BASIC ELECTRICAL AND ELECTRONICS ENGINEERING(AEEB04)

I B. Tech I semester (Autonomous IARE R-18)

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MODULE - I
ELECTRICCIRCUITS,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.

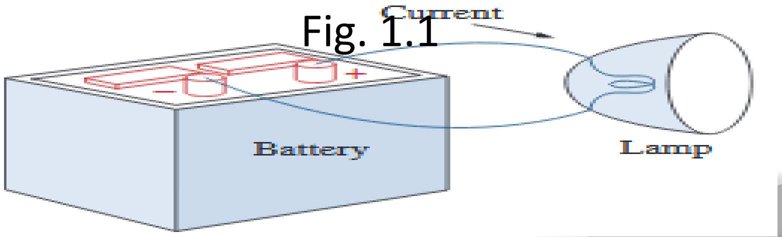
INTRODUCTION

- Electricity is the flow of electrons from one place to another. Electrons can flow through any material, but does so more easily in some materials than in others. How easily it flows is called resistance. The resistance of a material is measured in Ohms.
- Matter can be broken down into:
- Conductors: electrons flow easily. Low resistance.
- Semi-conductors: electron can be made to flow under certain circumstances. Variable resistance according to formulation and circuit conditions.
- Insulator: electrons flow with great difficulty. High resistance.

BASICS OF ELECTRICAL ENERGY

- In electrical engineering, we are often interested in communicating or transferring energy from one point to another. To do this requires an interconnection of electrical devices. Such interconnection is referred to as an electric circuit, and each component of the circuit is known as an element.
- A simple electric circuit is shown in Fig. 1.1. It consists of three basic elements: a battery, a lamp, and connecting wires. Such a simple circuit can exist by itself; it has several applications, such as a flash- light, a search light.

Fig. 1.1



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

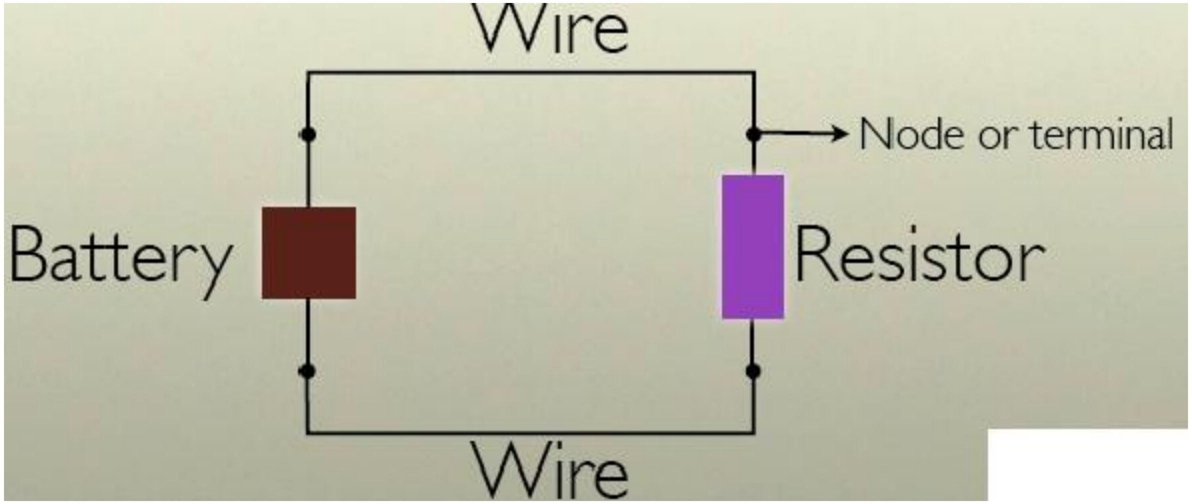
Multiplier	Prefix	symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

BASIC DEFINITIONS

- Voltage is the difference in charge between two points.
- Current is the rate at which charge is flowing.
- Power the rate at which work is done in an electric circuit is called electric power.
- Energy is defined as the ability to perform work. in electricity, the total work done in an electric circuit is called electrical energy.
- Electric field the region of the charge particle where its force can be experienced by any other charge particle.
- Electric Potential at any point in electric field is defined as work done in bringing a unit positive charge from infinity to that point against electric field. The ability of charged body to do work is called electric potential.

ELECTRIC CIRCUIT

An electric circuit is an interconnection of electrical elements linked together in a closed path so that electric current may flow continuously



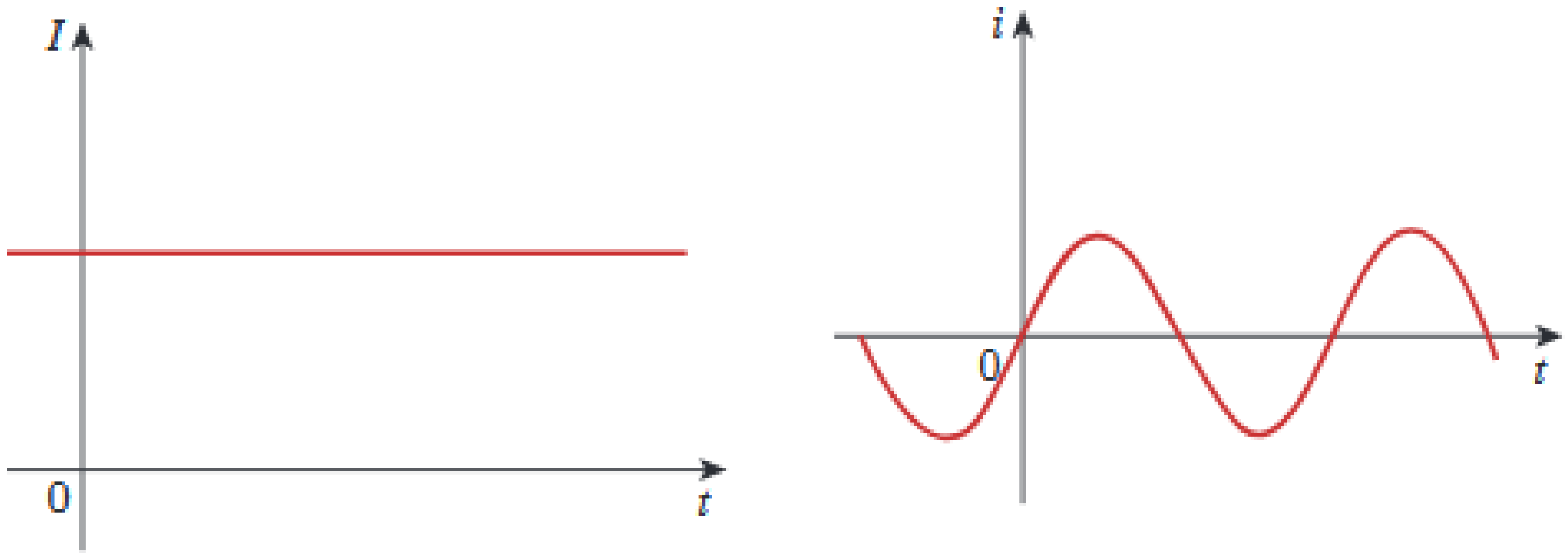
CHARGE AND CURRENT

- The concept of electric charge is the underlying principle for explaining all electrical phenomena. Also, the most basic quantity in an electric circuit is the electric charge.
- Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).
- Current is the rate of charge flow past a given point in a given direction.

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

- If the current does not change with time, but remains constant, we call it a direct current(dc).
- A time-varying current is represented by the symbol i. A common form of time-varying current is the sinusoidal current or Alternating current(ac).

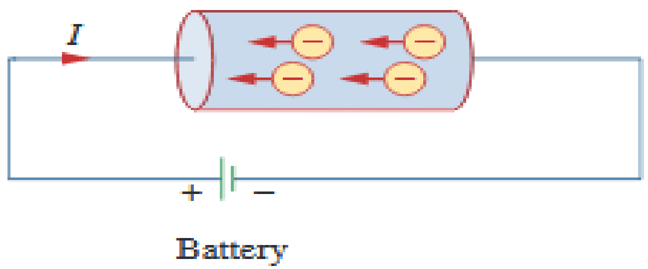
TYPES OF CURRENT



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

VOLTAGE

- To Move The Electron In A Conductor In A Particular Direction Requires Some Work Or Energy Transfer.
- This Work Is Performed By An External Electromotive Force (Emf), Typically Represented By The Battery In Fig. 1.3.



- This Emf Is Also Known As Voltage Or Potential Difference.
- The Voltage Between Two Points A And B In An Electric Circuit Is

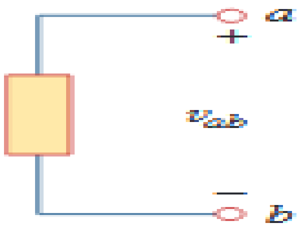
- The Energy (Or Work) Needed To Move A Unit Charge From A To B; Mathematically where ,W Is Energy In Joules (J) And Q Is Charge In Coulombs (C). The Voltage Or Simply V Is Measured In Volts (V)

  1 Volt=1 Joule/Coulomb=1 Newton-meter/Coulomb

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).

