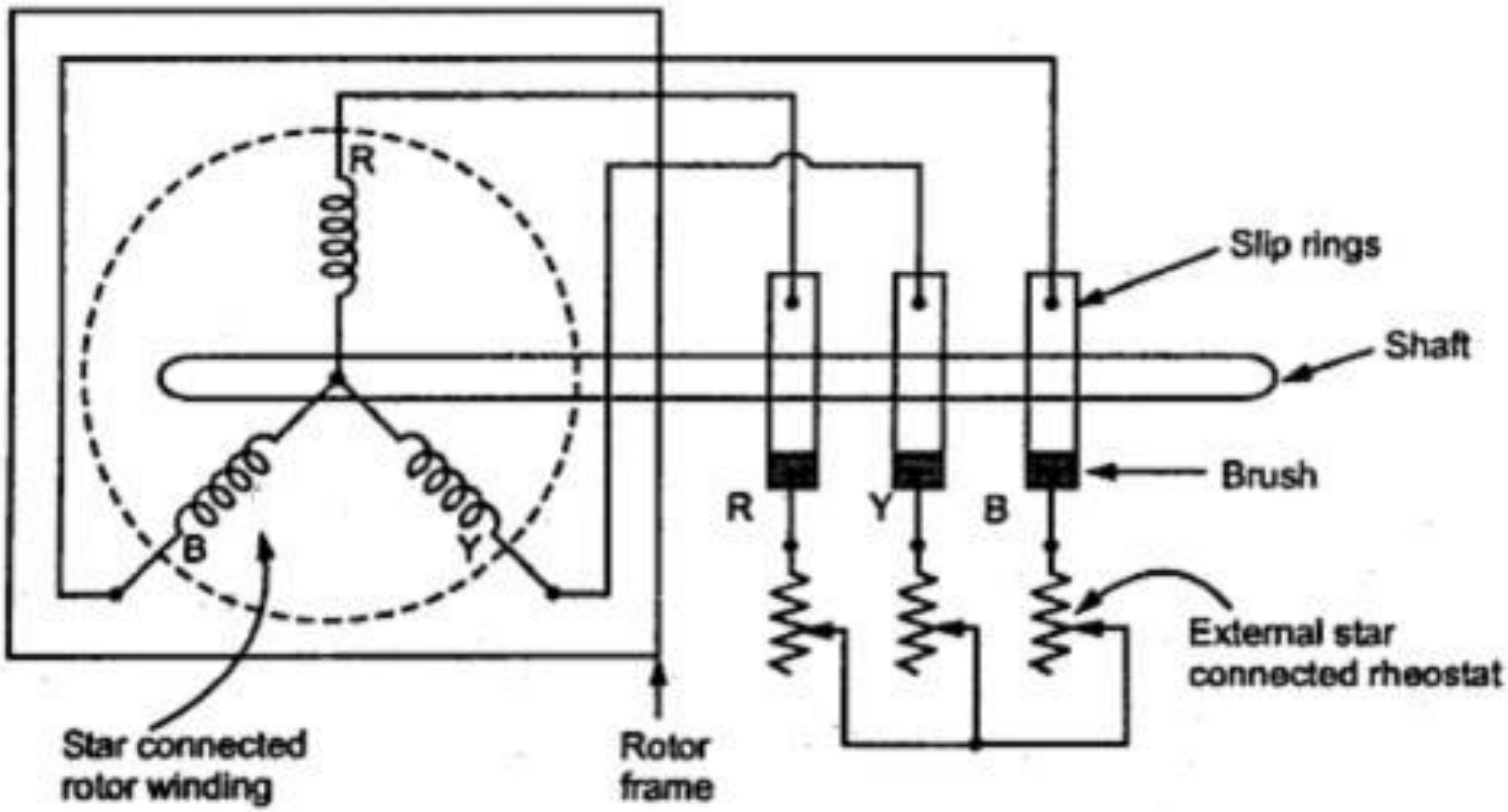


Fig 14: slip ring induction motor

CONSTRUCTION

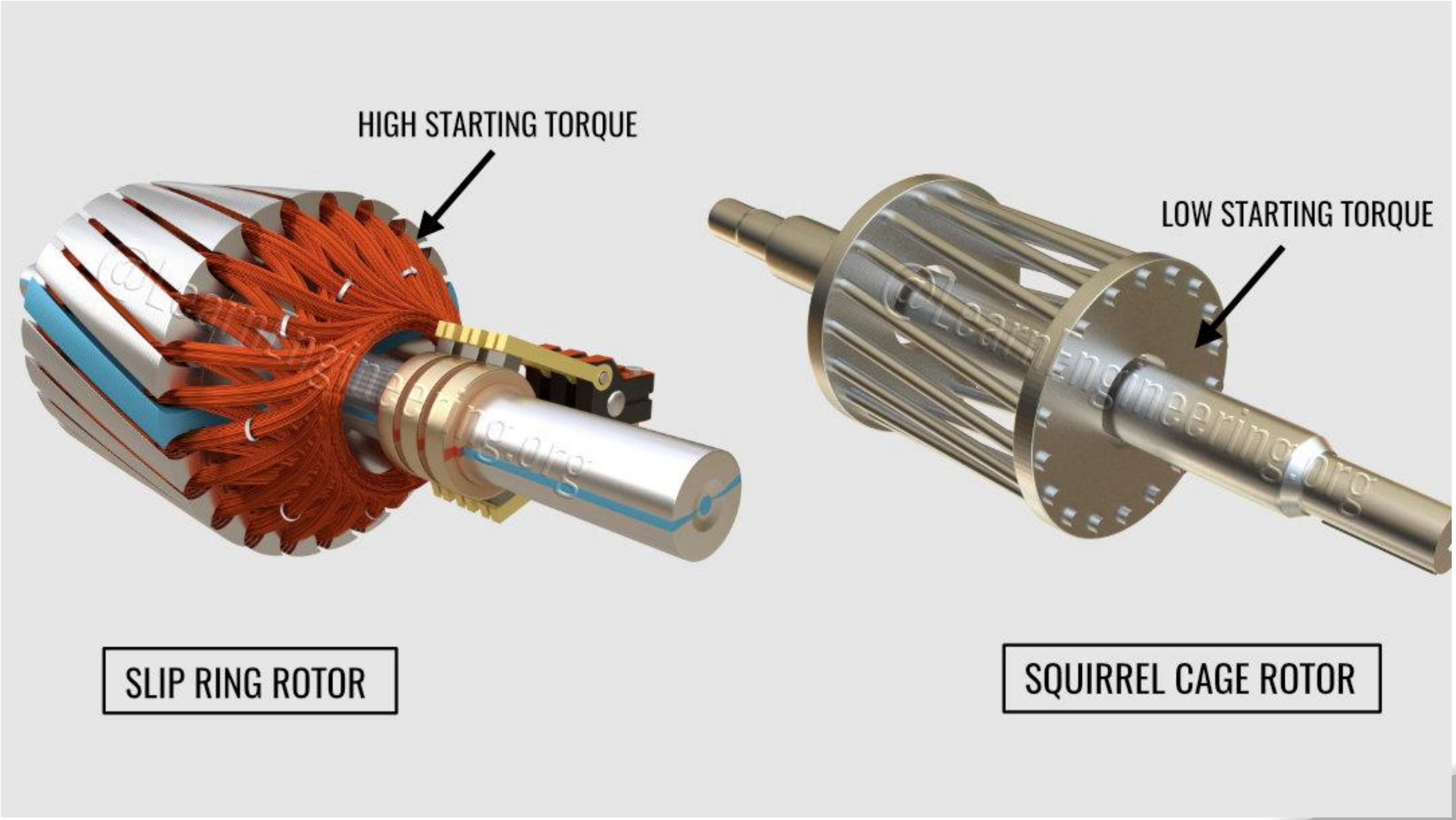


Fig 15: types of induction motor

TORQUE EQUATION

- The torque produced by three phase induction motor depends upon the following three factors:
  Firstly the magnitude of rotor current, secondly the flux which interact with the rotor of three phase induction motor and is responsible for producing emf in the rotor part of induction motor, lastly the power factor of rotor of the three phase induction motor.

Combining all these factors, we get the equation of torque as

$$T \propto \phi I_2 \cos\theta_2$$

We get,

$$Toeque,\ T = \frac{s\ E_2^2 R_2}{R_2^2 + (sX_2)^2} \times \frac{3}{2\pi N_s}$$

$$or,\ T = KsE_2^2 \frac{R_2}{R_2^2 + (sX_2)^2}$$

TORQUE SLIP CHARACTERISTICS:

LOW SLIP REGION:

At the synchronous speed, s = 0, therefore, the torque is zero. When the speed is very near to synchronous speed. The slip is very low and $(sX_{20})^2$ is negligible in comparison with R_2.

HIGH SLIP REGION:

Beyond the maximum torque point, the value of torque starts decreasing. As a result, the motor slows down and stops. At this stage, the overload protection must immediately disconnect the motor from the supply to prevent damage due to overheating of the motor.

TORQUE SLIP CHARACTERISTICS:

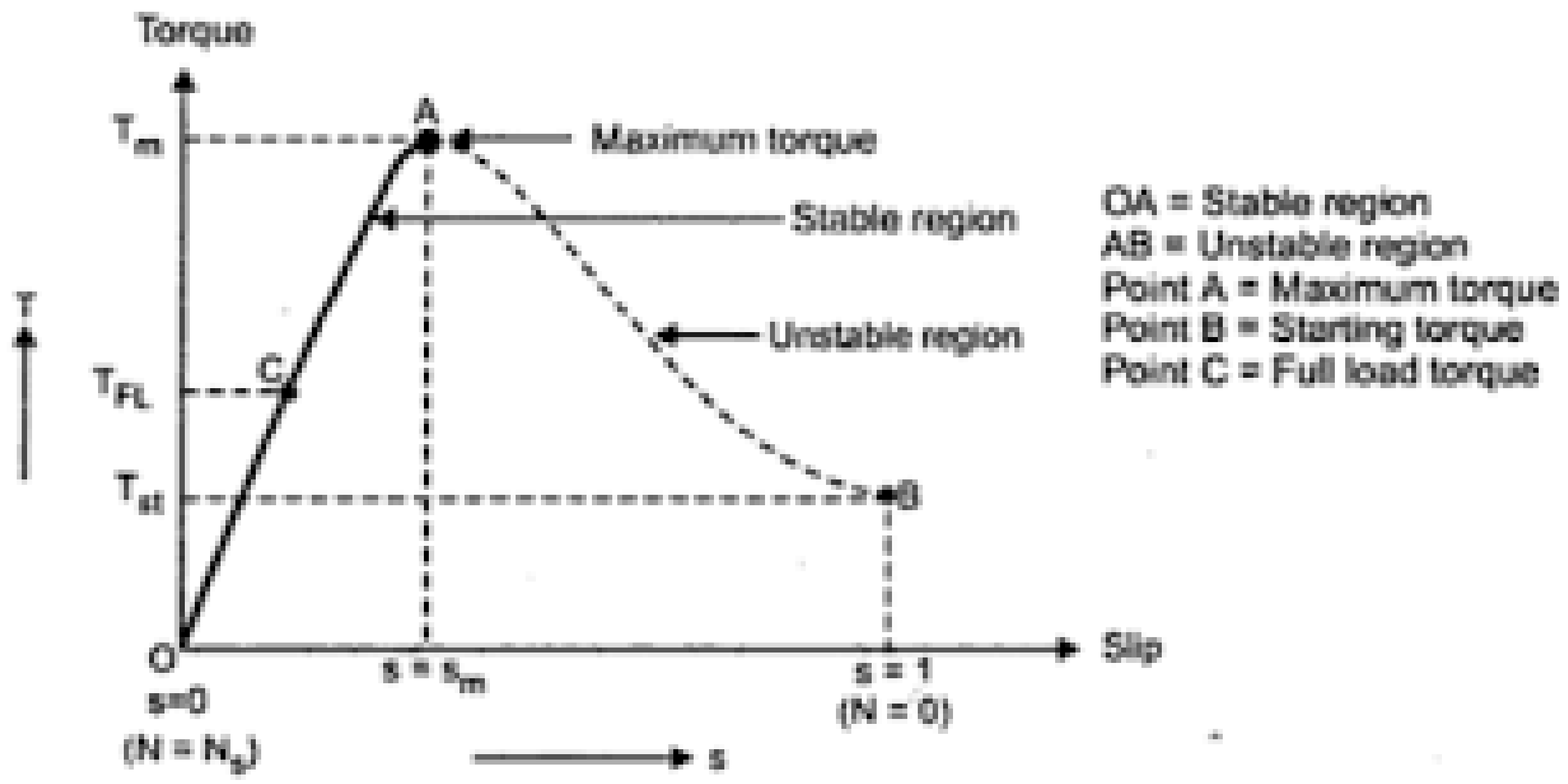


Fig 16: torque slip characteristics

OPERATION OF ALTERNATORS

- Similar to the case of DC generator, the behavior of a Synchronous generator connected to an external load is different than that at no-load. In order to understand the performance of the Synchronous generator when it is loaded, consider the flux distributions in the machine when the armature also carries a current. Unlike in the DC machine in alternators the emf peak and the current peak will not occur in the same coil due to the effect of the power factor of the load.
- The current and the induced emf will be at their peaks in the same coil only for UPF loads. For zero power factor lagging loads, the current reaches its peak in a coil which falls behind that coil wherein the induced emf is at its peak by 90 electrical degrees or half a pole-pitch.

OPERATION OF ALTERNATORS

- Likewise for zero power factor leading loads, the current reaches its peak in a coil which is ahead of that coil wherein the induced emf is at its peak by 90 electrical degrees or half a pole-pitch. For simplicity, assume the resistance and leakage reactance of the stator windings to be negligible.
- Also assume the magnetic circuit to be linear i.e. the flux in the magnetic circuit is deemed to be proportional to the resultant ampere-turns - in other words the machine is operating in the linear portion of the magnetization characteristics. Thus the emf induced is the same as the terminal voltage, and the phase-angle between current and emf is determined only by the power factor (pf) of the external load connected to the synchronous generator.