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 ELEMENTS

- ACTIVE ELEMENTS
  - Voltage source
  - Current source

- PASSIVE ELEMENTS

- Resistance
- Inductance
- Capacitance

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)**

$$[\ V = I \times R\ ] \qquad V\ (\text{volts}) = I\ (\text{amps}) \times R\ (\Omega)$$

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

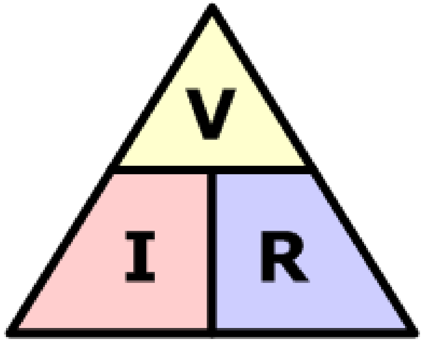
[I = V ÷ R]   I (amps) = V (volts) ÷ R (Ω)

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

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

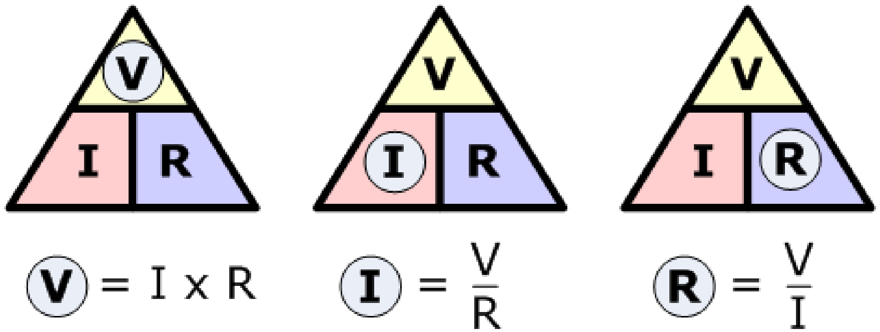
OHMS LAW

- 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:



- 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.

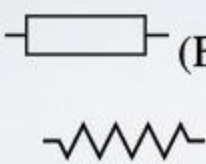
RESISTORS

Resistor

Three resistors

Type	Passive

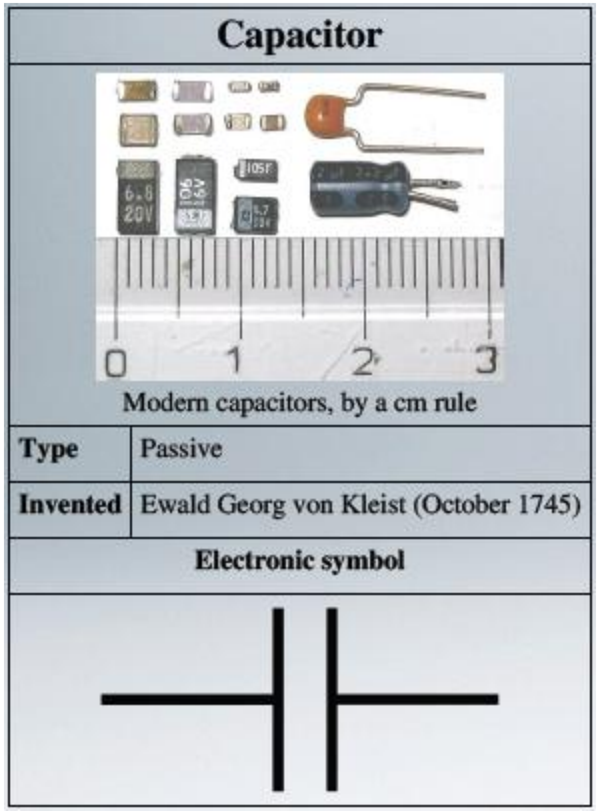
Electronic symbol



- 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)

CAPACITORS



- 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

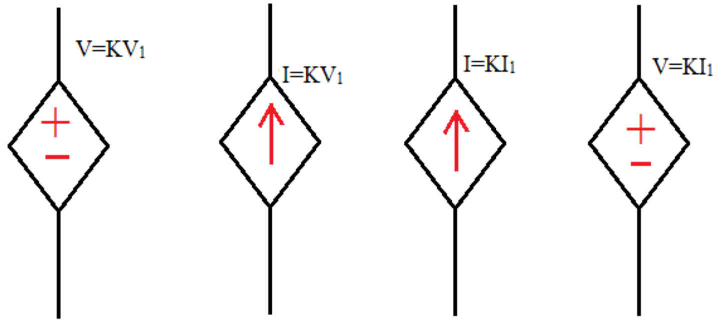
Type	Passive
Working principle	Electromagnetic induction
First production	Michael Faraday (1831)

Electronic symbol

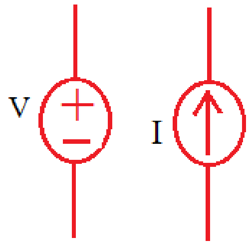
- An inductor is a two terminal element consisting of a winding of N turns capable of storing energy in the form of a magnetic field
- Inductance (L) is a measure of the ability of a device to store energy in the form of a magnetic field. It is measured in Henries (H)

INDEPENDENT,DEPENDENT SOURCES

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



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

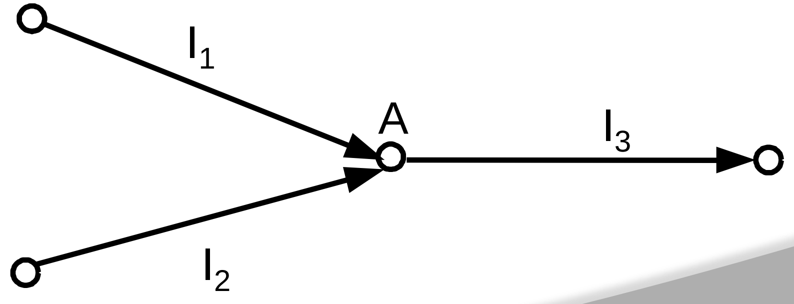


KIRCHHOFF'S CURRENT LAW

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

$$I_1 + I_2 - I_3 = 0$$

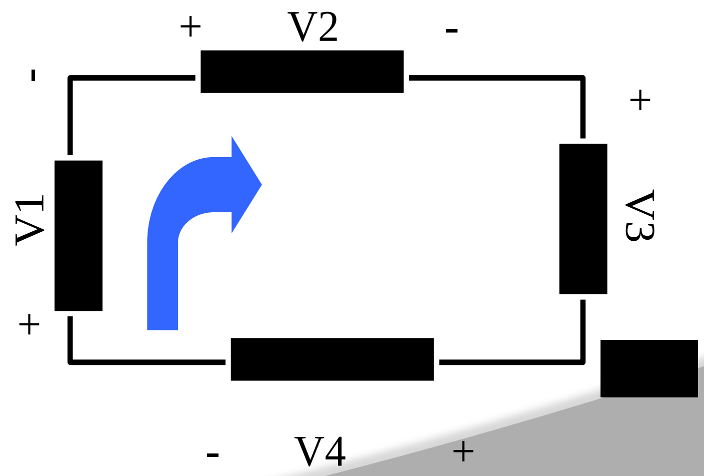
- Current entering a node is assigned positive sign. Current leaving a node is assigned a negative sign.



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.

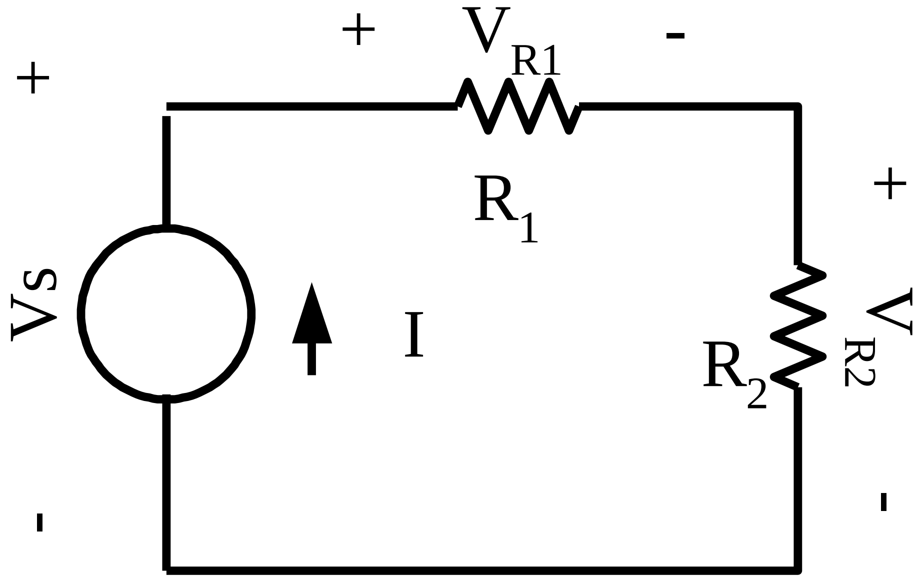
$$V_1 + V_2 + V_3 + V_4 = 0$$



LAW OF VOLTAGE DIVISION

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

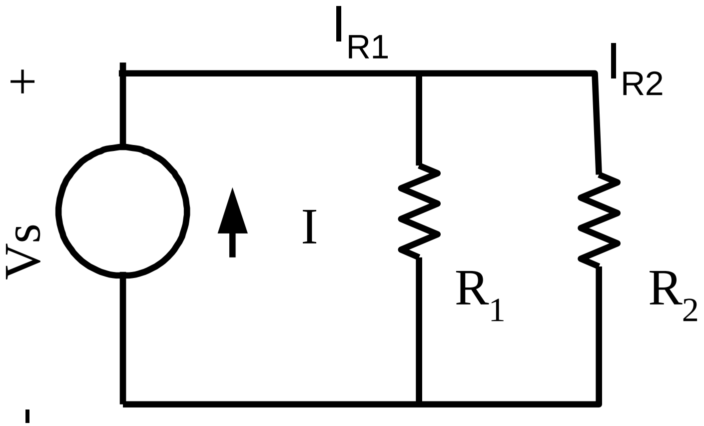
$$V_{R_2} = \frac{R_2}{R_1 + R_2} V_s$$



LAW OF CURRENT DIVISION

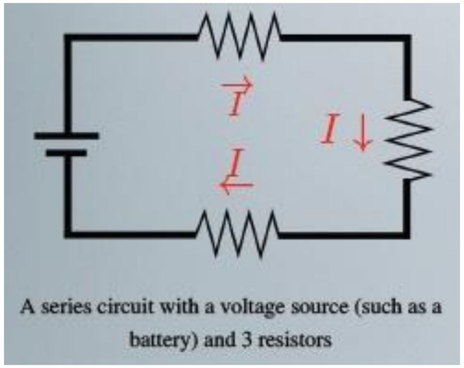
$$I_{R_1} = \frac{R_2}{R_1 + R_2} I$$

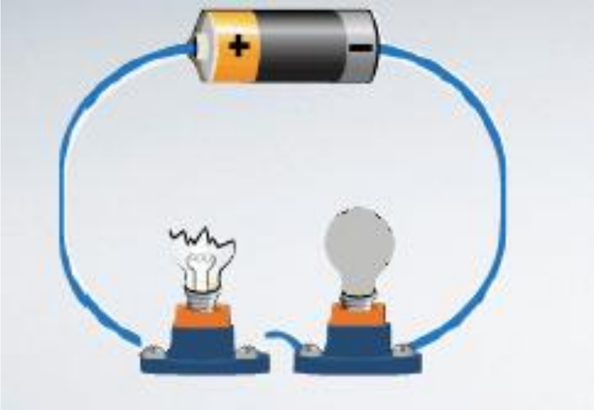
$$I_{R_2} = \frac{R_1}{R_1 + R_2} I$$



SERIES CIRCUITS

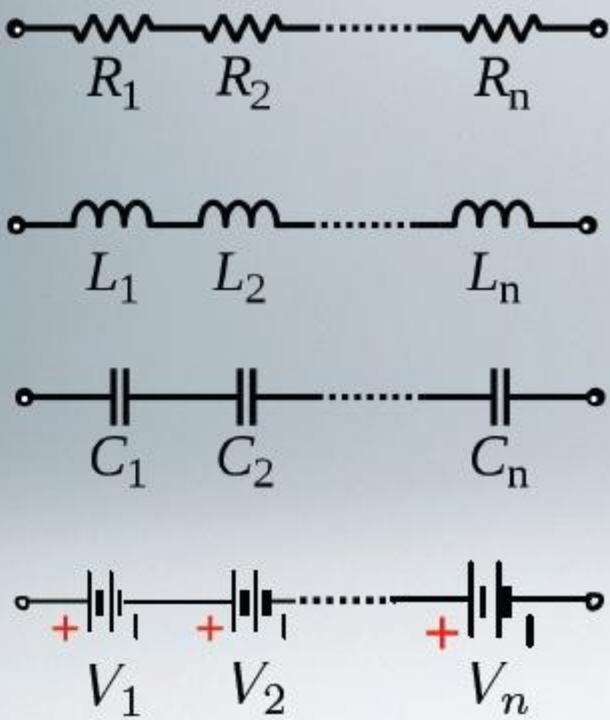
- A **series circuit** has only **one current path**





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

EQUIVALENT R,L AND C IN SERIES



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

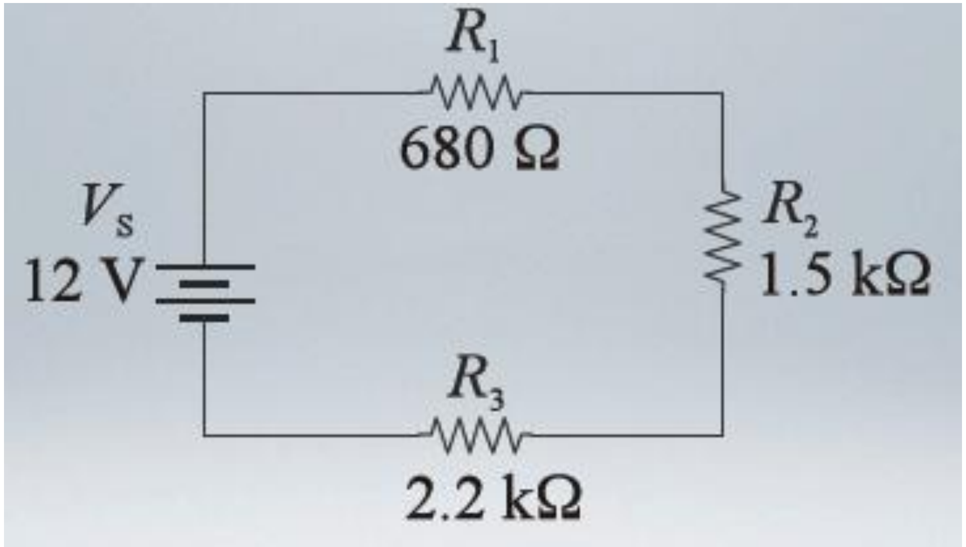
$$L_{total} = L_1 + L_2 + \ldots + L_n$$

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

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

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?

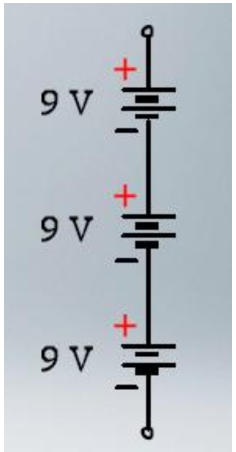


$$
\begin{aligned}
R_{total} &= R_1 + R_2 + R_3 \\
&= 680\Omega + 1500\Omega + 2200\Omega \\
&= 4380\Omega \\
&= 4.38k\Omega
\end{aligned}
$$

VOLTAGE SOURCES IN SERIES

- Find the total voltage of the sources shown

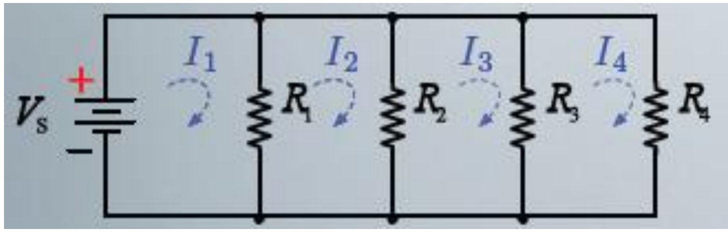
$$V_{total} = V_1 + V_2 + V_3 = 27V$$



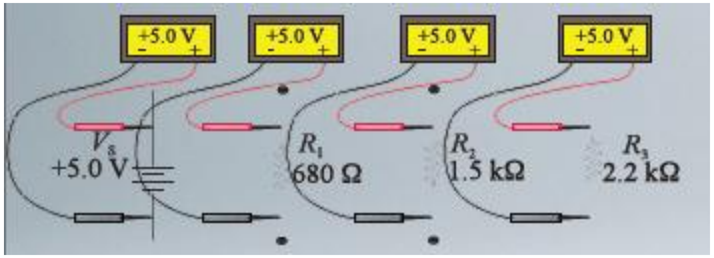
- What happens if you reverse a battery?

PARALLEL CIRCUITS

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

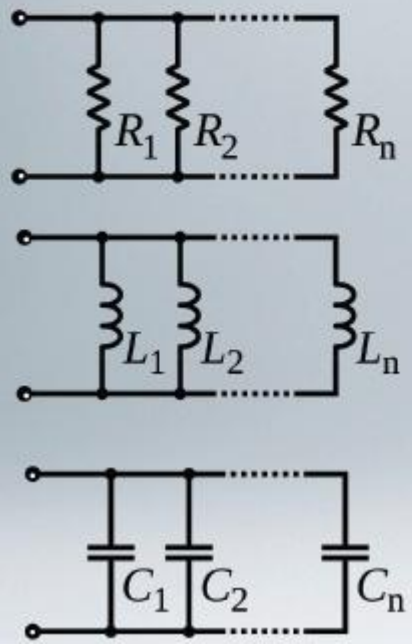


- Voltage across each pathway is the same



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

EQUIVALENT R,L AND C IN PARALLEL



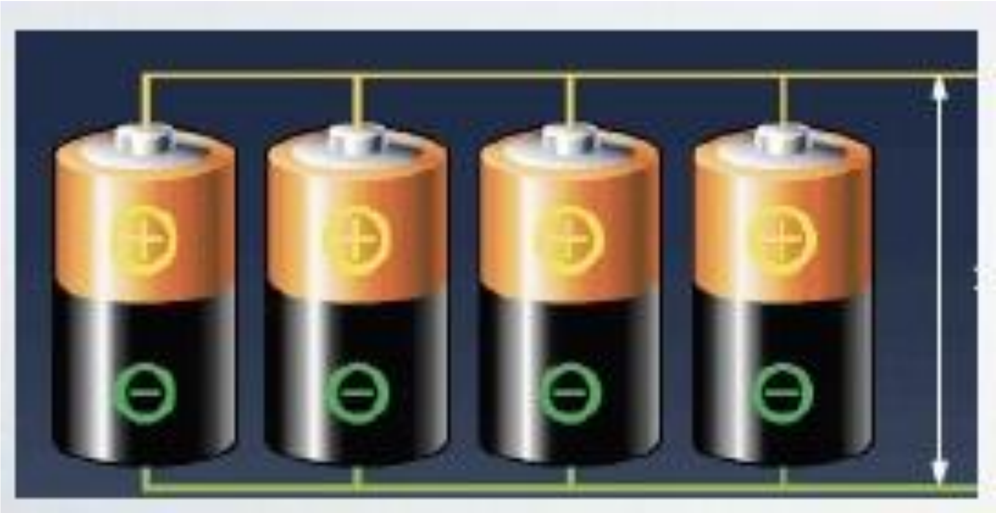
$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$$