PRINCIPLE OF ALTERNATOR

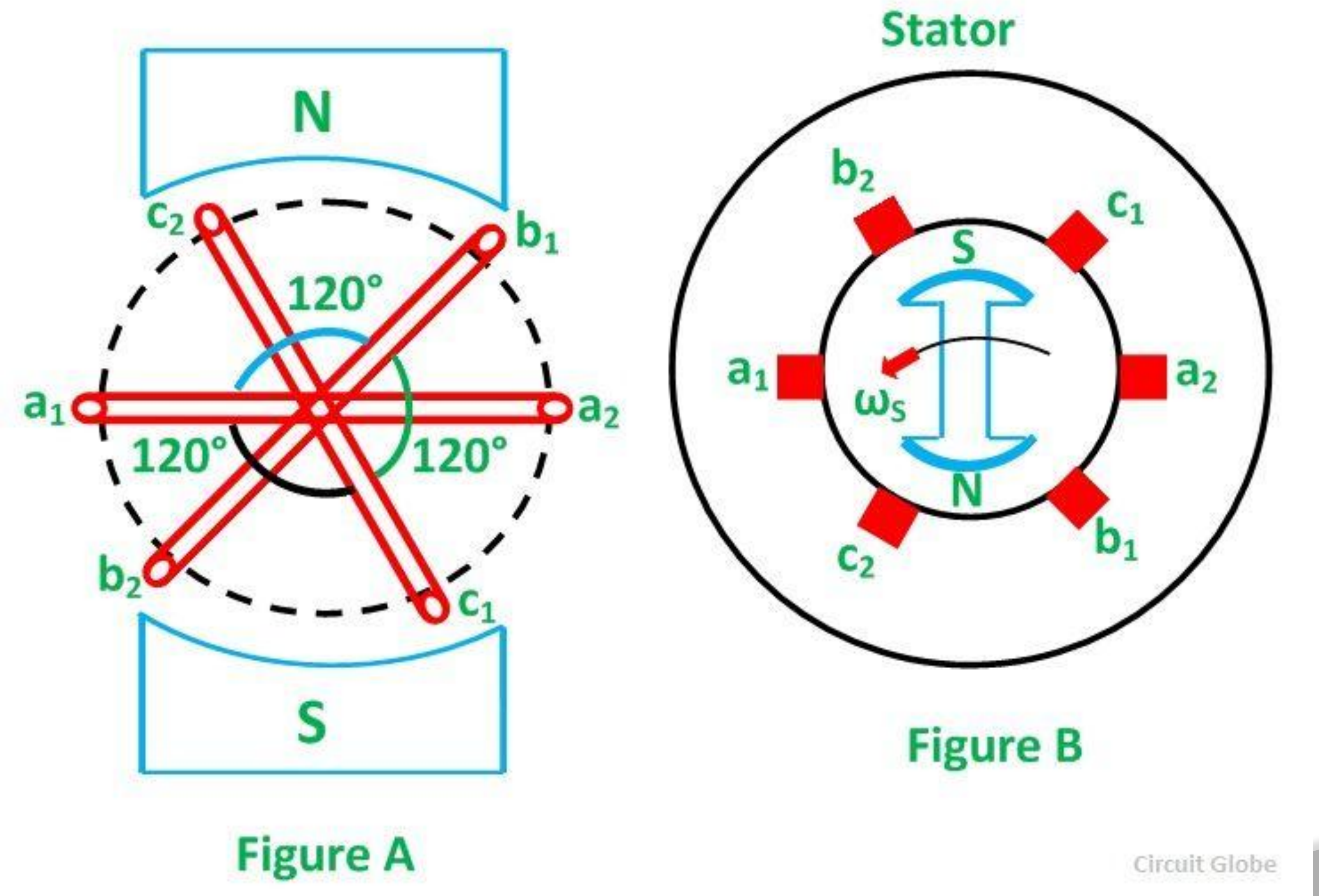


Fig 15: Principle of alternator

PRINCIPLE OF ALTERNATOR

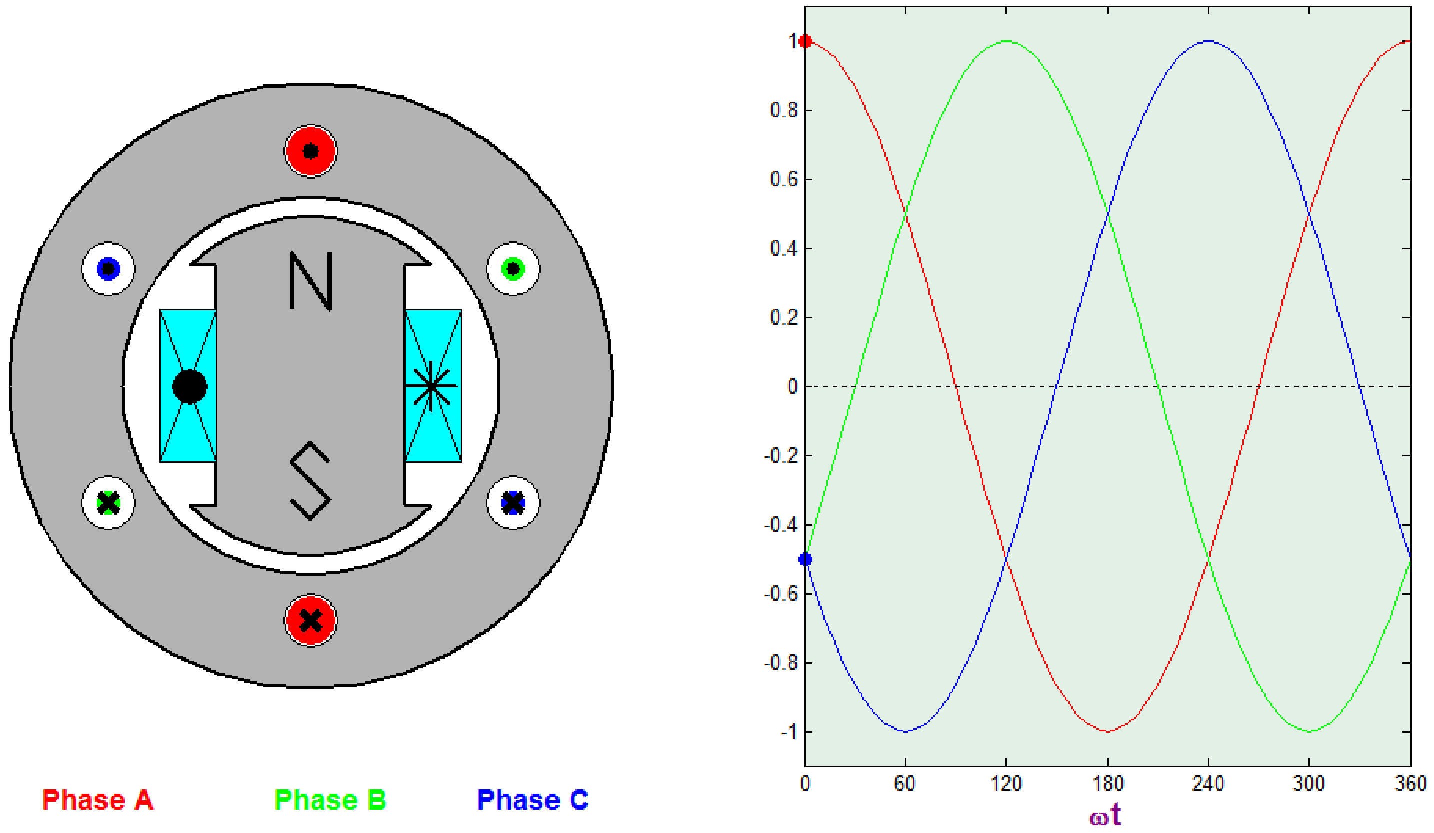


Fig 16: Principle of alternator

TYPES OF SYNCHRONOUS MACHINES

- According to the arrangement of armature and field winding, the synchronous machines are classified as rotating armature type or rotating field type.
- In rotating armature type the armature winding is on the rotor and the field winding is on the stator. The generated emf or current is brought to the load via the slip rings. These type of generators are built only in small units.
- In case of rotating field type generators field windings are on the rotor and the armature windings are on the stator. Here the field current is supplied through a pair of slip rings and the induced emf or current is supplied to the load via the stationary terminals.

TYPES OF SYNCHRONOUS MACHINES

- Based on the type of the prime movers employed the synchronous generators are classified as
- Hydrogenerators : The generators which are driven by hydraulic turbines are called hydrogenerators. These are run at lower speeds less than 1000 rpm.
- Turbogenerators: These are the generators driven by steam turbines. These generators are run at very high speed of 1500rpm or above.
- Engine driven Generators: These are driven by IC engines.
- These are run at a speed less than 1500 rpm.

CONSTRUCTION OF SYNCHRONOUS MACHINES

- **Salient pole Machines:** These type of machines have salient pole or projecting poles with concentrated field windings. This type of construction is for the machines which are driven by hydraulic turbines or Diesel engines.
- **Non salient pole or cylindrical rotor or Round rotor Machines:** These machines are having cylindrical smooth rotor construction with distributed field winding in slots. This type of rotor construction is employed for the machine driven by steam turbines.

Stator core:

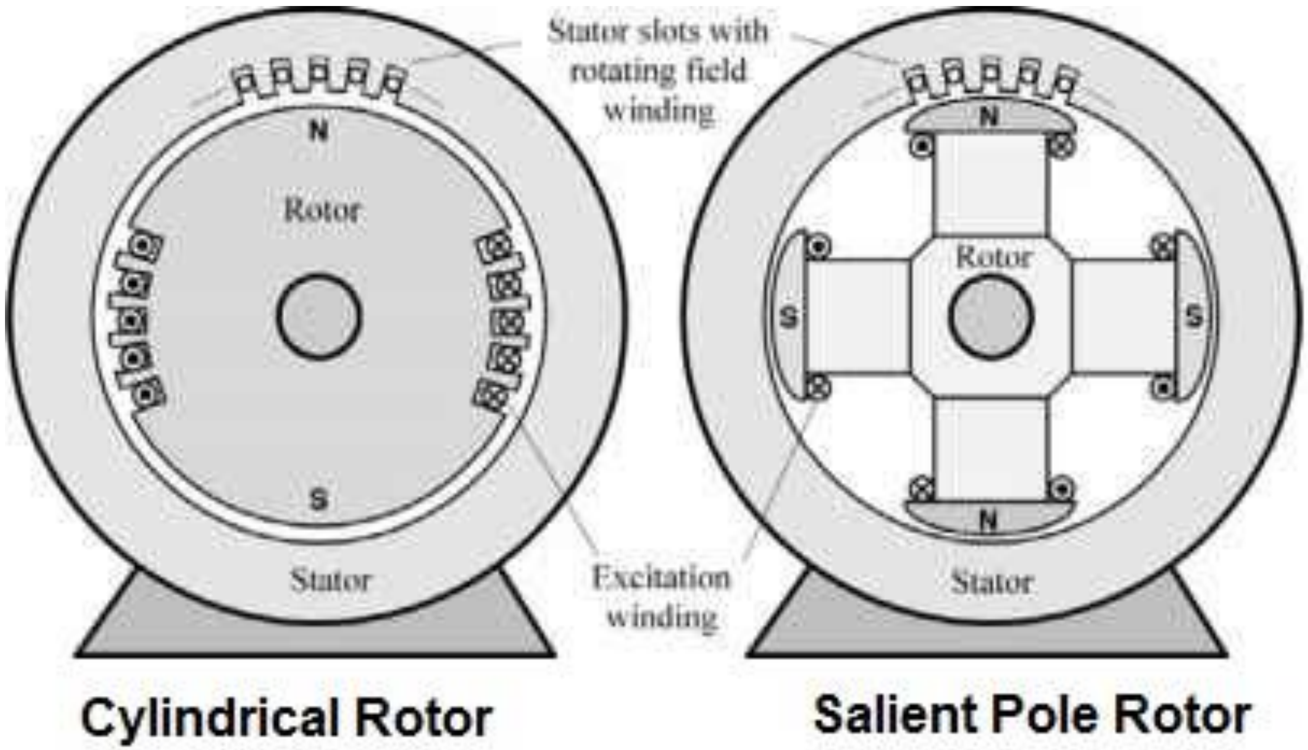


Fig 17: Types of synchronous motor

PITCH FACTOR

In short pitched coil, the induced emf of two coil sides get vectorially added and give resultant emf of the loop. In short pitched coil, the phase angle between the induced emf of two opposite coil sides is less than 180o (electrical). But we know that, in full pitched coil, the phase angle between the induced emf of two coil sides is exactly 180o (electrical). The pitch factor is the measure of resultant emf of a short-pitched coil in comparison with resultant emf of a full pitched coil.

$$K_p = \frac{Resultant\ emf\ of\ short\ pitched\ coil}{Resultant\ emf\ of\ full\ pitched\ coil}$$

$$= \frac{Phasor\ sum\ of\ coil\ side\ emfs}{Arithmetic\ sum\ of\ coil\ side\ emfs}$$

$$= \frac{2E\cos\frac{\alpha}{2}}{2E} = \cos\frac{\alpha}{2}$$

DISTRIBUTION FACTOR

- As per definition, distribution factor is a measure of resultant emf of a distributed winding in compared to a concentrated winding.
- We express it as the ratio of the phasor sum of the emfs induced in all the coils distributed in some slots under one pole to the arithmetic sum of the emfs induced. Distribution factor is,

$$k_d = \frac{EMF\ induced\ in\ distributed\ winding}{EMF\ induced\ if\ the\ winding\ would\ have\ been\ concentrated}$$

$$= \frac{Phasor\ sum\ of\ component\ emfs}{Arithmetic\ sum\ of\ component\ emfs}$$

$$E_R = AB = 2 \times OA \sin\frac{\angle AOB}{2} = 2 \times OA \sin\frac{m\beta}{2}$$

$$Therefore,\ Distribution\ Factor$$

$$K_d = \frac{Phasor\ sum\ of\ component\ emfs}{Arithmetic\ sum\ of\ component\ emfs}$$

$$= \frac{2 \times OA \sin\frac{m\beta}{2}}{m \times 2 \times OA \sin\frac{\beta}{2}} = \frac{\sin\frac{m\beta}{2}}{m \sin\frac{\beta}{2}}$$

EMF EQUATION

Let Φ = Flux per pole, in Wb

P = Number of poles

N_s = Synchronous speed in r.p.m.

f = Frequency of induced e.m.f. in Hz

Z = Total number of conductors

Z_{ph} = Conductors per phase connected in series

$\therefore$ $Z_{ph} = Z/3$ as number of phases = 3.

Consider a single conductor placed in a slot.

The average value of e.m.f. induced in a conductor

$= d\Phi/dt$

For one revolution of a conductor,

e_{avg} per conductor = (Flux cut in one revolution)/(time taken for one revolution)

Total flux cut in one revolution is $\Phi \times P$

Time taken for one revolution is $60/N_s$ seconds.

EMF EQUATION

∴ e_{avg} per conductor = $\Phi P / (60/N_s)$

$= \Phi (PN_s/60)$ .... (1)

But $f = PN_s/6120$

∴ $PN_s/60 = 2f$

Substation in (1),

e_{avg} per conductor = $2 f \Phi$ volts

Assume full pitch winding for simplicity i.e. this conductor is connected to a conductor which is 180^o electrical apart. So there two e.m.f.s will try to set up a current in the same direction i.e. the two e.m.f. are helping each other and hence resultant e.m.f. per turn will be twice the e.m.f. induced in a conductor.

∴ e.m.f. per turn = 2 x (e.m.f. per conductor) = $2 \times (2 f \Phi) = 4 f \Phi$ V

EMF EQUATION

Let T_{ph} be the total number of turn per phase connected in series. Assuming concentrated winding, we can say that all are placed in single slot per pole per phase. So induced e.m.f.s in all turns will be in phase as placed in single slot. Hence net e.m.f. per phase will be algebraic sum of the e.m.f.s per turn.

∴ Average E_{ph} = T_{ph} x (Average e.m.f. per turn)

∴ Average Eph = T_{ph} x 4 f Φ

But in a.c. circuits R.M.S. value of an alternating quantity is used for the analysis. The form factor is 1.11 of sinusoidal e.m.f.

K_f = (R.M.S.)/Average = 1.11 .... for sinusoidal

∴ R.M.S. value of E_{ph} = K x Average value

$E = 4.44 \times f \, \Phi \, T_{ph}$ volts

EMF EQUATION

Considering full pitch, concentrated winding.

$$E_{ph} = 4.44\ f\ \Phi\ T_{ph} \quad \text{Volts.}$$

But due to short pitch, distributed winding used in practice, this will reduce by factors and . So generlised expression for e.m.f. equation can be written as

$$E_{ph} = 4.44\ K_c\ K_d\ f\ \Phi\ T_{ph} \quad \text{Volts}$$

For full pitch coil, $K_c = 1$.

For concentrated winding $K_d = 1$.

Note : For short pitch and distributed winding K_c and K_d are always less than unity.

VOLTAGE REGULATION

- Voltage regulation of an alternator is defined as the change in terminal voltage from no load to full load expressed as a percentage of rated voltage when the load at a given power factor is removed with out change in speed and excitation.

$$\% \text{ Regulation} = (E_{ph} - V_{ph} / V_{ph}) \times 100$$

where E_{ph} = induced EMF /phase, V_{ph} = rated terminal voltage/phase

different methods used for predetermination of regulation of alternators.

- Direct loading method
- EMF method or Synchronous impedance method
- MMF method or Ampere turns method
- ASA modified MMF method
- ZPF method or Potier triangle method

EMF METHOD

- This method is also known as synchronous impedance method. Here the magnetic circuit is assumed to be unsaturated. In this method the MMFs (fluxes) produced by rotor and stator are replaced by their equivalent EMF, and hence called EMF method.
- To predetermine the regulation by this method the following information's are to be determined. Armature resistance /phase of the alternator, open circuit and short circuit characteristics of the alternator.

OC & SC TEST ON ALTERNATOR

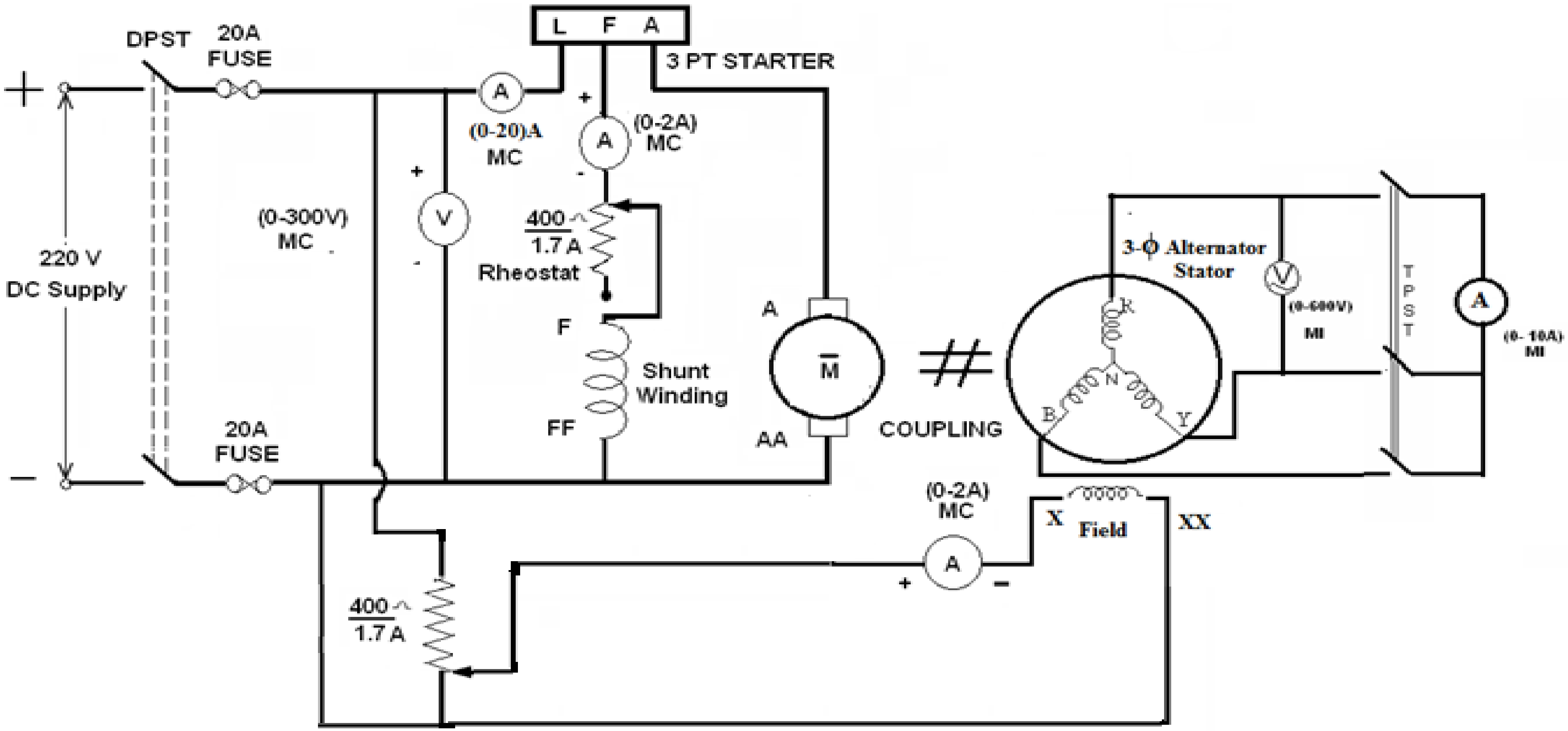


Fig 17: OC and SC test on alternator

OC & SC TEST ON ALTERNATOR

Procedure to conduct OC test:

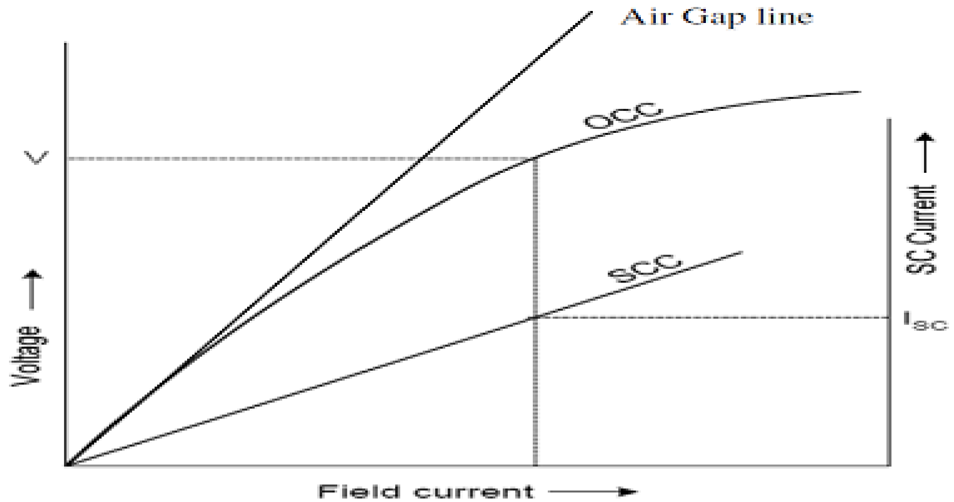
- Start the prime mover and adjust the speed to the synchronous speed of the alternator.
- Keep the field circuit rheostat in cut in position and switch on DC supply.
- Keep the TPST switch of the stator circuit in open position.
- Vary the field current from minimum in steps and take the readings of field current and stator terminal voltage, till the voltage read by the voltmeter reaches up to 110% of rated voltage. Reduce the field current and stop the machine.
- Plot of terminal voltage/ phase vs field current gives the OC curve.

OC & SC TEST ON ALTERNATOR

Short Circuit Characteristic (S.C.C.):

- The short-circuit characteristic, as its name implies, refers to the behavior of the alternator when its armature is short-circuited. In a single-phase machine the armature terminals are short-circuited through an ammeter, but in a three-phase machine all three phases must be short-circuited. An ammeter is connected in series with each armature terminal, the three remaining ammeter terminals being short-circuited. The machine is run at rated speed and field current is increased gradually to I_{f2} till armature current reaches rated value. The armature short-circuit current and the field current are found to be proportional to each other over a wide range

OC & SC TEST ON ALTERNATOR



Short-Circuit Ratio:

The short-circuit ratio is defined as the ratio of the field current required to produce rated volts on open circuit to field current required to circulate full-load current with the armature short-circuited.

Short-circuit ratio = I_{f1}/I_{f2}

DETERMINATION OF SYNCHRONOUS IMPEDANCE

- Synchronous impedance Z_s = (open circuit voltage per phase)/(short circuit current per phase) $_{\text{for same}}$ I_f
- Hence $Z_s = (V_{oc}) / (I_{sc})$ $_{\text{for same}}$ I_f
- From figure 33 synchronous impedance $Z_s = V/I_{sc}$
- Armature resistance R_a of the stator can be measured using Voltmeter – Ammeter method. Using synchronous impedance and armature resistance synchronous reactance and hence regulation can be calculated as follows using EMF method
- $Z_s = \sqrt{(R_a)^2 + (X_S)^2}$ and Synchronous reactance $X_s = \sqrt{(Z_S)^2 - (R_a)^2}$

Hence induced EMF per phase can be found as

$E_{ph} = \sqrt{[(V\cos + IR_a)^2 + (V\sin \pm IX_S)^2]}$

where V = phase voltage per phase = V_{ph} , I = load current per phase

OC & SC TEST ON ALTERNATOR

- In the above expression in second term + sign is for lagging pwer factor ans – sign is for leading power factor.
- % Regulation = [(E_{ph} – V_{ph} / V_{ph})] x 100
- Where E_{ph} = induced EMF /phase, V_{ph} = rated terminal voltage/phase
- Synchronous impedance method is easy but it gives approximate results. This method gives the value of regulation which is greater (poor) than the actual value and hence this method is called pessimistic method. The complete phasor diagram for the EMF method is shown in figure

MODULE – IV

SEMICONDUCTOR DIODE AND APPLICATIONS

MODULE - IV

CLOs	Course Learning Outcome
CLO 15	Understand the working of semi-conductor diode and its V-I characteristics.
CLO 16	Discuss the operation of half wave, full wave and bridge rectifiers.
CLO 17	Summarize various alternating quantities of half wave, full wave and bridge rectifiers.
CLO 18	Apply the concept of diodes in converting AC to DC rectification process.
CLO 19	Compare the operation of half wave, full wave and bridge rectifiers.

P-N JUNCTION DIODE

- The semiconductor diode is widely used within the electronics and semiconductor industry.
- It is used in its own right, and as a PN junction it is a critical element in transistors and many other semiconductor devices.
- However as a discrete component it is also a key part of many electronic circuits, being used in its own right.
- Diodes can be manufactured for a whole variety of applications from very low power signal applications right up to power rectification and the like. The technologies use may also differ and as a result there are many different types of diodes, both in ratings and the functions for which they are intended.
- In most cases the basic format for the diode is much the same. The diode contains a PN junction which provides the basic functionality for the device.

P-N JUNCTION DIODE

- applies to virtually any form of semiconductor diode.
- These diodes rely on the properties of semiconductors for their operation.
- Using semiconductor technology, the PN junction diode gains its name from the fact that it is formed from a semiconductor PN junction and by its nature it only allows current to flow in one direction. However the PN junction diode also has other properties that can be used in many other applications. These range from light emission to light detection and variable capacitance to voltage regulation.

P-N JUNCTION DIODE

- The theory behind semiconductor diodes uses the basic semiconductor ideas and applies them to a junction between the two types of semiconductor, p-type where the charge carriers are formed by holes and n-type where the charge carriers are electrons.
- The basic form of PN junction finds many uses in electronics circuits. The standard PN junction diodes are available in a variety of forms. They are mainly manufactured from silicon, although germanium diodes are also available. PN junction diodes can also be manufactured from other semiconductor materials, but these are generally specialised diodes used for particular applications.

DIODE

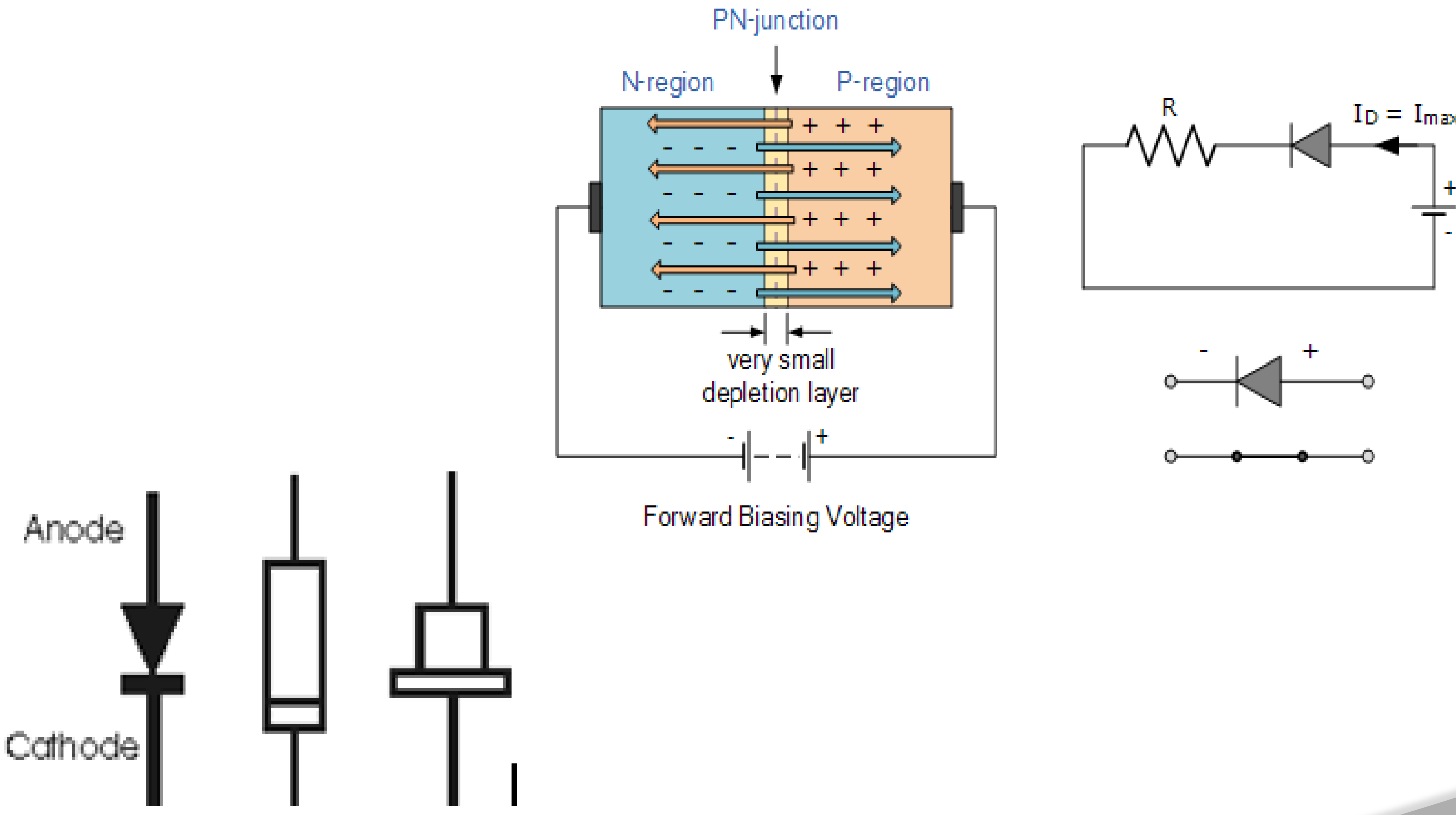


Fig 1: symbol and operation of PN junction diode

JUNCTION DIODE SYMBOL AND STATIC I-V CHARACTERISTICS

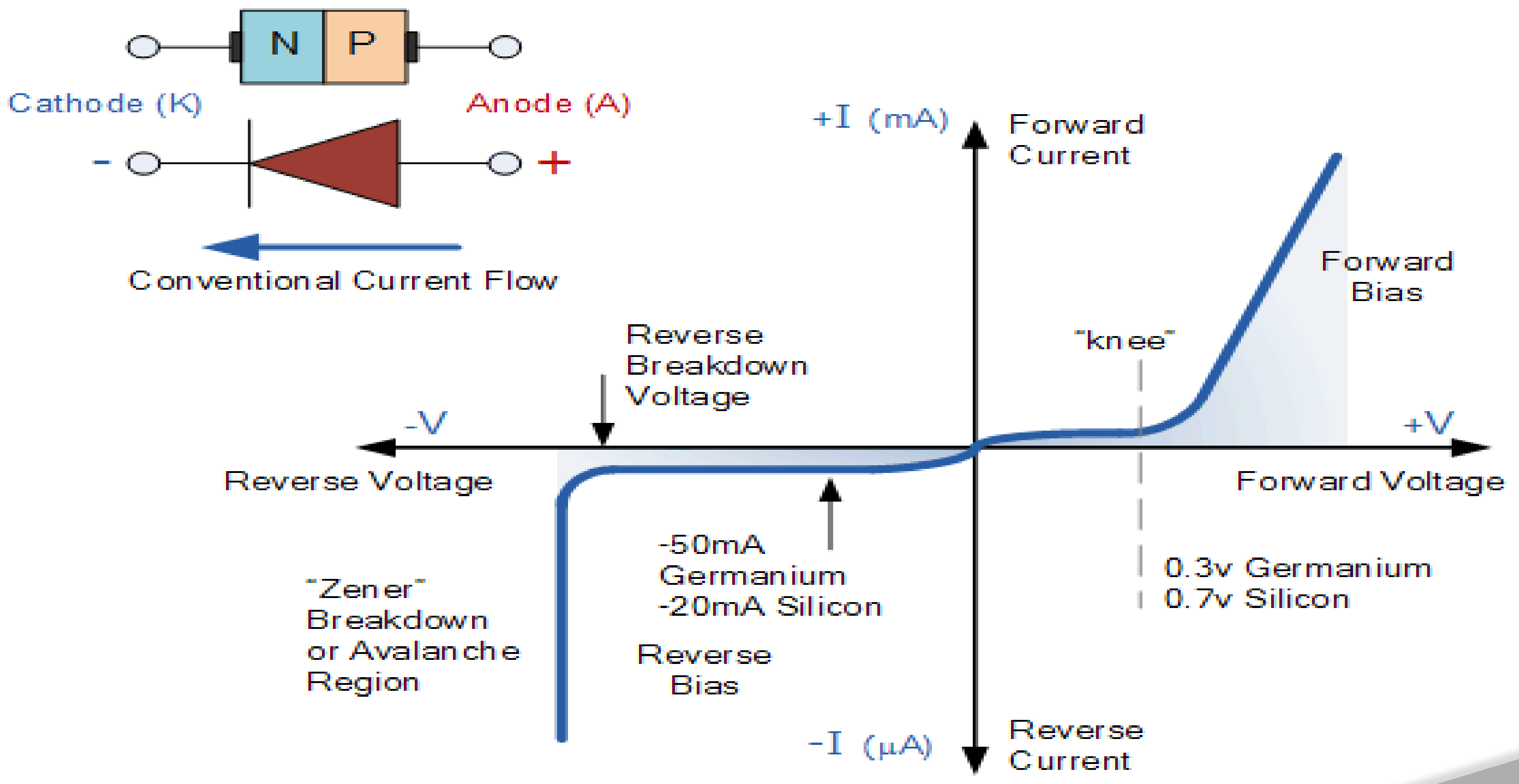


Fig 2: characteristics of PN junction diode

FORWARD BIASED PN JUNCTION DIODE

- When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.

JUNCTION DIODE SUMMARY

- Semiconductors contain two types of mobile charge carriers, “Holes” and “Electrons”.
- The holes are positively charged while the electrons negatively charged.
- A semiconductor may be doped with donor impurities such as Antimony (N-type doping), so that it contains mobile charges which are primarily electrons.
- A semiconductor may be doped with acceptor impurities such as Boron (P-type doping), so that it contains mobile charges which are mainly holes.
- The junction region itself has no charge carriers and is known as the depletion region.
- The junction (depletion) region has a physical thickness that varies with the applied voltage.
- When a diode is **Zero Biased** no external energy source is applied and a natural **Potential Barrier** is developed across a depletion layer which is approximately 0.5 to 0.7v for silicon diodes and approximately 0.3 of a volt for germanium diodes.
- When a junction diode is **Forward Biased** the thickness of the depletion region reduces and the diode acts like a short circuit allowing full current to flow.
- When a junction diode is **Reverse Biased** the thickness of the depletion region increases and the diode acts like an open circuit blocking any current flow, (only a very small leakage current).

INTRODUCTION

- Rectifier is an electronic device with covert the alternating current to unidirectional current, in other words rectifier converts the A.C voltage to D.C voltage. Rectifier is classified according to the period of conduction they are
  1. Half wave rectifier
  2. Full wave rectifier
- We use rectifier in almost all the electronic devices mostly in the power supply section to convert the main
- voltage into DC voltage. Every electronic device will work on the DC voltage supply only. In this session we
- will see about the working of half wave rectifier and its applications.

HALF WAVE RECTIFIER

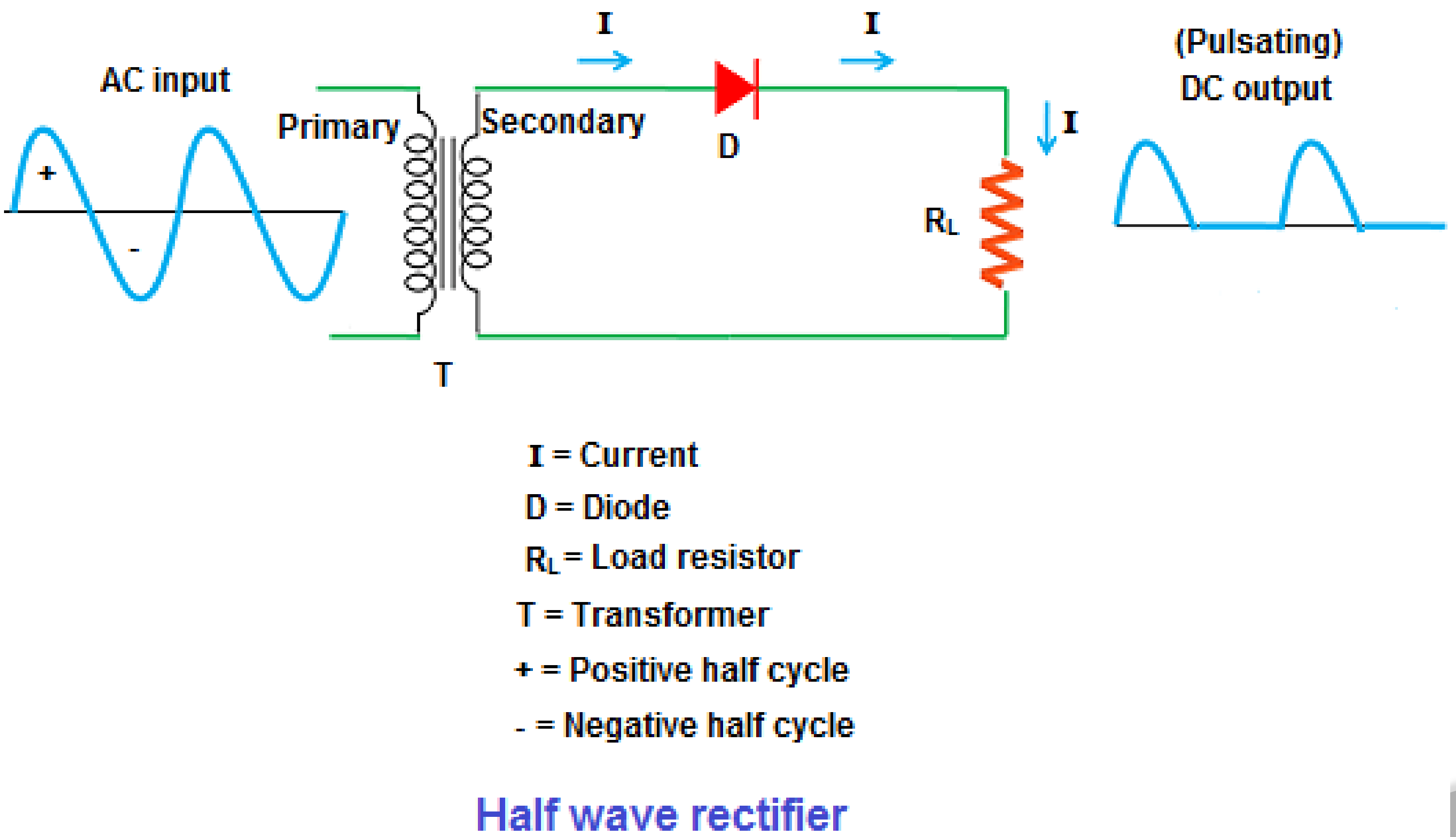


Fig 3: operation of half wave rectifier

POSITIVE HALF CYCLE

- In the positive half cycles when the input AC power is given to the primary winding of the step down transformer, we will get the decreased voltage at the secondary winding which is given to the diode.
- The diode will allow current flowing in clock wise direction from anode to cathode in the forward bias (diode conduction will take place in forward bias) which will generate only the positive half cycle of the AC.
- The diode will eliminate the variations in the supply and give the pulsating DC voltage to the load resistance RL. We can get the pulsating DC at the Load resistance.

NEGATIVE HALF CYCLE

- In the negative half cycle the current will flow in the anti-clockwise direction and the diode will go in to the reverse bias. In the reverse bias the diode will not conduct so, no current in flown from anode to cathode, and we cannot get any power at the load resistance.
- Only small amount of reverse current is flown from the diode but this current is almost negligible. And voltage across the load resistance is also zero.

HALF WAVE RECTIFIER

- The ratio of DC power output to the applied input AC power is known as **rectifier efficiency**. Mathematically it can be given as:
- **η = DC Power Output / AC power input**

FULL WAVE RECTIFIER

- The waveform diagram above shows only positive waveform at the output and suppressed or no negative waveform. During conduction period its instantaneous value is given by the equation:

  $\mathbf{i = v / (r_f + R_L)}$

  As we know,

  $v = V_m \sin \theta$

  Therefore,

  $i = V_m \sin \theta / (r_f + R_L)$

  When **$\sin \theta = 1$**, then **current = maximum**. Therefore,

  $I_m = V_m / (r_f + R_L)$

  Where,

  $i = I_m \sin \theta$

  remaining 9.4% is lost in the circuit.

HALF WAVE RECTIFIER

- Since output is obtained across R_L , therefore

  D.C power output = $I_{dc}^2 R_L$

  $= *I_{av}^2 R_L$

  Where,

  $I_{av} = \int (i\, d\theta) / 2\pi$ ..... (i)

  Integrate equation (i) from 0 to π,

  $I_{av} = (1 / 2\pi) * \int I_m \sin\theta\, d\theta$

  $= (I_m / 2\pi) * \int \sin\theta\, d\theta$

  $= (I_m / 2\pi) [- \cos\theta]$

  $= (I_m / 2\pi) [-(-1-1)]$

  $= 2 (I_m / 2\pi)$

  $= (I_m / \pi)$

HALF WAVE RECTIFIER

- Therefore, DC power output is given as,

  $$P_{dc} = I_{dc}^2 R_L = (I_m / \pi)^2 R_L$$

  And AC power input is given as,

  $$P_{ac} = I_{rms}^2 (r_f + R_L)$$

  Where,

  ** $I_{rms} = \int (i^2 d\theta) / 2\pi$ ..... (ii)

  Integrate equation (ii) from 0 to π,

  $= \sqrt{} (1 / 2\pi) * \int I_m^2 \sin^2 \theta \, d\theta$

  $= \sqrt{} (I_m^2 / 2\pi) * \int (1- \cos 2\theta)/ 2 \ d\theta$

  $= \sqrt{} (I_m^2 / 4\pi) * [\int d\theta - \int \cos 2\theta \, d\theta]$

  $= \sqrt{} (I_m^2 / 4\pi) * [[\theta] - [\sin 2\theta / 2]]$

  $= \sqrt{} (I_m^2 / 4\pi) * [\pi - 0]$

  $= I_m / 2$

HALF WAVE RECTIFIER

- Therefore, AC power input is given as,

  $\mathbf{P_{ac} = I_{rms}^2 (r_f + R_L)}$

  $=(I_m / 2)^2 (r_f + R_L)$

  As we know,

  Rectifier Efficiency (η) = $\mathbf{P_{dc} / P_{ac}}$

  Put the values of P_{dc} and P_{ac} from above equations, therefore,

  $\eta =[(I_m / \pi)^2 * R_L] / (I_m / 2)^2 * (r_f + R_L)$

  $= 0.406 R_L / (r_f + R_L)$

  $= 0.406 / (1+ r_f R_L)$

  If r_f is neglected as compare to R_L then the efficiency of the rectifier is maximum. Therefore,

  $\mathbf{\eta_{max} = 0.406 = 40.6\%}$

- This indicates that the half wave rectifier can convert maximum 40.6% of AC power into DC power, and the remaining power of 59.4% is lost in the rectifier circuit. In fact, 50% power in the negative half cycle is not converted and the

FULL WAVE RECTIFIER

- While this method may be suitable for low power applications it is unsuitable to applications which need a “steady and smooth” DC supply voltage. One method to improve on this is to use every half-cycle of the input voltage instead of every other half-cycle. The circuit which allows us to do this is called a **Full Wave Rectifier**.

FULL WAVE RECTIFIER

- The full wave rectifier circuit consists of two *power diodes* connected to a single load resistance (R_L) with each diode taking it in turn to supply current to the load. When point A of the transformer is positive with respect to point C, diode D_1 conducts in the forward direction as indicated by the arrows.

FULL WAVE RECTIFIER

- When point B is positive (in the negative half of the cycle) with respect to point C, diode D_2 conducts in the forward direction and the current flowing through resistor R is in the same direction for both half-cycles. As the output voltage across the resistor R is the phasor sum of the two waveforms combined, this type of full wave rectifier circuit is also known as a “bi-phase” circuit.

FULL WAVE RECTIFIER

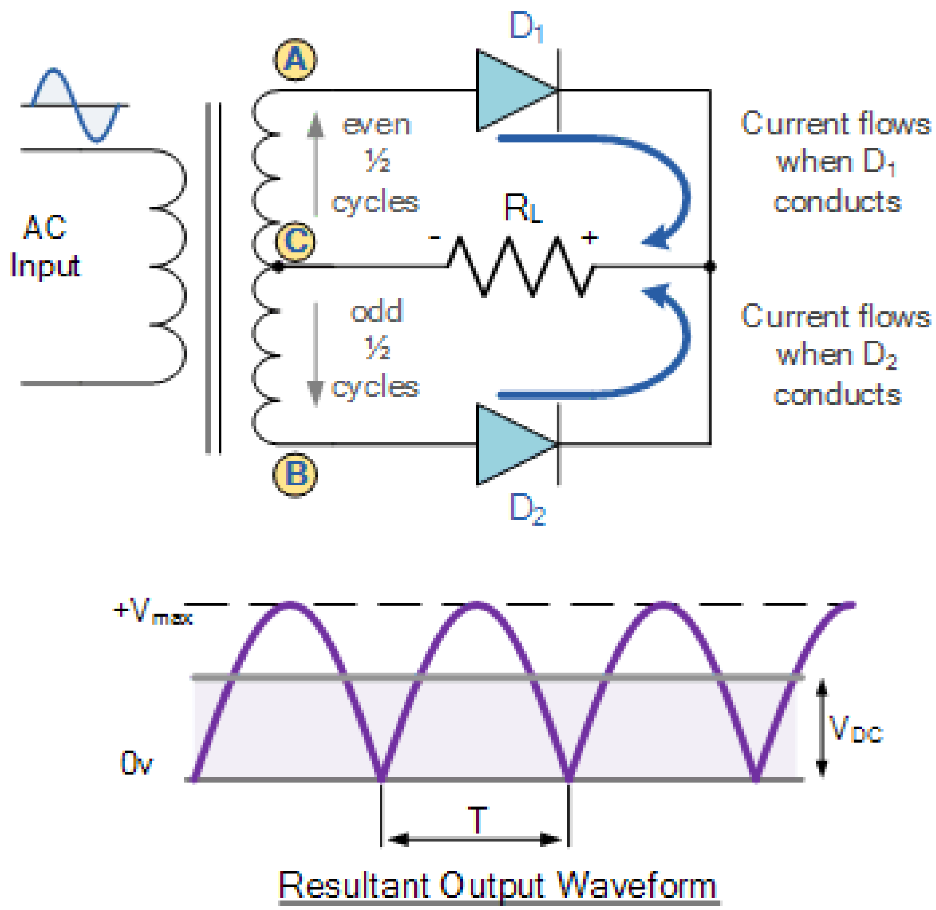


Fig 4: operation of full wave rectifier

FULL WAVE RECTIFIER

$I_{av} = \int (i\, d\theta) / \pi$ ..... (i)

Integrate equation (i) from 0 to π,

$I_{av} = (1 / \pi) * \int I_m \sin\theta\, d\theta$

$= (I_m / \pi) * \int \sin\theta\, d\theta$

$= (I_m / \pi) [- \cos\theta]$

$= (I_m / \pi) [-(-1-1)]$

$= 2 (I_m / \pi)$

$= (2I_m / \pi)$

FULL WAVE RECTIFIER

Therefore, DC power output is given as,

$P_{dc} = I_{dc}^2 R_L = (2I_m / \pi)^2 R_L$

And AC power input is given as,

$P_{ac} = I_{rms}^2 (r_f + R_L)$

Where,

** $I_{rms} = \sqrt{\int (i^2 d\theta) / \pi}$ ..... (ii)

$= \sqrt{(1 / \pi) * \int I_m^2 \sin^2 \theta \, d\theta}$

$= \sqrt{(I_m^2 / \pi) * \int (1 - \cos 2\theta)/ 2 \, d\theta}$

$= \sqrt{(I_m^2 / 2\pi) * [\int d\theta - \int \cos 2\theta \, d\theta]}$

$= \sqrt{(I_m^2 / 2\pi) * [[\theta] - [\sin 2\theta / 2]]}$

$= \sqrt{(I_m^2 / 2\pi) * [\pi - 0]}$

$= I_m / \sqrt{2}$

FULL WAVE RECTIFIER

Therefore, AC power input is given as,

$\mathbf{P_{ac} = I_{rms}^2 (r_f + R_L)}$

$= (I_m / \sqrt{2})^2 (r_f + R_L)$

As we know,

Rectifier Efficiency (η) = $\mathbf{P_{dc} / P_{ac}}$

Put the values of P_{dc} and P_{ac} from above equations, therefore,

$\eta = [(2I_m / \pi)^2 * R_L] / [(I_m / \sqrt{2})^2 * (r_f + R_L)]$

$= 0.812\, R_L / (r_f + R_L)$

$= 0.812 / (1 + r_f / R_L)$

If r_f is neglected as compared to R_L then the efficiency of the rectifier is maximum. Therefore,

$\mathbf{\eta_{max} = 0.812 = 81.2\%}$

- **Filters**

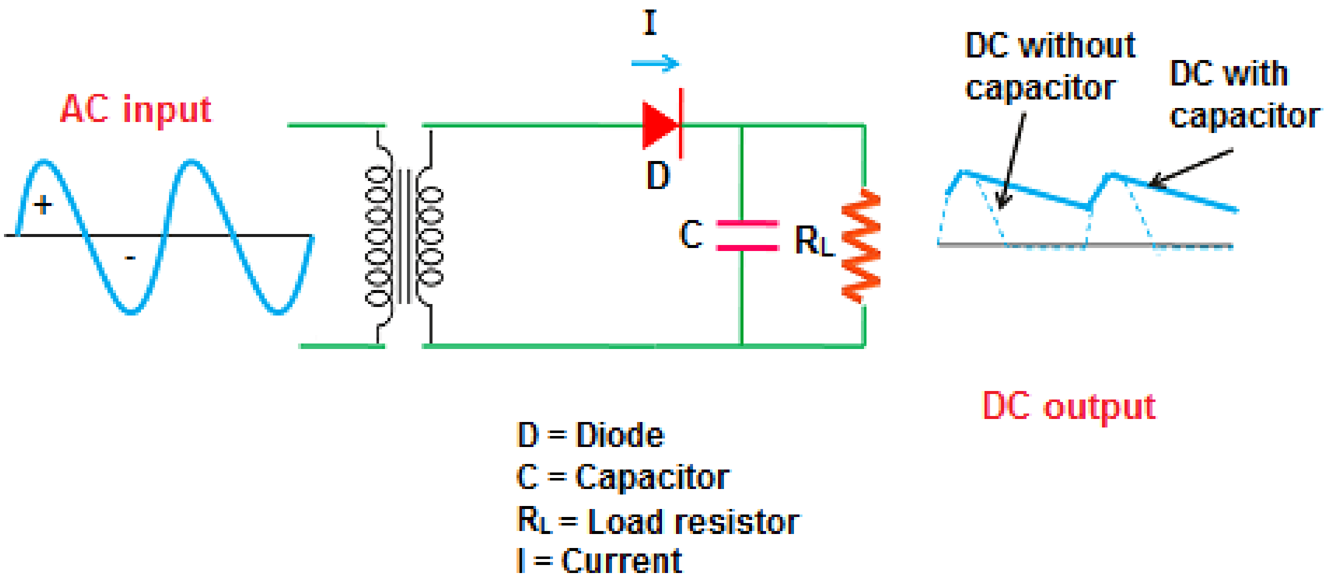
  The devices which converts the pulsating DC in to pure DC is called filter. As the name specifies it filters the oscillations in the signal and provides a pure DC at the output. The electronic reactive elements like capacitor and inductors are used to do this work

- **Inductive Filter (L)**

  The property of the inductor is that it opposes any sudden change that occurs in a circuit an provides a smoothed output. In the case of AC, there is change in the magnitude of current with time. So the inductor offers some impendence (opposing force) for AC ((XL = jwL) and offers shot circuit for DC. So by connecting inductor in series with the supply blocks AC and allows DC to pass.