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

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

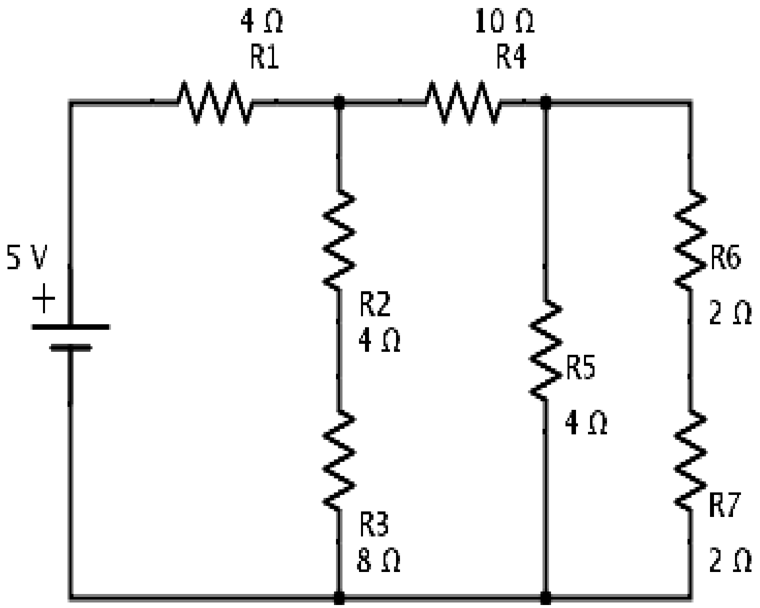
SIMPLE CIRCUIT IN PARALLEL

- 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



PROBLEMS ON SERIES AND PARALLEL CIRCUITS

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



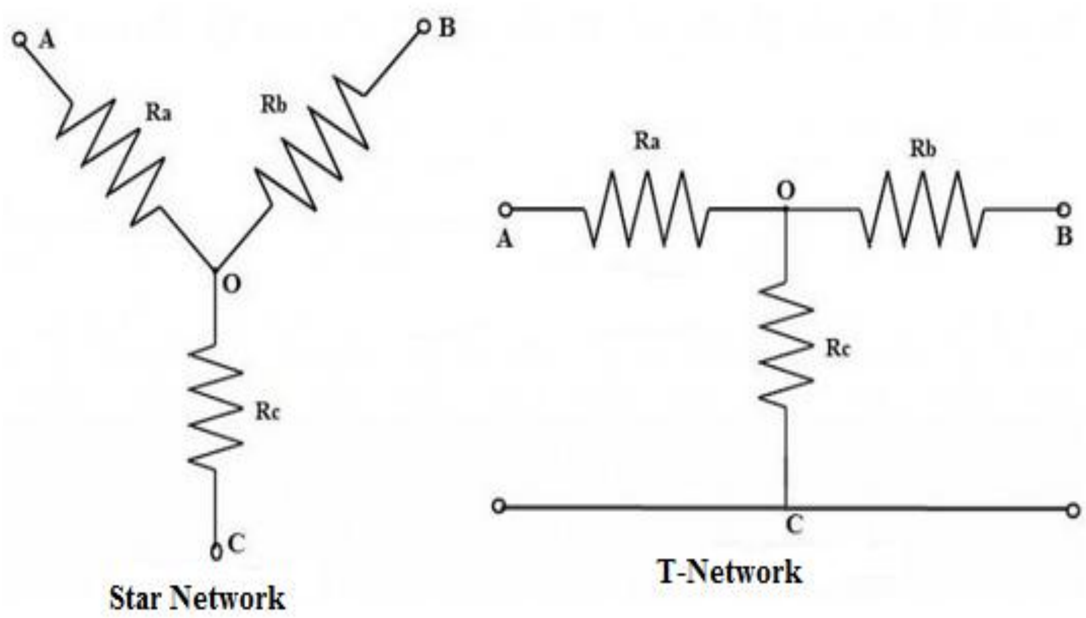
STAR-DELTA TRANSFORMATION

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:



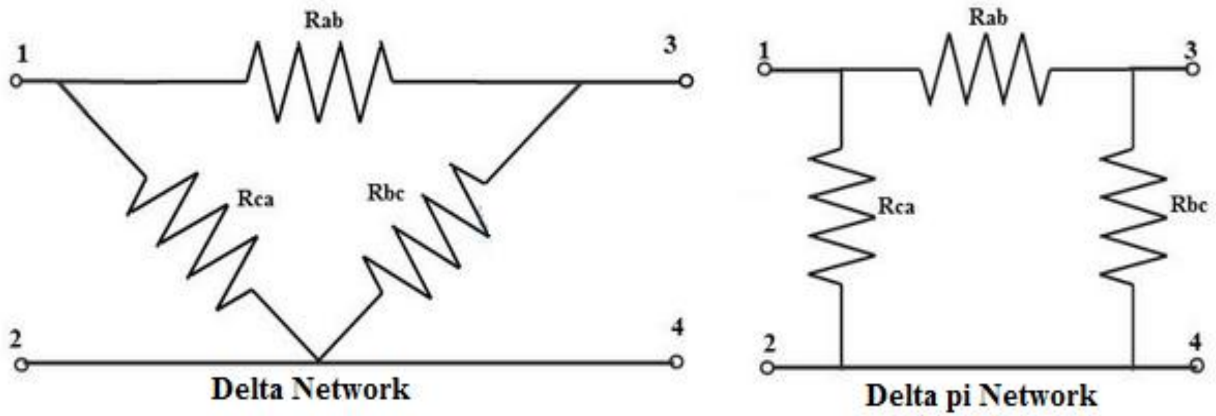
DELTA CONNECTION

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.

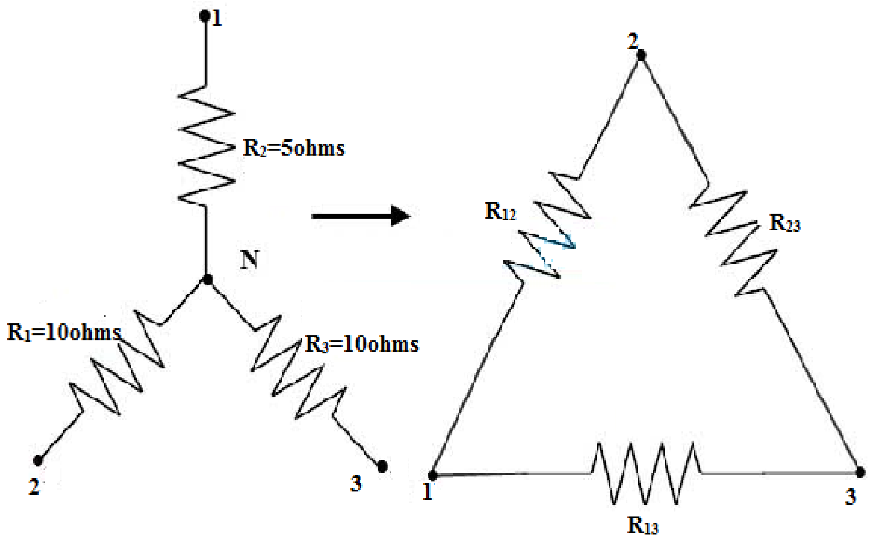
DELTA CONNECTION

- Delta and PI network representation:



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

$$R_{12} = 350/ R_3= 350/20= 17.5 \text{ ohms}$$

$$R_{23} = 350/ R_1= 350/ 10= 35 \text{ ohms}$$

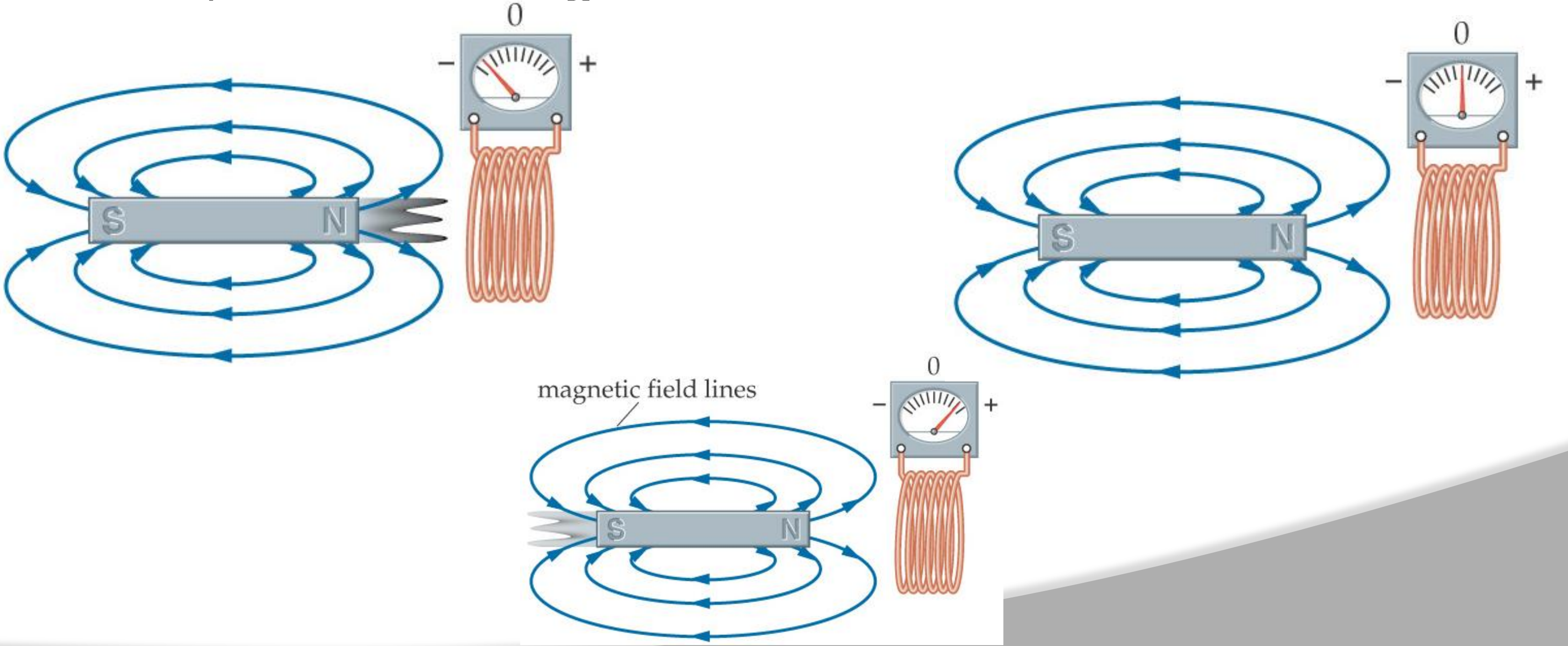
$$R_{31}= 350/R_2= 350 /5= 70 \text{ ohms}$$

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.