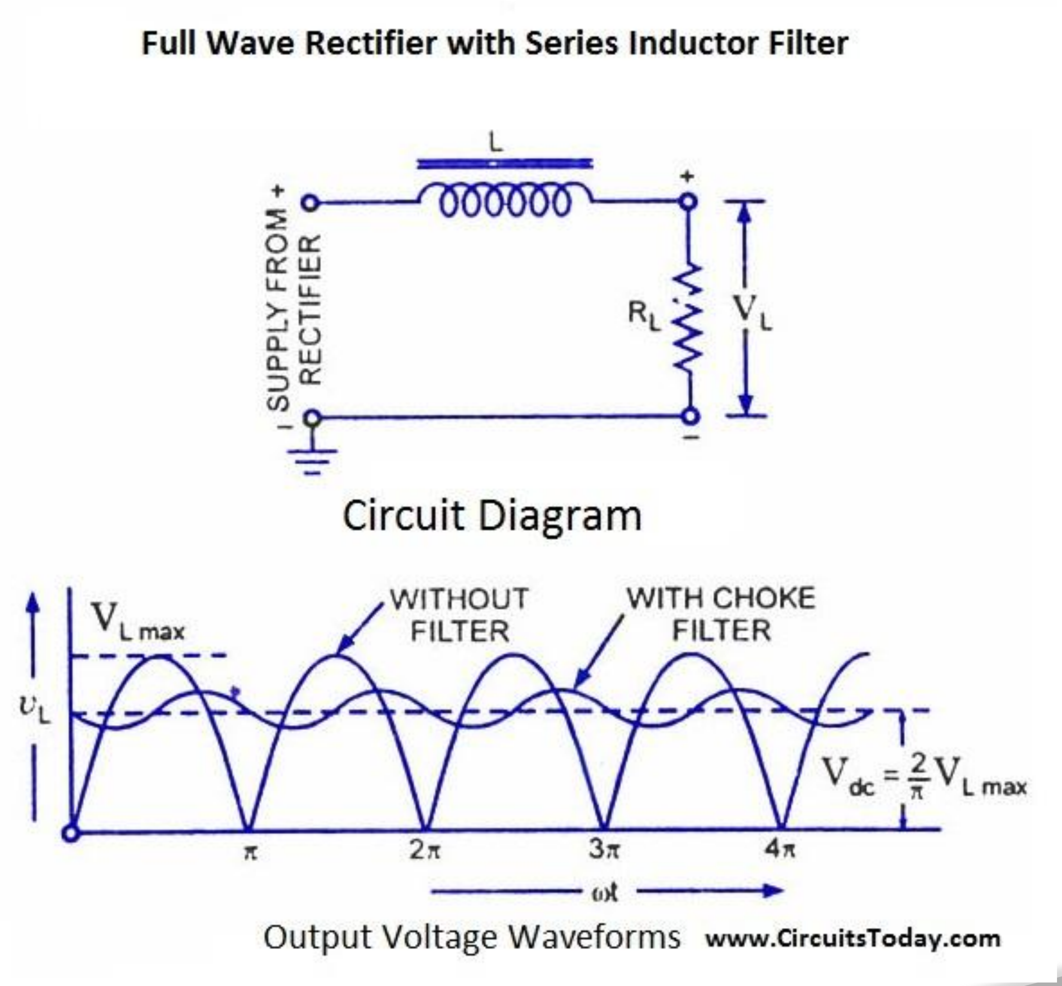
CAPACITOR FILTER

- The elegant quality of the capacitor is it stores the electrical energy for short time and discharges it. By controlling the charging and discharging rate of the capacitor the pure DC can be obtained from the pulsating DC. In simple the capacitor allows AC and blocks DC, so the capacitor can connect parallel to the power supply so that the AC is filtered out and DC will reach the load.



Half wave rectifier with capacitor filter

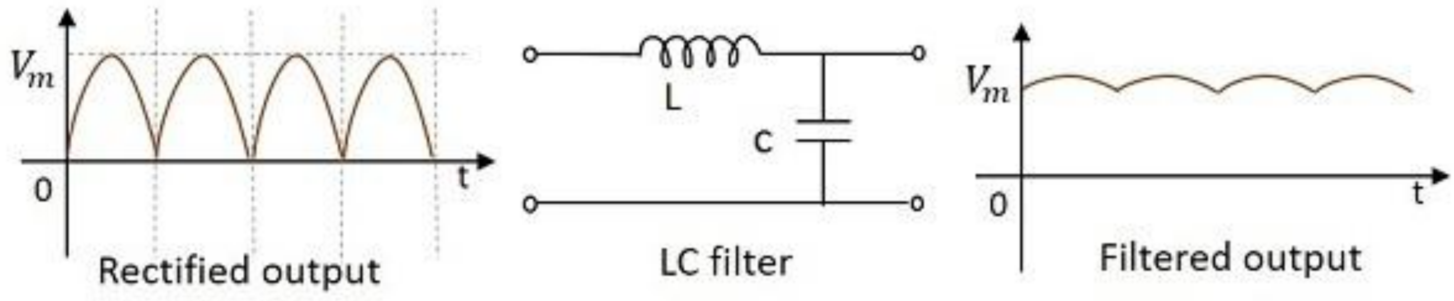
INDUCTOR FILTER

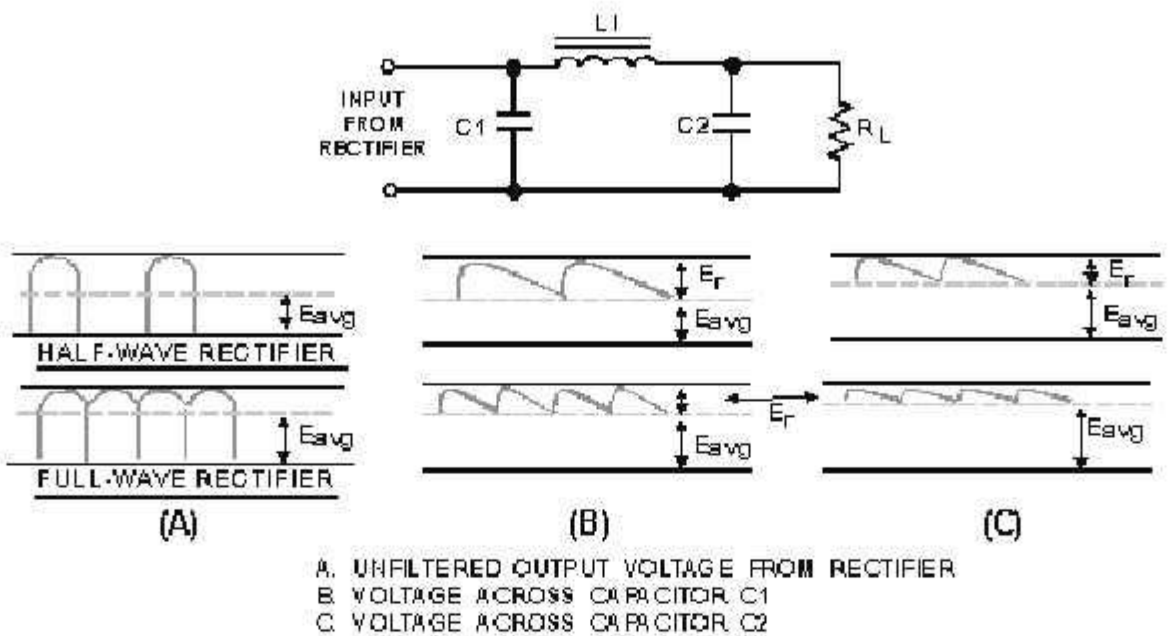


LC AND CLC FILTER

- In the above two filters the reactive components are singly connected, however no element will be perfect in doing the job i.e. inductor in series may pass small quantity of AC and Capacitor in parallel may not block all the AC component. So for better filtering two components are connected as filter which provides less ripple factor at the output compared to the above filter.
- In L and LC filter the inductor connected in series to the power supply drops more AC voltage which reduces the efficiency. So to avoid this increase the efficiency a capacitor is connected at the input of the LC filter. The input capacitor charges & discharges and provides a ripple DC at the input of inductor. Then the drop at the inductor is less and provides a ripple less DC which again filtered by capacitor at the output.

CLC OR Π FILTER





ZENER DIODE

The special property of the diode is that there will be a breakdown in the circuit if the voltage applied across a reversely biased circuit. This does not allow the current to flow across it. When the voltage across the diode is increased, temperature also increases and the crystal ions vibrate with greater amplitude and all these leads to the breakdown of the depletion layer. The layer at the junction of ‘P’ type and ‘N’ type. When the applied voltage exceeds an specific amount Zener breakdown takes place.

VI CHARACTERISTICS OF ZENER DIODE

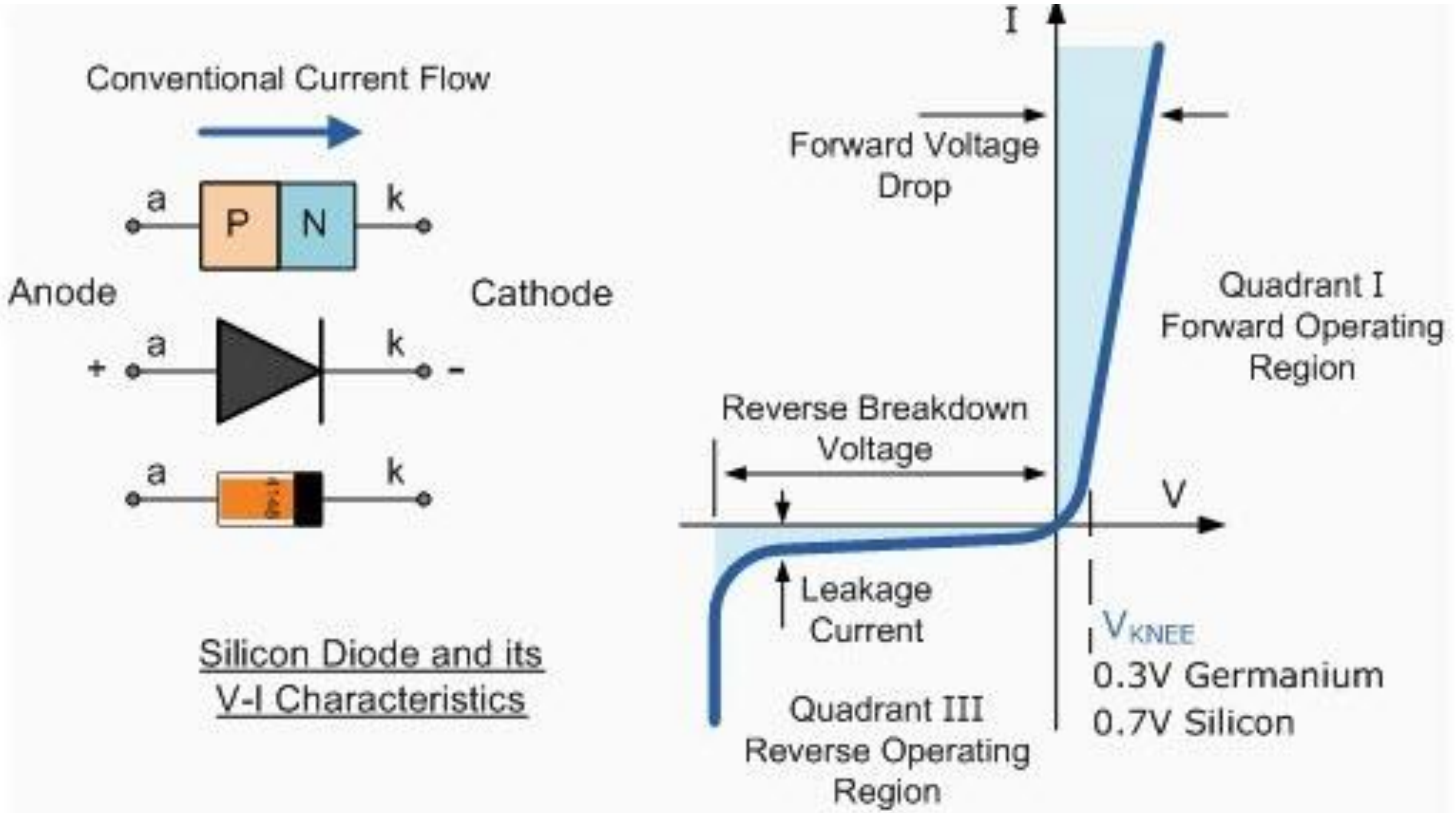


Fig 5: VI characteristics of Zener diode

VI CHARACTERISTICS OF ZENER DIODE

- When reverse biased voltage is applied to a zener diode, it allows only a small amount of leakage current until the voltage is less than zener voltage. When reverse biased voltage applied to the zener diode reaches zener voltage, it starts allowing large amount of electric current. At this point, a small increase in reverse voltage will rapidly increases the electric current. Because of this sudden rise in electric current, breakdown occurs called zener breakdown. However, zener diode exhibits a controlled breakdown that does damage the device.
- The zener breakdown voltage of the zener diode is depends on the amount of doping applied. If the diode is heavily doped, zener breakdown occurs at low reverse voltages. On the other hand, if the diode is lightly doped, the zener breakdown occurs at high reverse voltages. Zener diodes are available with zener voltages in the range of 1.8V to 400V.

APPLICATIONS OF ZENER DIODE

APPLICATIONS:

Zener diode is popularly used as Shunt Regulator or Voltage Regulator. As we have gone through the first part of the article we know what is Zener diode and what is the basic principle of operation. Here the question arises where this type of diodes can be useful. Main application of this type of diodes are as voltage regulator. Over voltage protector, as voltage reference.

ZENER DIODE AS VOLTAGE REGULATORS

- The function of a regulator is to provide a constant output voltage to a load connected in parallel with it in spite of the ripples in the supply voltage or the variation in the load current and the zener diode will continue to regulate the voltage until the diodes current falls below the minimum $I_{Z(min)}$ value in the reverse breakdown region. It permits current to flow in the forward direction as normal, but will also allow it to flow in the reverse direction when the voltage is above a certain value - the breakdown voltage known as the Zener voltage. The Zener diode specially made to have a reverse voltage breakdown at a specific voltage. Its characteristics are otherwise very similar to common diodes. In breakdown the voltage across the Zener diode is close to constant over a wide range of currents thus making it useful as a shunt voltage regulator.

ZENER DIODE SHUNT REGULATOR

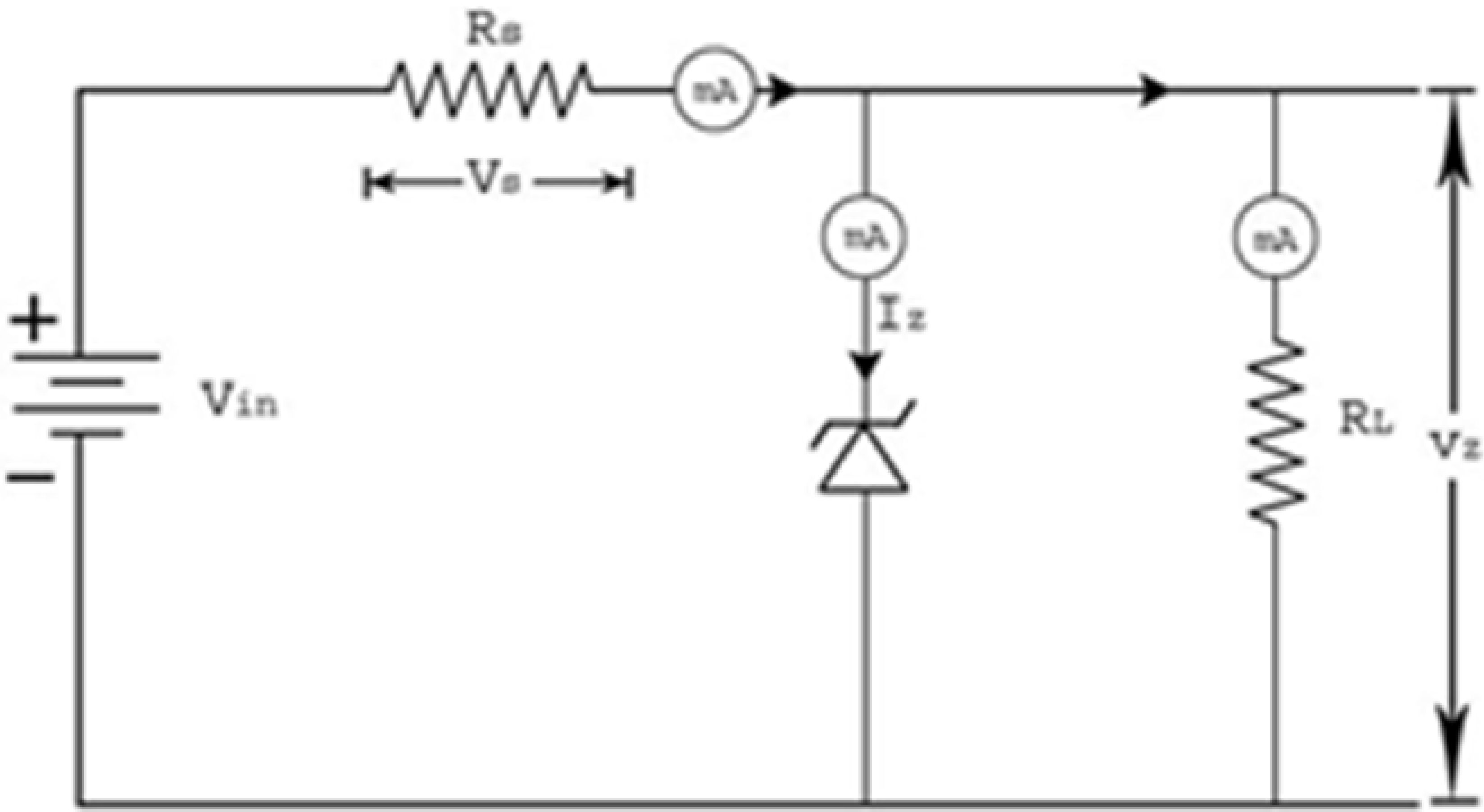


Fig 6: Zener diode as voltage regulator

ZENER DIODE SHUNT REGULATOR

$Is = I_z min + I_L max$

$I_z min$ = Please Refer Datasheet

$Vs = V_{in} min – Vz$

$R_s min = Vs/Is$

To find the value of $R_s$max we should consider the extreme condition that Vin is maximum and load current is minimum (ie, no load connected).

$Is = I_z max + I_L min$

$I_z max = Pmax/Vz$

$Vs = V_{in} max – Vz$

$R_s max = Vs/Is$

ZENER DIODE SHUNT REGULATOR

- The purpose of a voltage regulator is to maintain a constant voltage across a load regardless of variations in the applied input voltage and variations in the load current. A typical Zener diode shunt regulator is shown in Figure 3. The resistor is selected so that when the input voltage is at $V_{IN(min)}$ and the load current is at $I_{L(max)}$ that the current through the Zener diode is at least $I_{z(min)}$. Then for all other combinations of input voltage and load current the Zener diode conducts the excess current thus maintaining a constant voltage across the load. The Zener conducts the least current when the load current is the highest and it conducts the most current when the load current is the lowest.

MODULE-V

BIPOLAR JUNCTION TRANSISTOR AND APPLICATIONS

MODULE - V

CLOs	Course Learning Outcome
CLO 20	Distinguish the different configurations of transistor.
CLO 21	Differentiate the operation of Diodes and transistors.
CLO 22	Understand the concept of biasing and load line of transistor.

TRANSISTOR

- The transistor in which one p-type material is placed between two n-type materials is known as NPN transistor. The NPN transistor amplifies the weak signal enter into the base and produces strong amplify signals at the collector end. In NPN transistor, the direction of movement of an electron is from the emitter to collector region due to which the current constitutes in the transistor. Such type of transistor is mostly used in the circuit because their majority charge carriers are electrons which have high mobility as compared to holes.

NPN TRANSISTOR

- The forward biased is applied across the emitter-base junction, and the reversed biased is applied across the collector-base junction. The forward biased voltage V_{EB} is small as compared to the reverse bias voltage V_{CB}.
- The emitter of the NPN transistor is heavily doped. When the forward bias is applied across the emitter, the majority charge carriers move towards the base. This causes the emitter current I_E. The electrons enter into the P-type material and combine with the holes.
- The base of the NPN transistor is lightly doped. Due to which only a few electrons are combined and remaining constitutes the base current I_B. This base current enters into the collector region.

NPN TRANSISTOR

- The reversed bias potential of the collector region applies the high attractive force on the electrons reaching collector junction. Thus attract or collect the electrons at the collector.
- The whole of the emitter current is entered into the base. Thus, we can say that the emitter current is the sum of the collector or the base current.

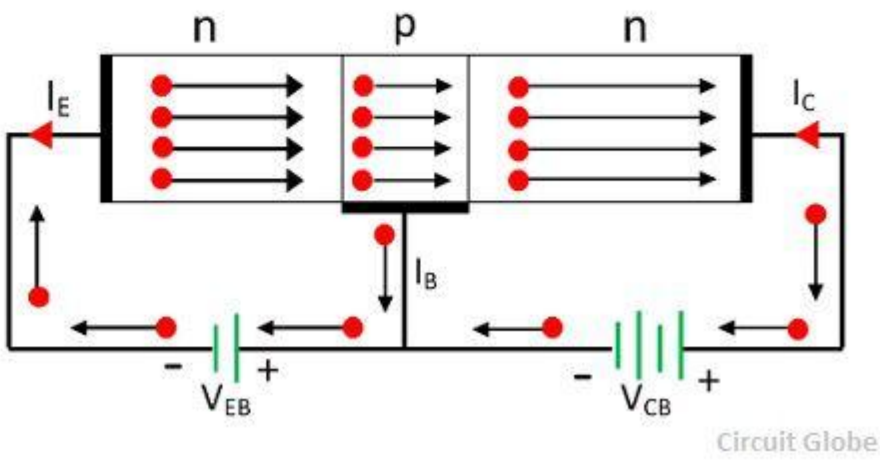


Fig 1: working of NPN transistor

PNP TRANSISTOR

- The emitter-base junction is connected in forward biased due to which the emitter pushes the holes in the base region. These holes constitute the emitter current. When these electrons move into the N-type semiconductor material or base, they combined with the electrons. The base of the transistor is thin and very lightly doped. Hence only a few holes combined with the electrons and the remaining are moved towards the collector space charge layer. Hence develops the base current.
- The collector base region is connected in reverse biased. The holes which collect around the depletion region when coming under the impact of negative polarity collected or attracted by the collector. This develops the collector current. The complete emitter current flows through the collector current I_C.

PNP TRANSISTOR

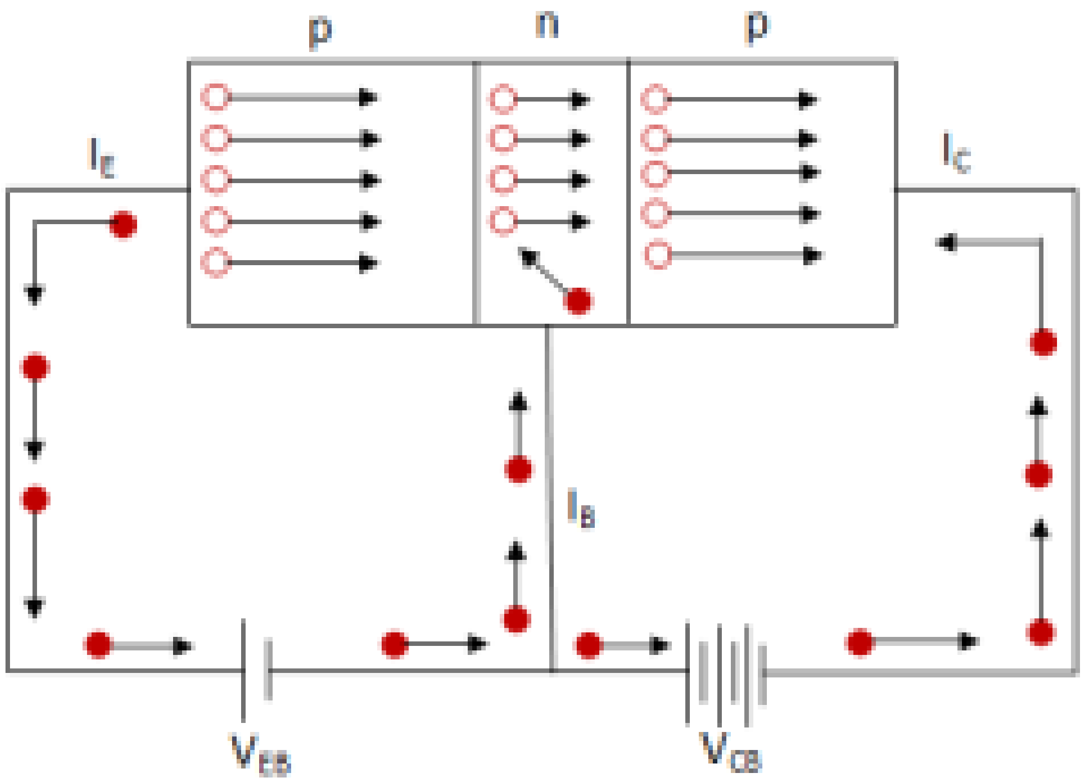


Fig 2: working of PNP transistor

TRANSISTOR CURRENT COMPONENTS

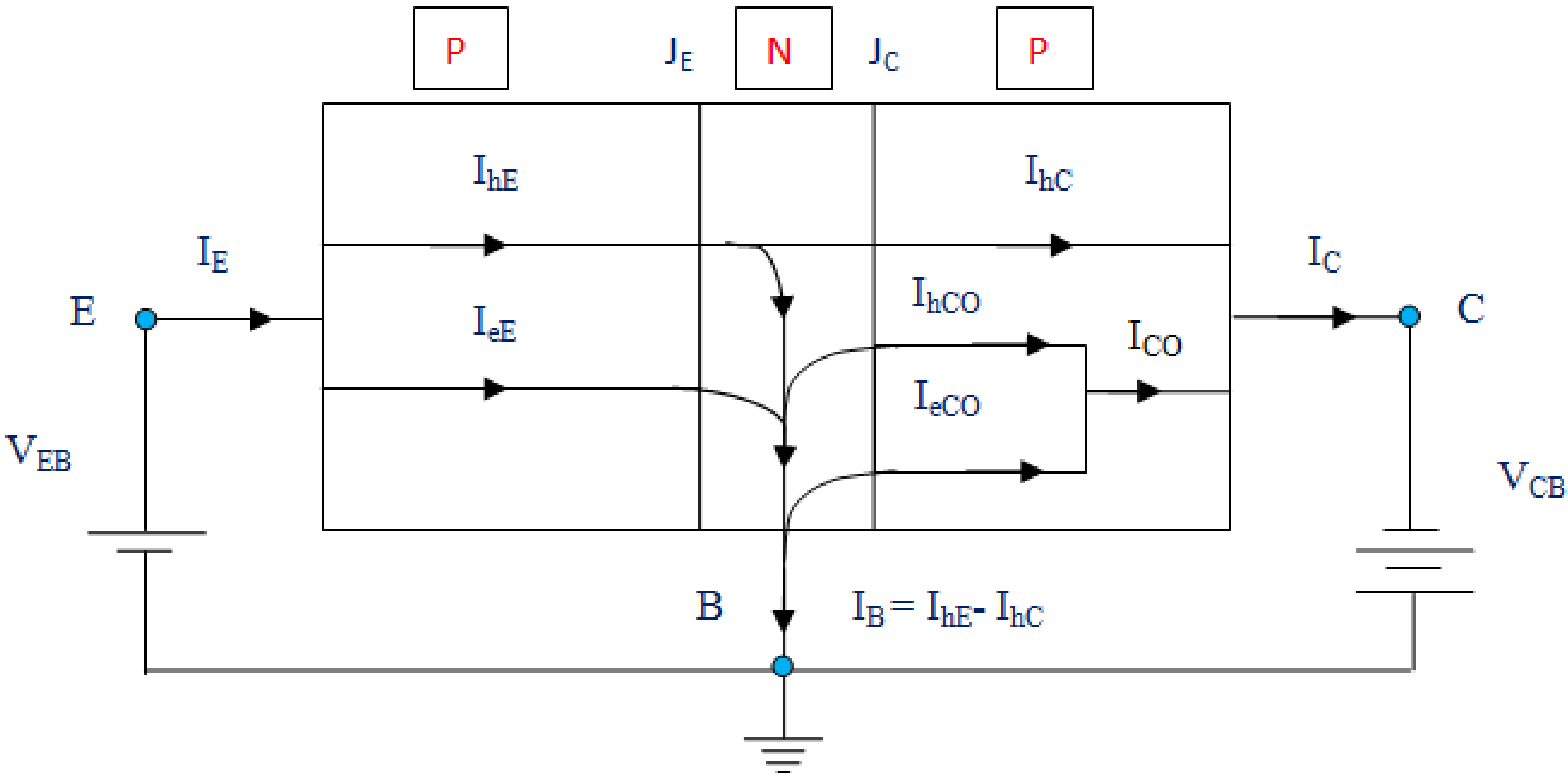


Fig 3: current components of transistor

COMMON-BASE(CB) CONFIGURATION

- Base is grounded and it is used as the common terminal for both input and output.

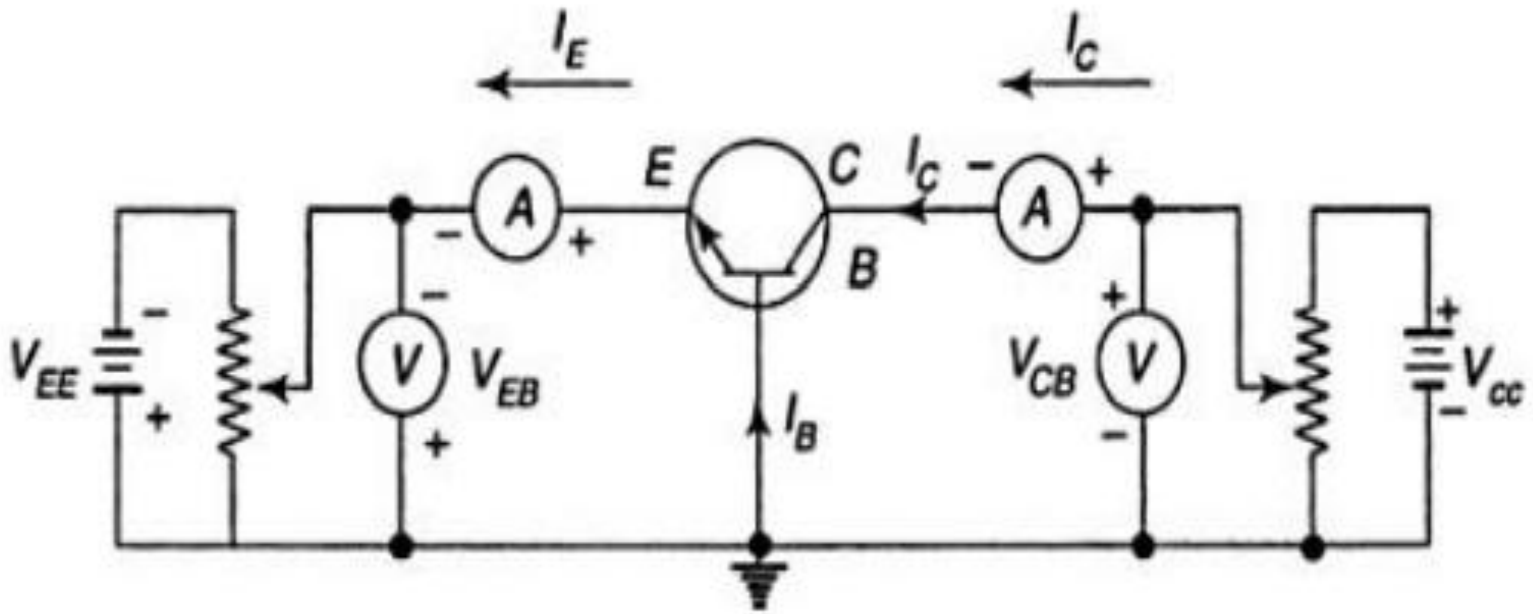


Fig 4: CB configuration

CB INPUT CHARACTERISTICS

- It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant
- To determine input characteristics, the collector base voltage VCB is kept constant at zero and emitter current IE is increased from zero by increasing VEB. This is repeated for higher fixed values of VCB.

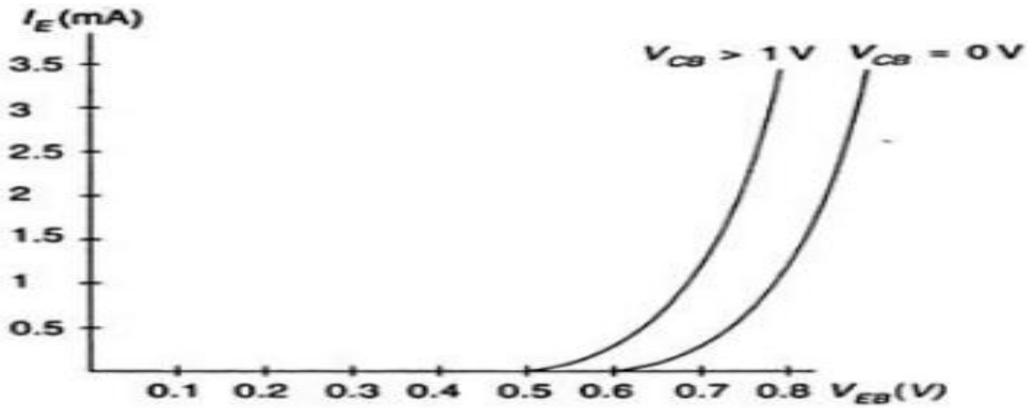


Fig 5: input characteristics of CB configuration

CB OUTPUT CHARACTERISTICS

- It is defined as the characteristic curve drawn between output voltage to output current whereas input current is constant.

- To determine output characteristics, the emitter current IE is kept constant at zero and collector current Ic is increased from zero by increasing VCB.This is repeated for higher fixed values of IE

CB OUTPUT CHARACTERISTICS

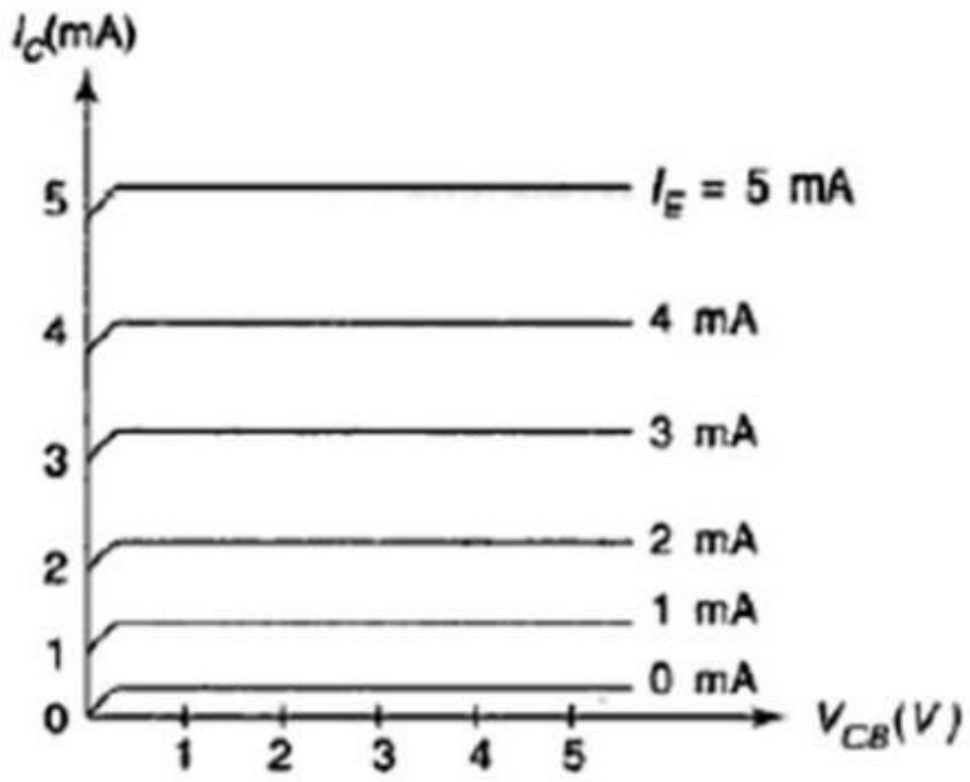


Fig 6: output characteristics of CB configuration

COMMON-EMITTER CONFIGURATION

- The term common-emitter is derived from the fact that the emitter is reference to both the input and output terminals.