Faraday’s First Law Of Electromagnetic Induction

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”

FARADAY'S SECOND LAW:

Second Law Of Electromagnetic Induction

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."

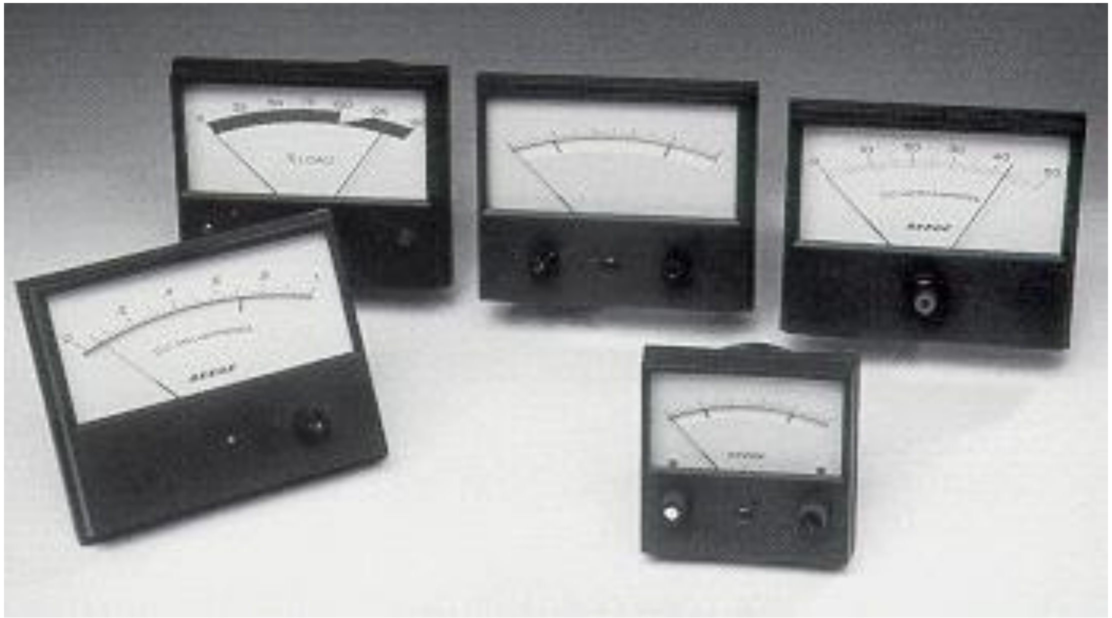
CLASSIFICATION OF INSTRUMENTS

- 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.



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.

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.

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

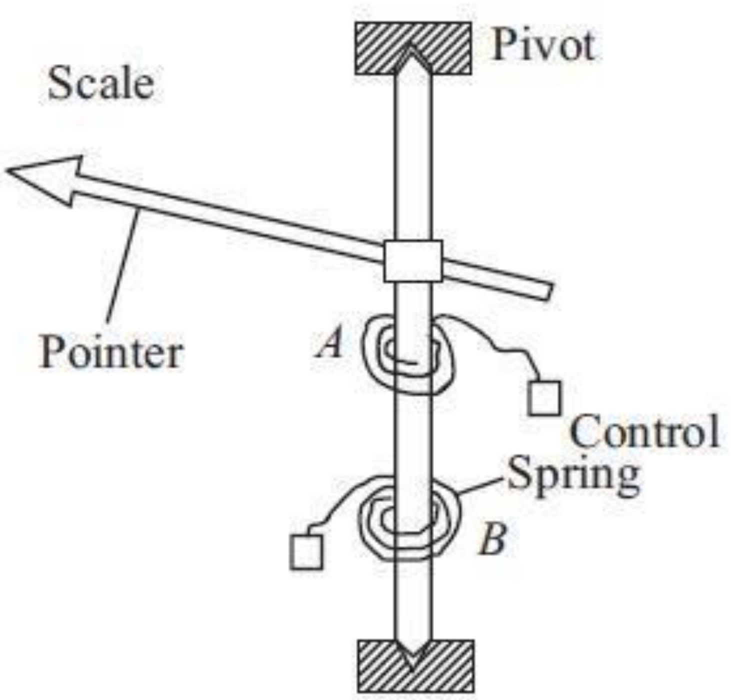
- The deflecting torque is produced by making one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effect of current or voltage and cause the moving system of the instrument to move from its zero position.
- The method of producing this torque depends upon the type of instrument.

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.

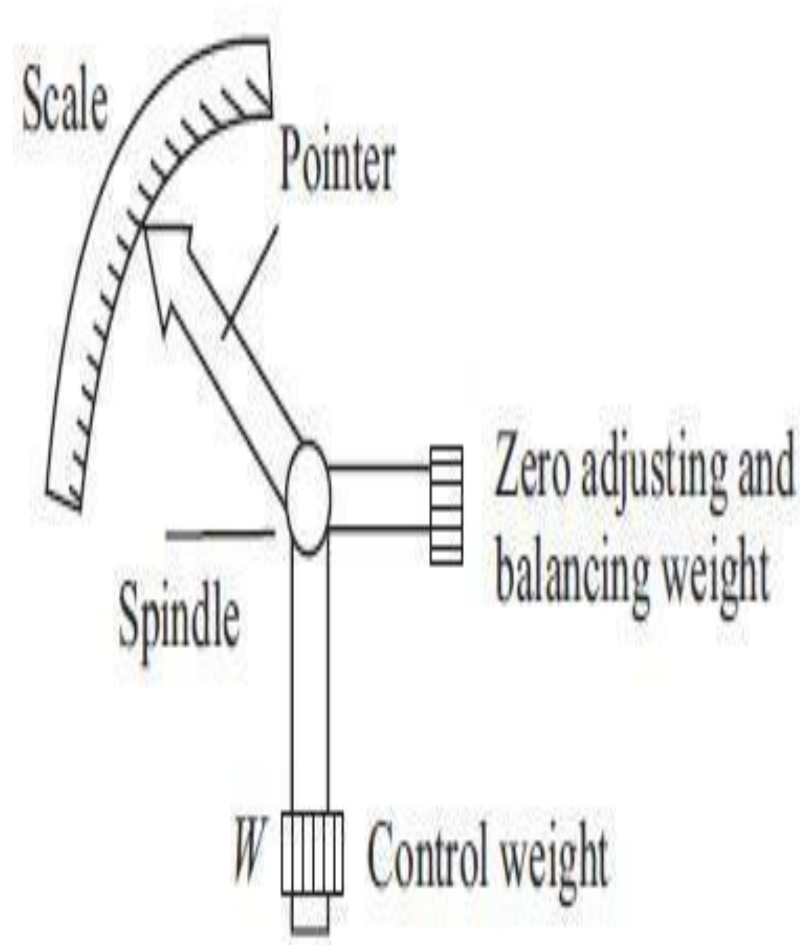
SPRING CONTROL

- 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



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.



DAMPING TORQUE

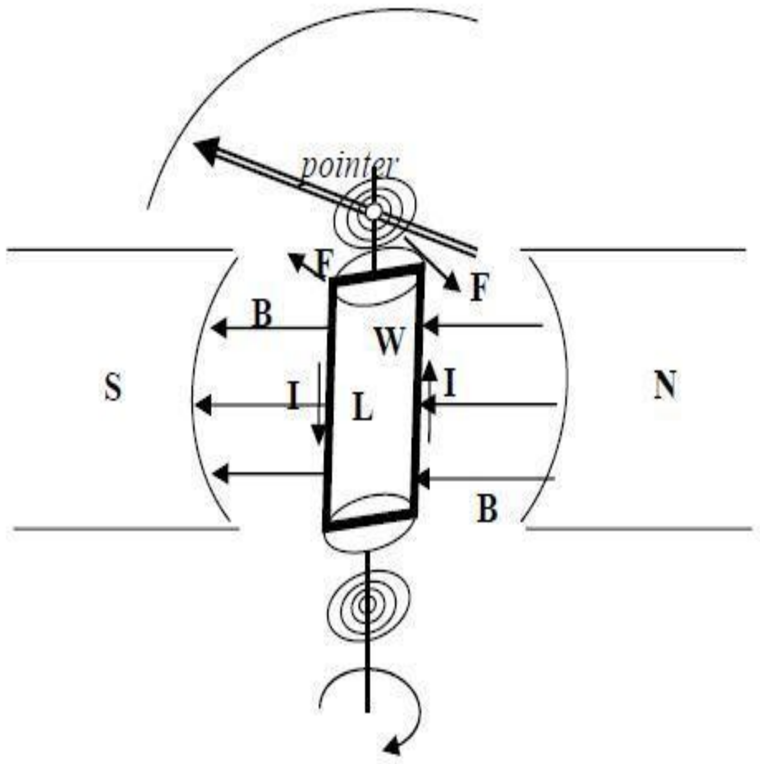
- We have already seen that the moving system of the instrument will tend to move under the action of deflecting torque.
- But on account of the control torque, it will try to occupy a position of rest when the two torques are equal and opposite.
- However, due to inertia of the moving system, the pointer 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.

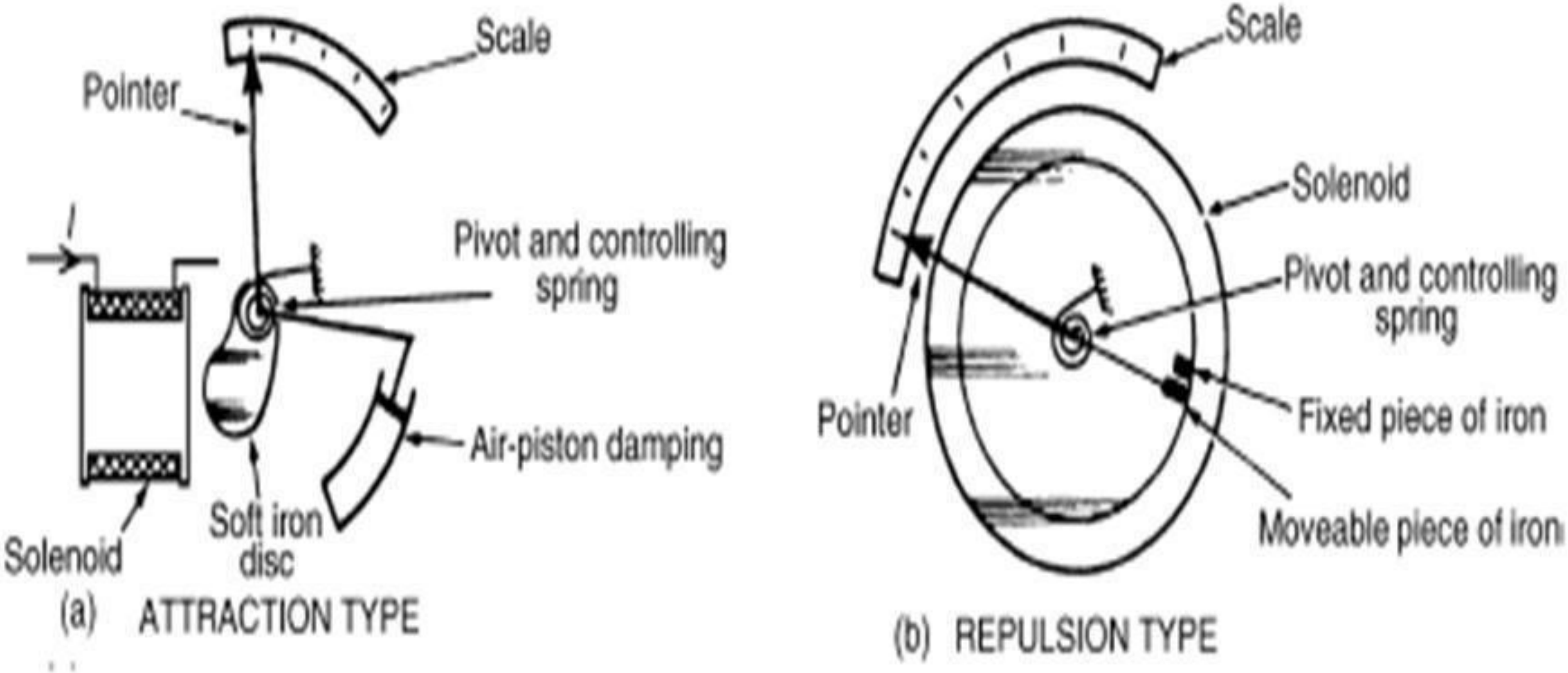
PERMANENT MAGNET MOVING COIL

- "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."



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.



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.

INTRODUCTION

- DC motors are rarely utilized in normal applications as a result of all electrical supply firms furnish electrical energy but, for special applications like in steel mills, mines and electric traction, it's advantageous to convert AC into DC so as to use DC motors. The rationale is that speed/torque characteristics of DC motors are much more superior thereto of AC motors.
- Therefore, it's not stunning to notice that for industrial drives, DC motors are as common as 3-phase induction motors. Similar to DC generators, DC motors are also classified into 3 kinds; they are series-wound, shunt-wound and compound- wound. The employment of a specific motor depends upon the mechanical load it's to drive.

PRINCIPLE OF DC MOTOR

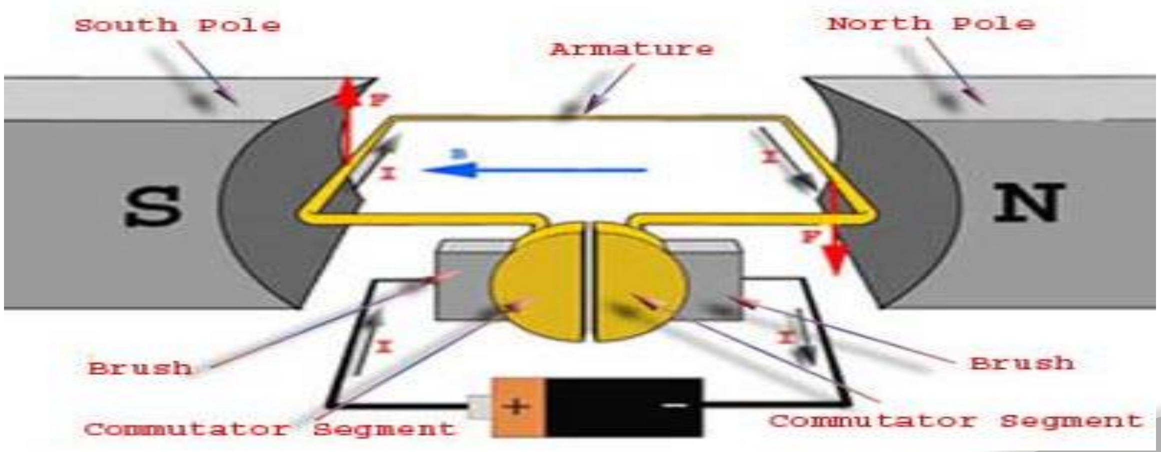
- A machine which transforms the DC power into mechanical power is called as a DC motor. Its operation relies on the principle that once a current carrying conductor is placed in a very magnetic field, the conductor experiences a mechanical force. The direction of this force is given by Fleming’s left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

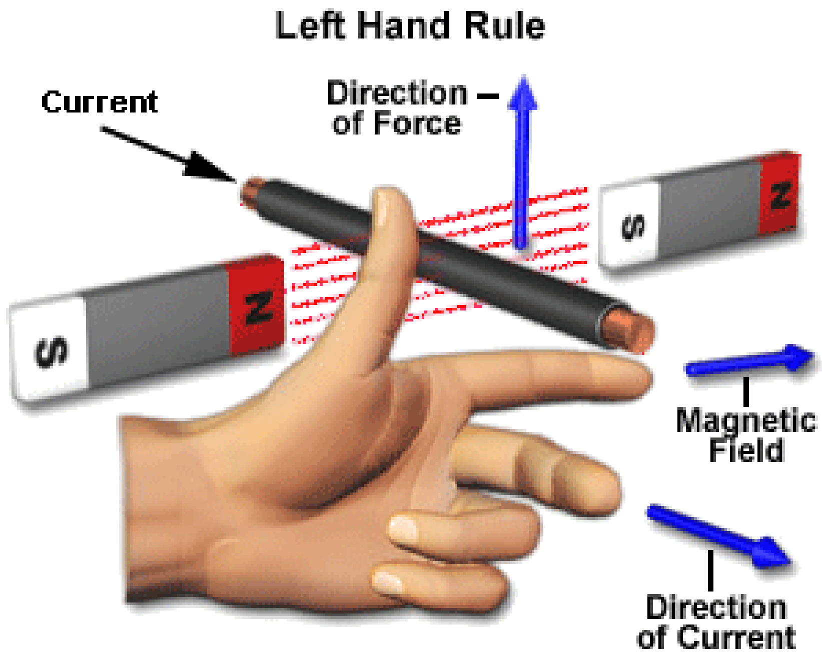
WORKING PRINCIPLE OF DC MOTOR

- 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.



- 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.
- 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



INTRODUCTION TO DC MOTOR

- The principle of operation of a dc motor can be stated as when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force. In a practical dc motor, the field winding produces the required magnetic held while armature conductor play the role of current carrying conductor and hence the armature conductors experience a force.
- As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductive acts as a twisting or turning force on the armature which is called a torque.
- The torque is the product of force and the radius at which this force acts, so overall armature experiences a torque and starts rotating.

- **Direction of rotation of motor**

The magnitude of the force experienced by the conductor in a motor is given by F = BIL newtons.

The direction of the main field can be revoked y changing the direction of current passing through the field winding, which is possible by interchanging the polarities of supply which is given to the field winding.

The direction of current through armature can be reversed by changing supply polarities of dc supplying current to the armature.

INTRODUCTION TO DC MOTOR

- The principle of operation of a dc motor can be stated as when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force.
- In a practical dc motor, the field winding produces the required magnetic held while armature conductor play the role of current carrying conductor and hence the armature conductors experience a force.
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INTRODUCTION TO DC MOTOR

- Consider a single conductor placed in a magnetic field , the magnetic field is produced by a permanent magnet but in practical dc motor it is produced by the field winding when it carries a current.
- Now this conductor is excited by a separate supply so that it carries a current in a particular direction. Consider that it carries a current away from an current.
- Any current carrying conductor produces its own magnetic field around it, hence this conductor also produces its own flux, around. The direction of this flux can be determined by right hand thumb rule.
- For direction of current considered the direction of flux around a conductor is clock-wise. Now, there are two fluxes present

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 ∝ 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**.