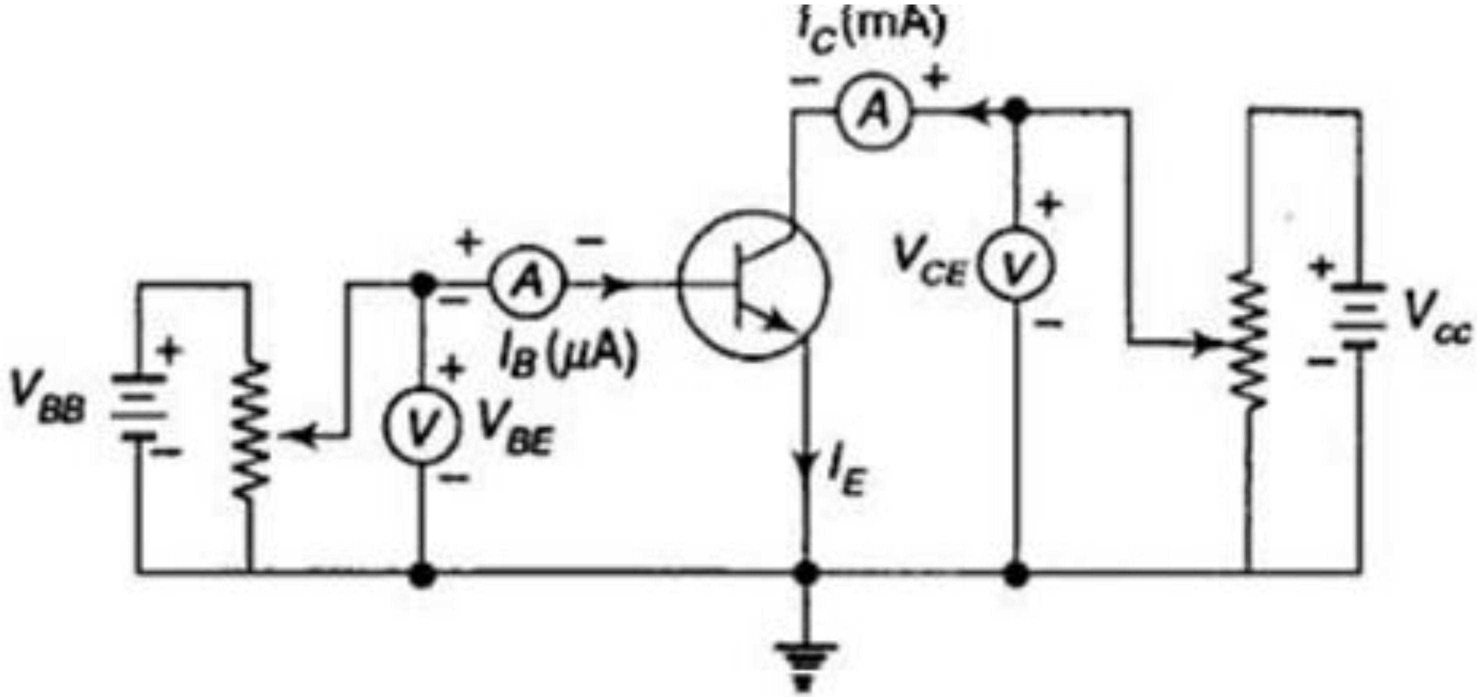


Fig 7: CE configuration

CE INPUT CHARACTERISTICS

- It is defined as the characteristic curve drawn between input voltages to input current whereas output voltage is constant
- To determine input characteristics, the collector base voltage VCB is kept constant at zero and base current IB is increased from zero by increasing VBE. This is repeated for higher fixed values of VCE.

CE INPUT CHARACTERISTICS

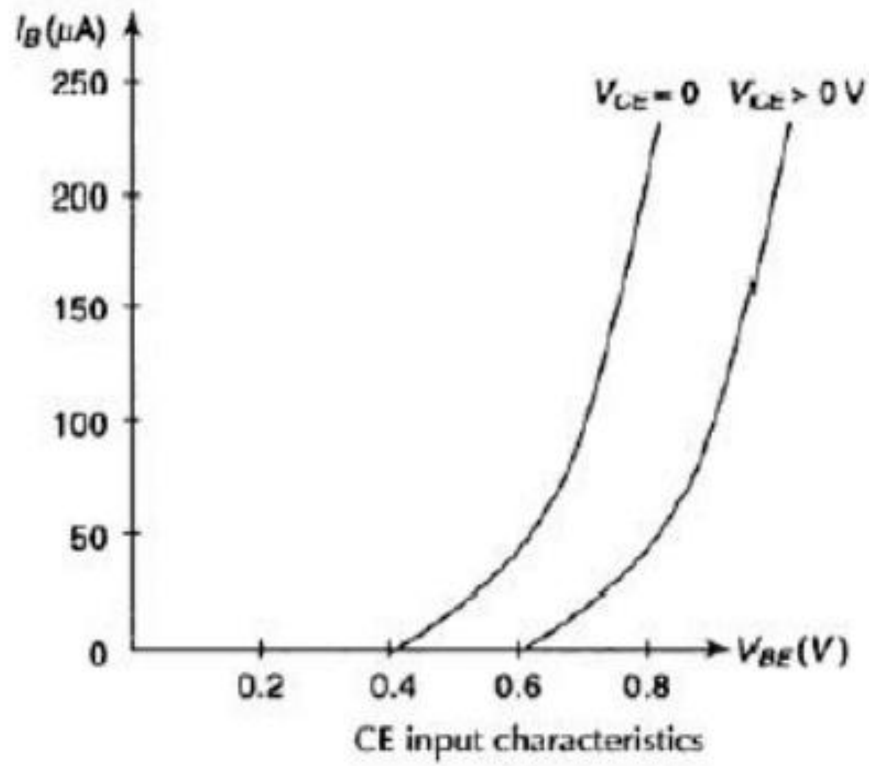


Fig 8: input characteristics of CE configuration

OUTPUT CHARACTERISTICS

- It is defined as the characteristic curve drawn between output voltage to output current whereas input, the base current IB i s kept constant at zero current is constant
- To determine output characteristics and collector current Ic is increased from zero by increasing VCE. This is repeated for higher fixed values of IB.

OUTPUT CHARACTERISTICS

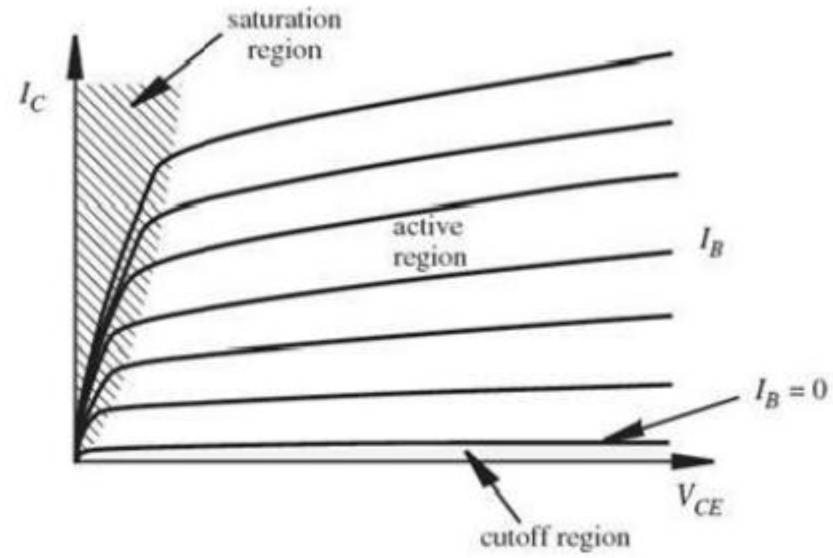


Fig 9: output characteristics of CE configuration

COMMON COLLECTOR CONFIGURATION

- collector is grounded and it is used as the common terminal for both input and output

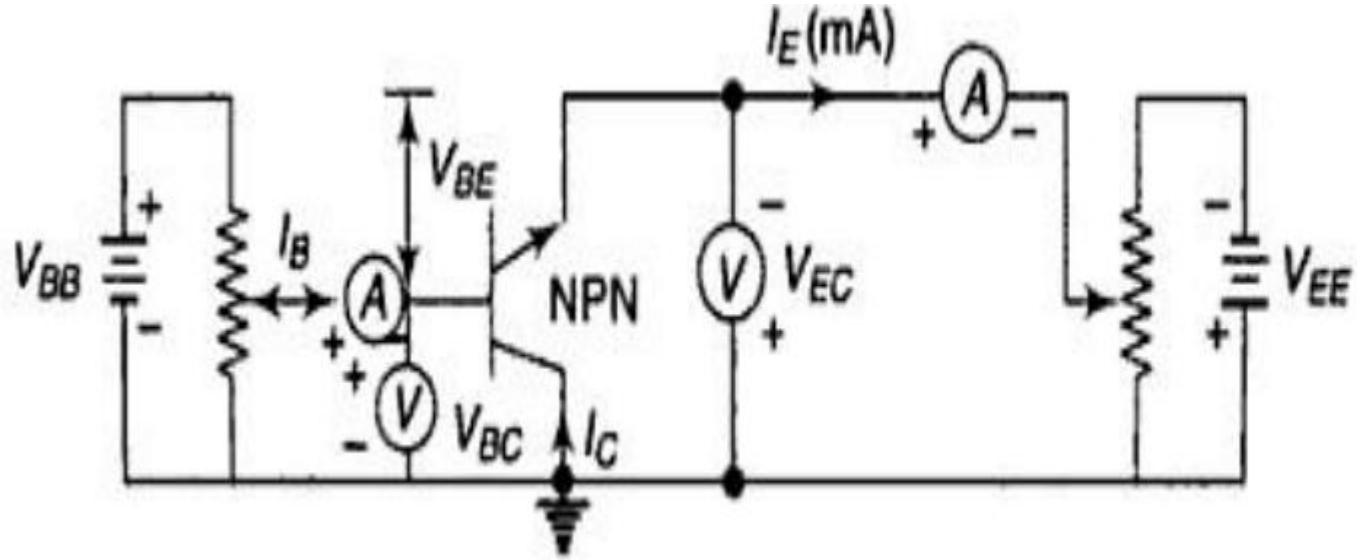


Fig 10: CC configuration

CB INPUT CHARACTERISTICS

- It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constan
- To determine input characteristics, the collector base voltage VCB is kept constant at zero and emitter current IE is increased from zero by increasing VEB. This is repeated for higher fixed values of VCB.

INPUT CHARACTERISTICS

Defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constant.

To determine input characteristics, the emitter base voltage VEB is kept constant at zero and base current IB is increased from zero by increasing VBC. This is repeated for higher fixed values of VCE

INPUT CHARACTERISTICS

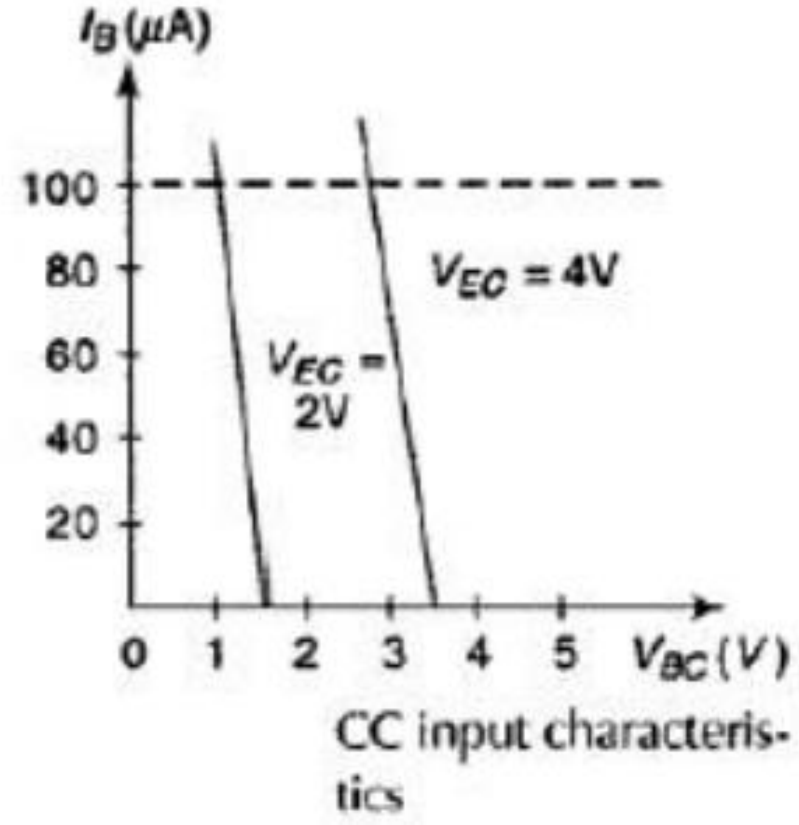


Fig 11: input characteristics of CC configuration

OUTPUT CHARACTERISTICS

- To determine output characteristics, the base current IB is kept constant at zero and emitter current IE is increased from zero by increasing VEC. This is repeated for higher fixed values of IB

OUTPUT CHARACTERISTICS

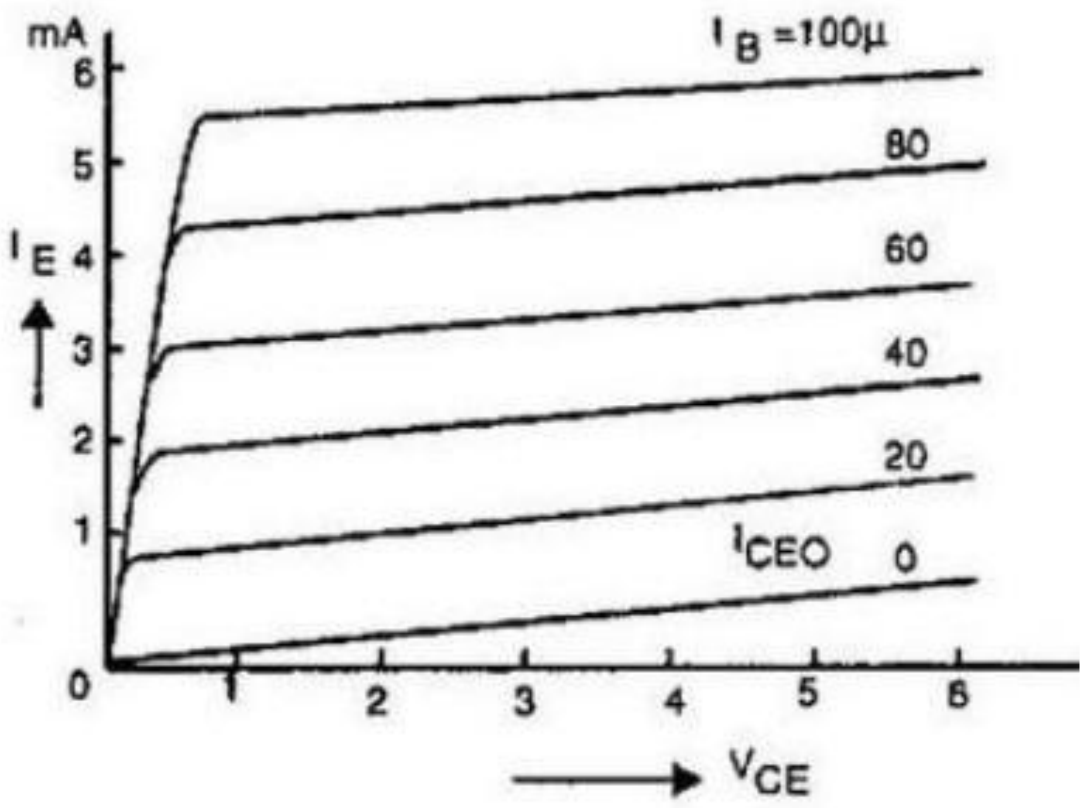


Fig 12: output characteristics of CC configuration

TRANSISTOR AS AN AMPLIFIER

- For a transistor to act as an amplifier, it should be properly biased
- A transistor acts as an amplifier by raising the strength of a weak signal. The DC bias voltage applied to the emitter base junction, makes it remain in forward biased condition. This forward bias is maintained regardless of the polarity of the signal. The below figure shows how a transistor looks like when connected as an amplifier.