Torque Current Characteristic of DC shunt motor

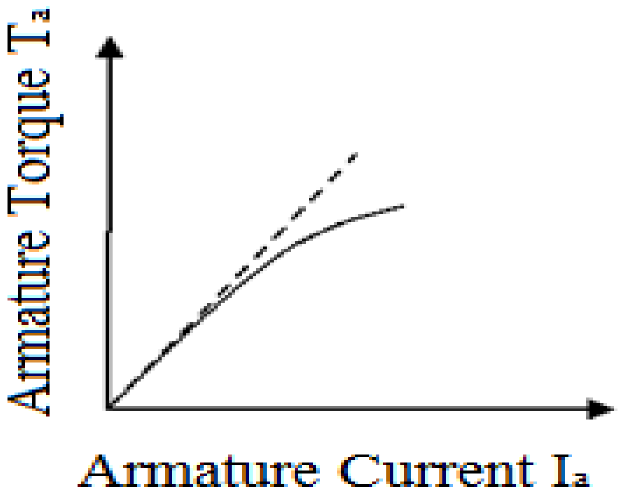

Fig. 3.3 Torque Current Characteristic of DC shunt motor

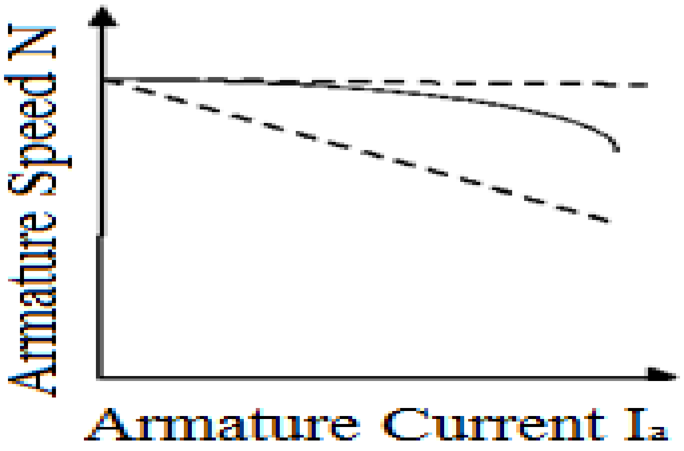

Fig. 3.4 Speed vs armature current characteristics of DC shunt motor

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 α 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 ∝ 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.
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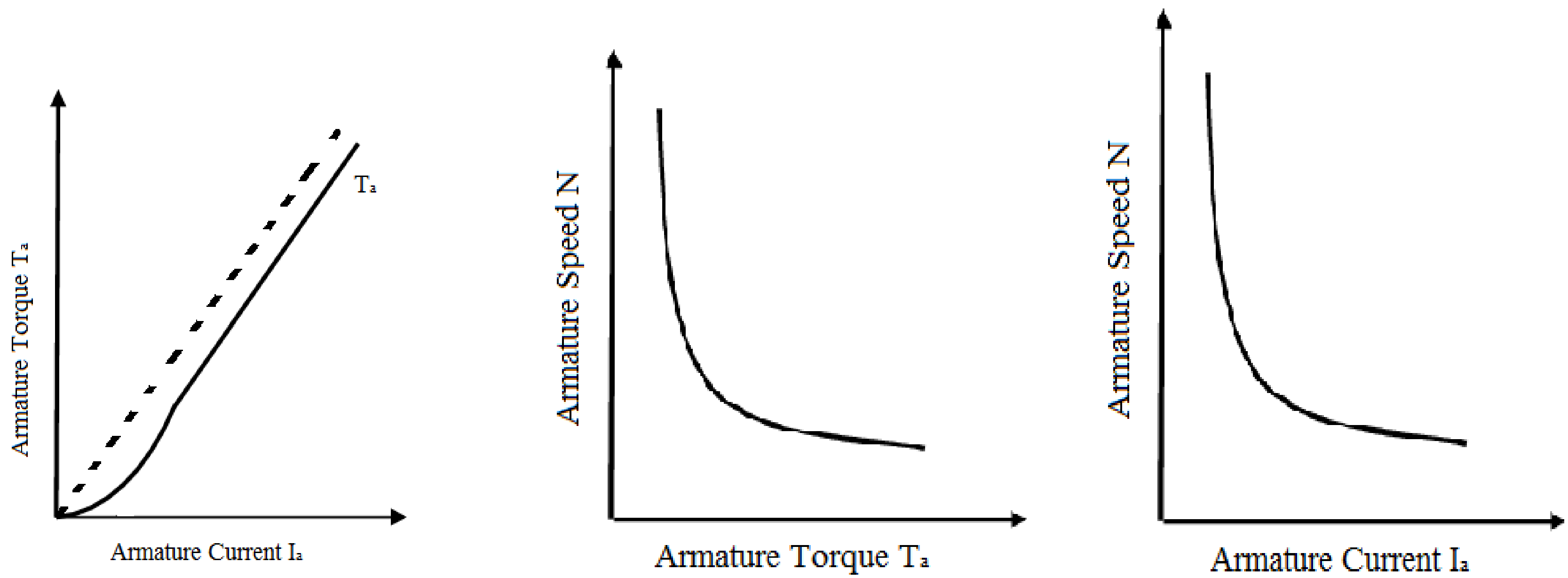
Characteristics of DC series motors



Characteristic of dc compound motor

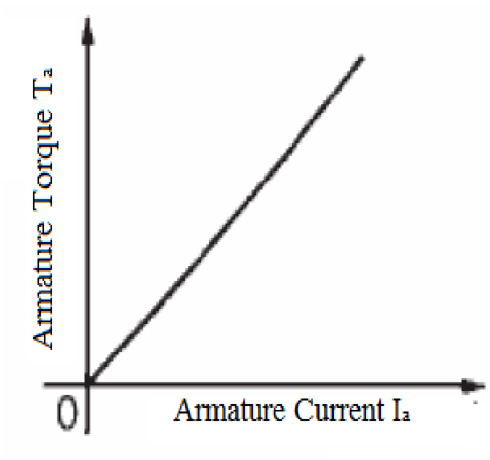
- DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of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

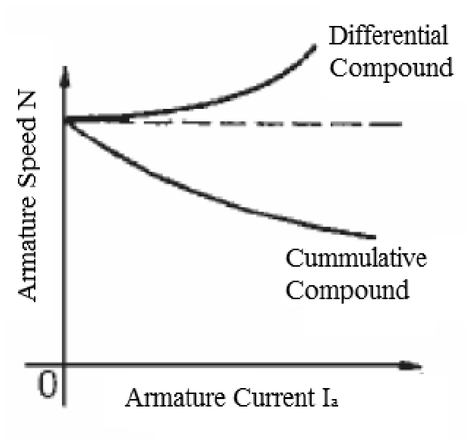
(a) Cumulative compound motor

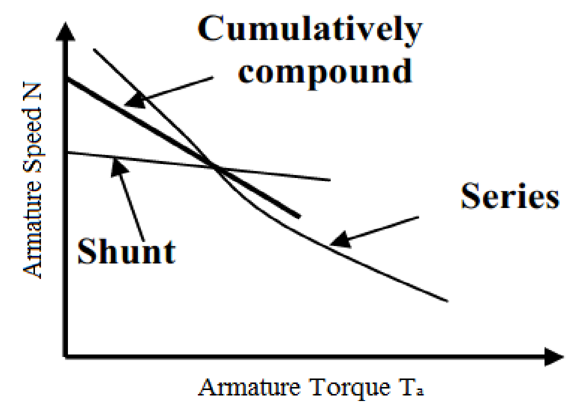
- Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors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

(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.







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

- All the generators work on the principle of dynamically induced emf.
- The change in flux associated with the conductor can exist only when there exists a relative motion between the conductor and the flux.
- The relative motion can be achieved by rotating the conductor w.r.t flux or by rotating flux w.r.t conductor. So, a voltage gets generated in a conductor as long as there exists a relative motion between conductor and the flux. Such an induced emf which is due to physical movement of coil or conductor w.r.t flux or movement of flux w.r.t coil or conductor is called dynamically induced emf.

- Whenever a conductor cuts magnetic flux, dynamically induced emf is produced in it according to Faraday's laws of Electromagnetic Induction.
- This emf causes a current to flow if the conductor circuit is closed.
- So, a generating action requires the following basic components to exist.
  1. The conductor or a coil
  2. Relative motion between the conductor and the flux.

- In a practical generator, the conductors are rotated to cut the magnetic flux, keeping flux stationary.
- To have a large voltage as output, a number of conductors are connected together in a specific manner to form a winding. The winding is called armature winding of a dc machine and the part on which this winding is kept is called armature of the dc machine.
- The magnetic field is produced by a current carrying winding which is called field winding.