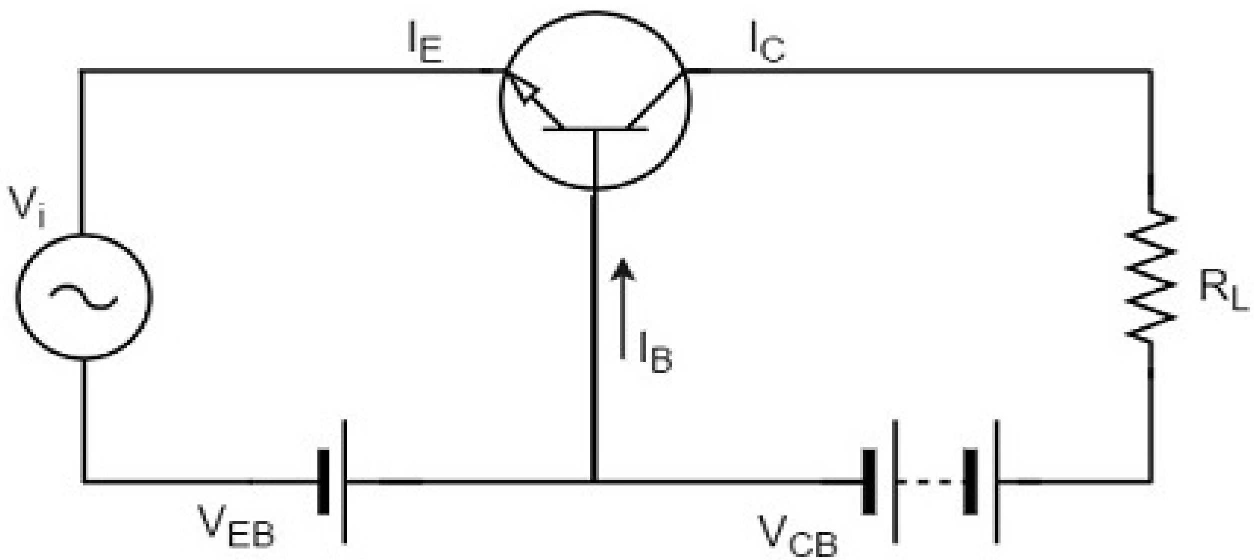


Fig 13: Transistor as an amplifier

TRANSISTOR AS AN AMPLIFIER

- The low resistance in input circuit, lets any small change in input signal to result in an appreciable change in the output.
- The emitter current caused by the input signal contributes the collector current, which when flows through the load resistor R_L, results in a large voltage drop across it.
- Thus a small input voltage results in a large output voltage, which shows that the transistor works as an amplifier.

PERFORMANCE OF AMPLIFIER

- As the common emitter mode of connection is mostly adopted, let us first understand a few important terms with reference to this mode of connection.

Input Resistance

- As the input circuit is forward biased, the input resistance will be low. The input resistance is the opposition offered by the base-emitter junction to the signal flow.
- By definition, it is the ratio of small change in base-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector-emitter voltage.

Input resistance, $Ri = \Delta VBE / \Delta IB$

Where R_i = input resistance, V_{BE} = base-emitter voltage, and I_B = base current.

PERFORMANCE OF AMPLIFIER

Output Resistance

- The output resistance of a transistor amplifier is very high. The collector current changes very slightly with the change in collector-emitter voltage.
- By definition, it is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant base current.

Output resistance = $Ro=\Delta VCE\Delta IC$

Where R_o = Output resistance, V_{CE} = Collector-emitter voltage, and I_C = Collector-emitter voltage.

Effective Collector Load

- The load is connected at the collector of a transistor and for a single-stage amplifier, the output voltage is taken from the collector of the transistor and for a multi-stage amplifier, the same is collected from a cascaded stages of transistor circuit.
- By definition, it is the total load as seen by the a.c. collector current. In case of single stage amplifiers, the effective collector load is a parallel combination of R_C and R_o.

  Effective Collector Load, $RAC=RC//Ro$
- Hence for a single stage amplifier, effective load is equal to collector load R_C.

Current Gain

- The gain in terms of current when the changes in input and output currents are observed, is called as **Current gain**. By definition, it is the ratio of change in collector current (ΔI_C) to the change in base current (ΔI_B).

Current gain, $\beta = \Delta IC / \Delta IB$

- The value of β ranges from 20 to 500. The current gain indicates that input current becomes β times in the collector current.

Voltage Gain

- The gain in terms of voltage when the changes in input and output currents are observed, is called as **Voltage gain**. By definition, it is the ratio of change in output voltage (ΔV_{CE}) to the change in input voltage (ΔV_{BE}).

$$\text{Voltage gain, } A_V = \frac{\Delta V_{CE}}{\Delta V_{BE}}$$

$$= \frac{Change\ in\ output\ current \times effective\ load}{Change\ in\ input\ current \times input\ resistance}$$

$$= \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i} = \frac{\Delta I_C}{\Delta I_B} \times \frac{R_{AC}}{R_i} = \beta \times \frac{R_{AC}}{R_i}$$

- For a single stage, $R_{AC} = R_C$.

TRANSISTOR BIASING

- Transistors are one of the largely used semiconductor devices which are used for wide variety of applications including amplification and switching. However to achieve these functions satisfactorily, transistor has to be supplied with certain amount of current and/or voltage. The process of setting these conditions for a transistor circuit is referred to as **Transistor Biasing**.
- This goal can be accomplished by variety of techniques which give rise to different kinds of biasing circuits. However, all of these circuits are based on the principle of providing right-amount of base current, I_B and inturn the collector current, I_C from the supply voltage, V_{CC} when no signal is present at the input. Moreover the collector resistor R_C has to be chosen so that the collector-emitter voltage, V_{CE} remains greater than 0.5V for transistors made of germanium and greater than 1V for the transistors made of silicon.

BIASING METHODS

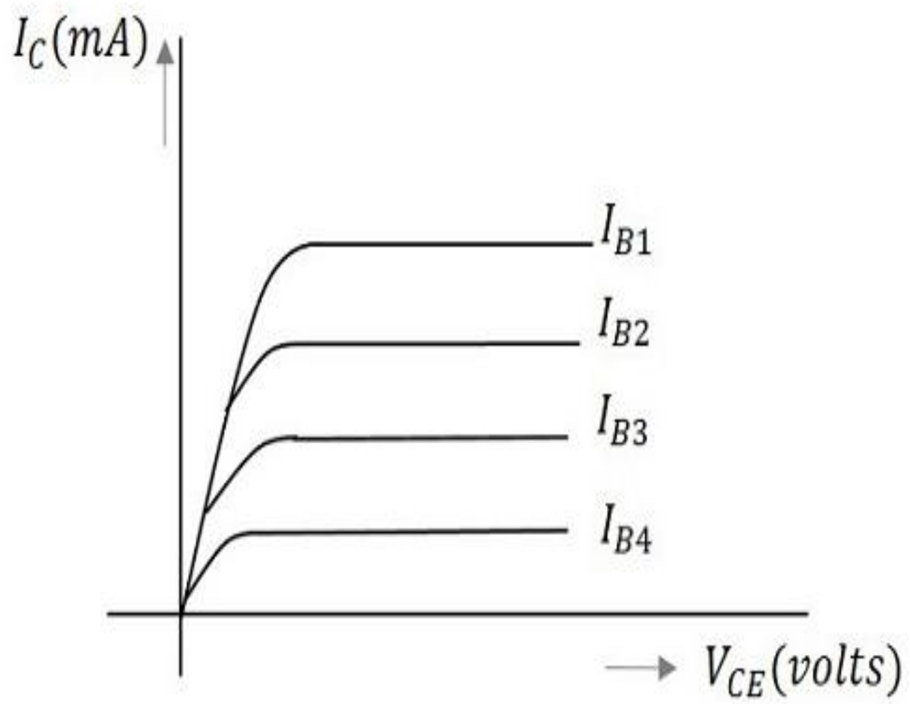
1) fixed base bias/fixed resistance bias
2) collector feedback bias
3) emitter bias
4) voltage divider bias

TRANSISTOR LOAD LINE ANALYSIS

- we have discussed different regions of operation for a transistor. But among all these regions, we have found that the transistor operates well in active region and hence it is also called as **linear region**. The outputs of the transistor are the collector current and collector voltages.

OUTPUT CHARACTERISTICS

- When the output characteristics of a transistor are considered, the curve looks as in figure for different input values.
- In the figure, the output characteristics are drawn between collector current $\mathbf{I_C}$ and collector voltage $\mathbf{V_{CE}}$ for different values of base current $\mathbf{I_B}$. These are considered here for different input values to obtain different output curves.



OPERATING POINT

- When a value for the maximum possible collector current is considered, that point will be present on the Y-axis, which is nothing but the **saturation point**. As well, when a value for the maximum possible collector emitter voltage is considered, that point will be present on the X-axis, which is the **cutoff point**.

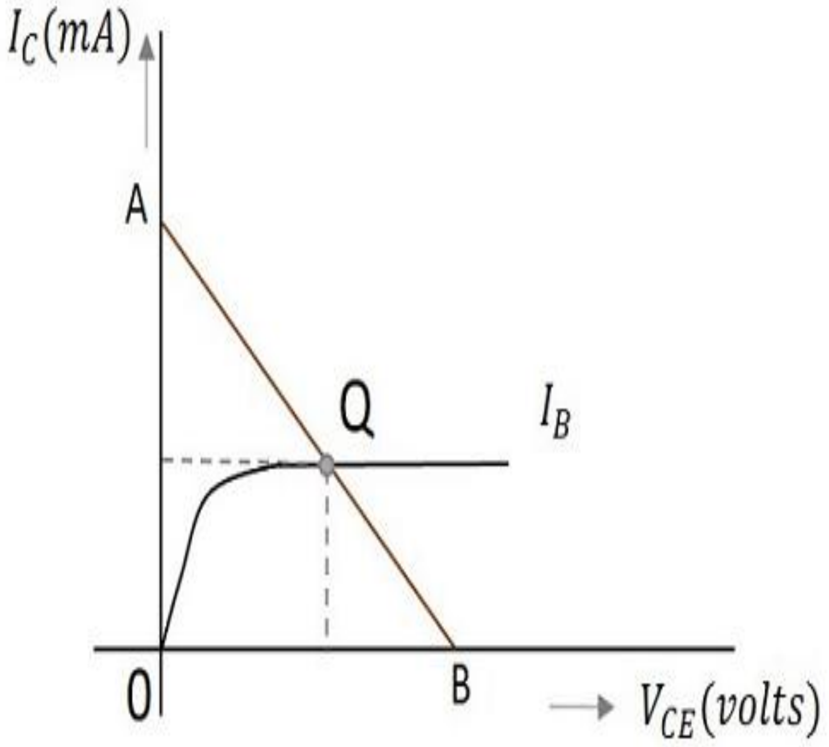
- When a line is drawn joining these two points, such a line can be called as **Load line**. This is called so as it symbolizes the output at the load. This line, when drawn over the output characteristic curve, makes contact at a point called as **Operating point**.

- his operating point is also called as **quiescent point** or simply **Q-point**. There can be many such intersecting points, but the Q-point is selected in such a way that irrespective of AC signal swing, the transistor remains in active region.

LOAD LINE

- The load line has to be drawn in order to obtain the Q-point. A transistor acts as a good amplifier when it is in active region and when it is made to operate at Q-point, faithful amplification is achieved.

Faithful amplification is the process of obtaining complete portions of input signal by increasing the signal strength. This is done when AC signal is applied at its input.



DC LOAD LINE

- When the transistor is given the bias and no signal is applied at its input, the load line drawn at such condition, can be understood as **DC** condition. Here there will be no amplification as the signal is absent. The circuit will be as shown below.

- The value of collector emitter voltage at any given time will be

$$V_{CE} = V_{CC} - I_C R_C$$

- As V_{CC} and R_C are fixed values, the above one is a first degree equation and hence will be a straight line on the output characteristics. This line is called as **D.C. Load line**.

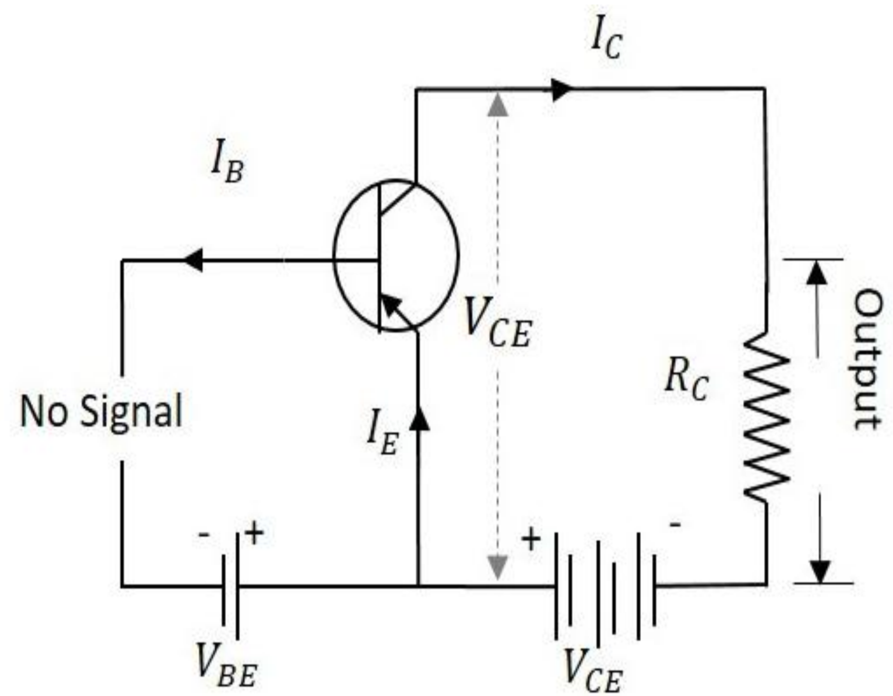


Fig 14: Transistor DC load line

DC LOAD LINE

The figure below shows the DC load line.

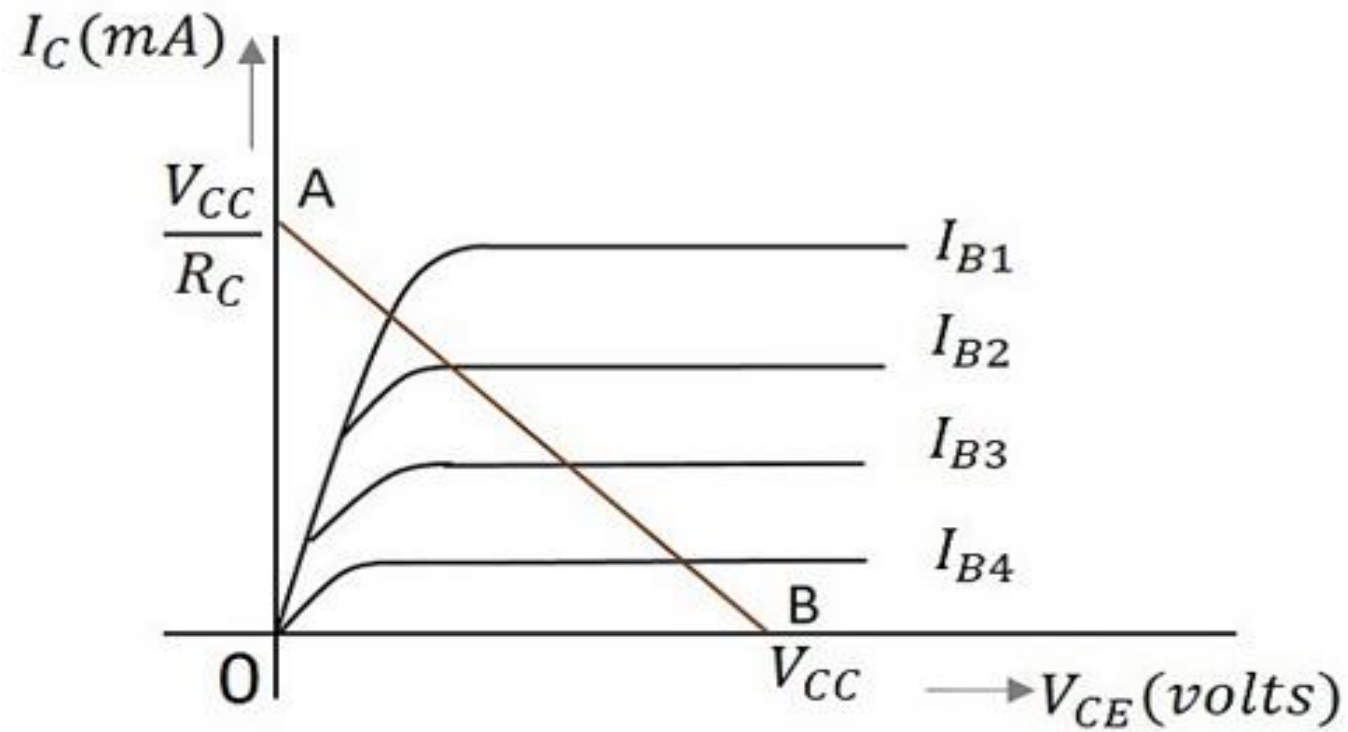


Fig 15: Transistor DC load line

- To obtain the load line, the two end points of the straight line are to be determined. Let those two points be A and B.

DC LOAD LINE

- **To obtain Point A**

When collector emitter voltage V_{CE} = 0, the collector current is maximum and is equal to V_{CC}/R_C. This gives the maximum value of V_{CE}. This is shown as

$$V_{CE} = V_{CC} - I_C R_C$$

$$0 = V_{CC} - I_C R_C$$

$$I_C = \frac{V_{CC}}{R_C}$$

This gives the point A (OA = V_{CC}/R_C) on collector current axis, shown in the above figure.

DC LOAD LINE

- **To obtain Point B**

When the collector current IC = 0, then collector emitter voltage is maximum and will be equal to the VCC. This gives the maximum value of IC. This is shown as

$$V_{CE} = V_{CC} - I_C R_C$$

$$= V_{CC}$$

$$(\text{As } I_C = 0)$$

- This gives the point B, which means (OB = V_{CC}) on the collector emitter voltage axis shown in the above figure.

- Hence we got both the saturation and cutoff point determined and learnt that the load line is a straight line. So, a DC load line can be drawn.

THANK YOU