- The conductors placed on the armature are rotated with the help of some external device. Such an external device is called a prime mover.
- The commonly used prime movers are diesel engines, steam engines, steam turbines, water turbines etc.
- The purpose of the prime mover is to rotate the electrical conductor as required by Faraday's laws The direction of induced emf can be obtained by using Flemings right hand rule.
- The magnitude of induced emf = $e = BLV \sin\emptyset = E_m \sin\emptyset$

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

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

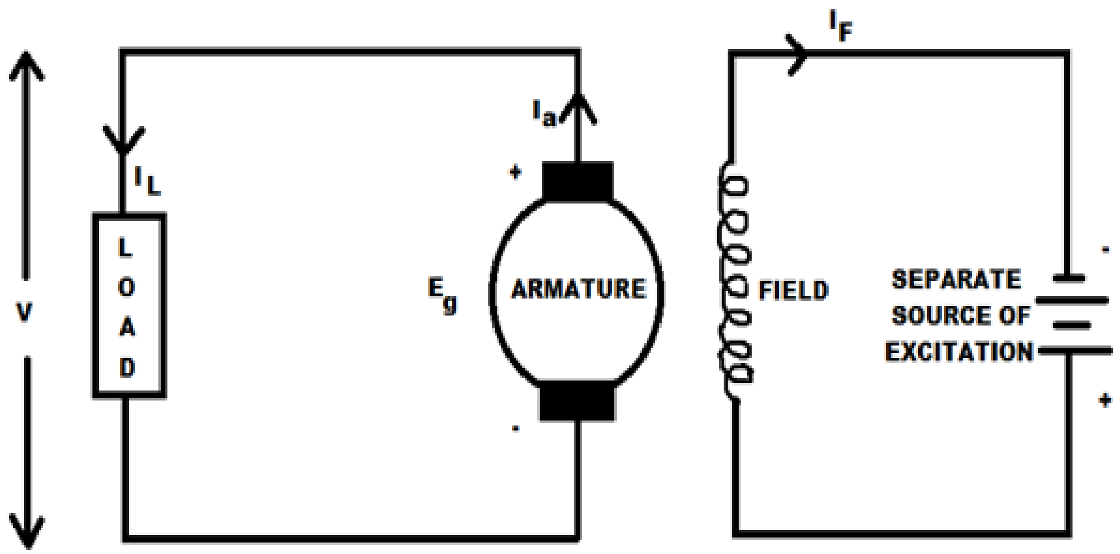
EMF generated/path = ØPN/60 x Z/2 = ØZPN/120 volt

TYPES OF DC GENERATOR

- **Permanent Magnet DC Generator:**
- When the flux in the magnetic circuit is established by the help of permanent magnets then it is known as Permanent magnet dc generator. It consists of an armature and one or several permanent magnets situated around the armature.
- This type of dc generators generates very low power. So, they are rarely found in industrial applications. They are normally used in small applications like dynamos in motor cycles.
- **Separately Excited DC Generator**
- These are the generators whose field magnets are energized by some external dc source such as battery .
- A circuit diagram of separately excited DC generator is shown in figure.

WORKING PRINCIPLE

- Ia = Armature current
- IL = Load current
- V = Terminal voltage
- Eg = Generated emf



Separately excited 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.

- This small current flows through the field coil as well as the load and
- thereby strengthening the pole flux. As the pole flux strengthened, it will produce more armature emf, which cause further increase of current through the field.
- This increased field current further raises armature emf and this cumulative phenomenon continues until the excitation reaches to the rated value

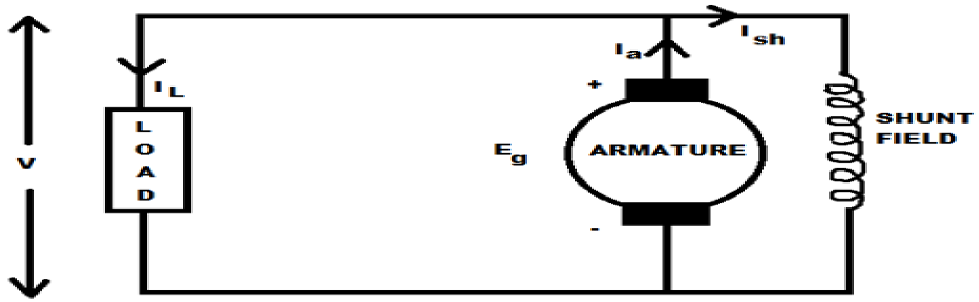
Series Wound Generator

- 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.
- As series field winding carries full load current it is designed with relatively few turns of thick wire
- .The electrical resistance of series field winding is therefore very low (nearly 0.5Ω).
- Let, Rsc = Series winding resistance Isc = Current flowing through the series field Ra = Armature resistance Ia = Armature current IL = Load current V = Terminal voltage Eg = Generated emf

TYPES OF DC GENERATORS

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.
- LIn shunt wound generators the voltage in the field winding is same as the voltage across the terminal.
- et, Rsh = Shunt winding resistance Ish = Current flowing through the shunt field Ra = Armature resistance Ia = Armature current IL = Load current V = Terminal voltage Eg = Generated emf



Shunt Wound Generator

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

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

- **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.

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.

MODULE-III

ALTERNATING QUANTITIES AND AC MACHINES

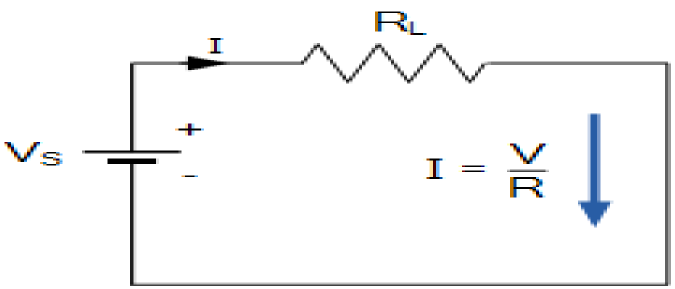
MODULE - III

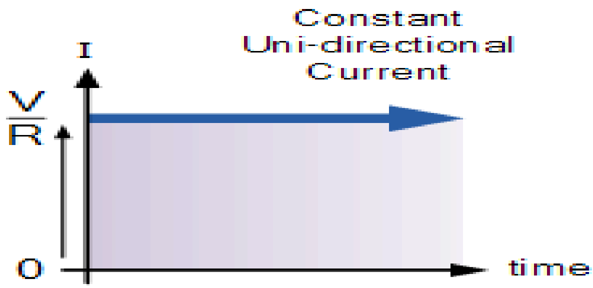
CLOs	Course Learning Outcome
CLO 10	List out various alternating quantities such as Sinusoidal AC voltage, average and RMS values, form and peak factor, and understand concept of three phase alternating quantity.
CLO 11	Discuss the principle of operation of induction motor.
CLO 12	Explain the construction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

DC CIRCUIT AND WAVEFORM

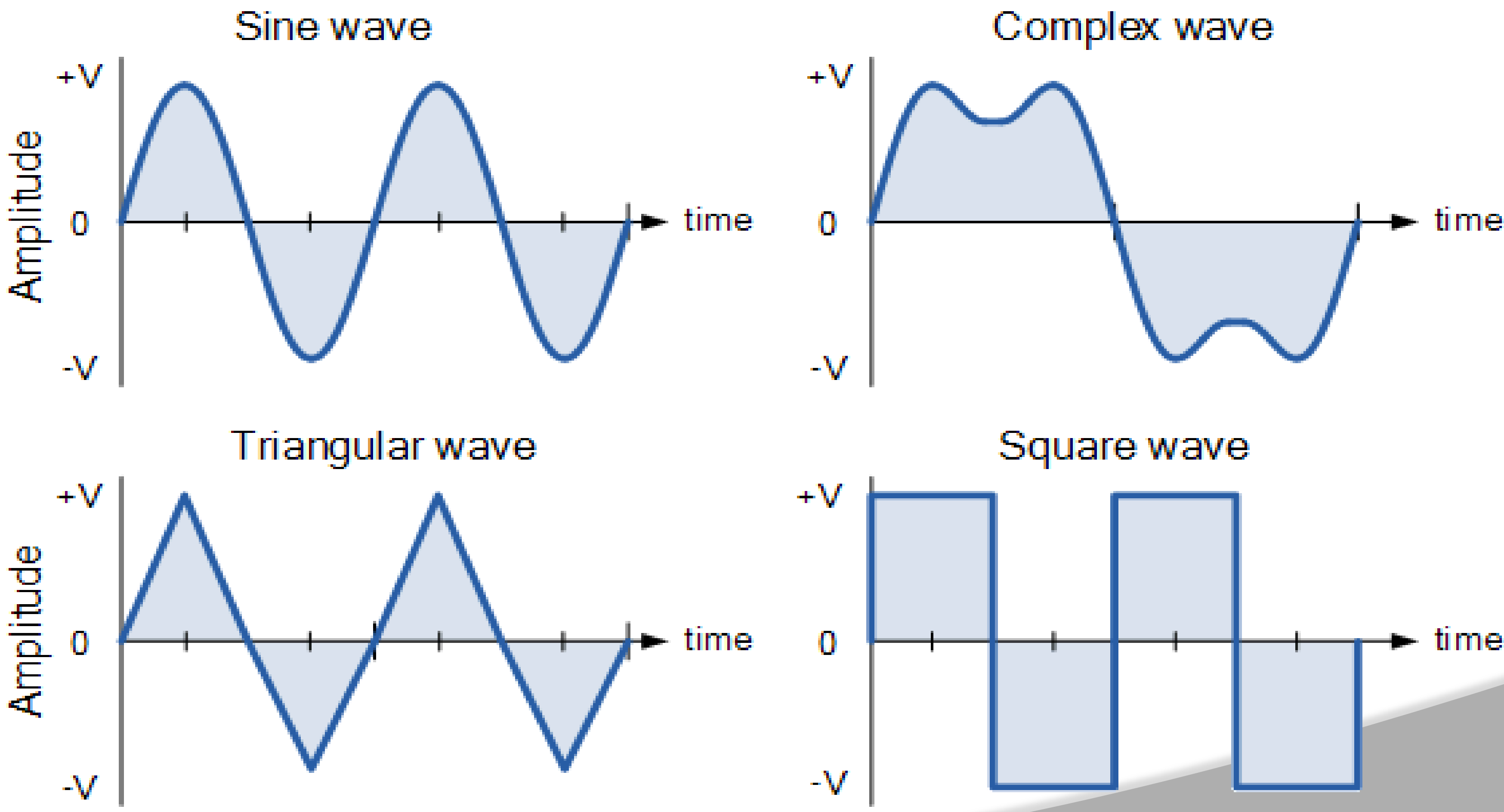




- An alternating function or **AC Waveform** on the other hand is defined as one that varies in both magnitude and direction in more or less an even manner with respect to time making it a “Bi-directional” waveform. An AC function can represent either a power source or a signal source with the shape 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, (ƒ) is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ($ƒ = 1/T$) 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

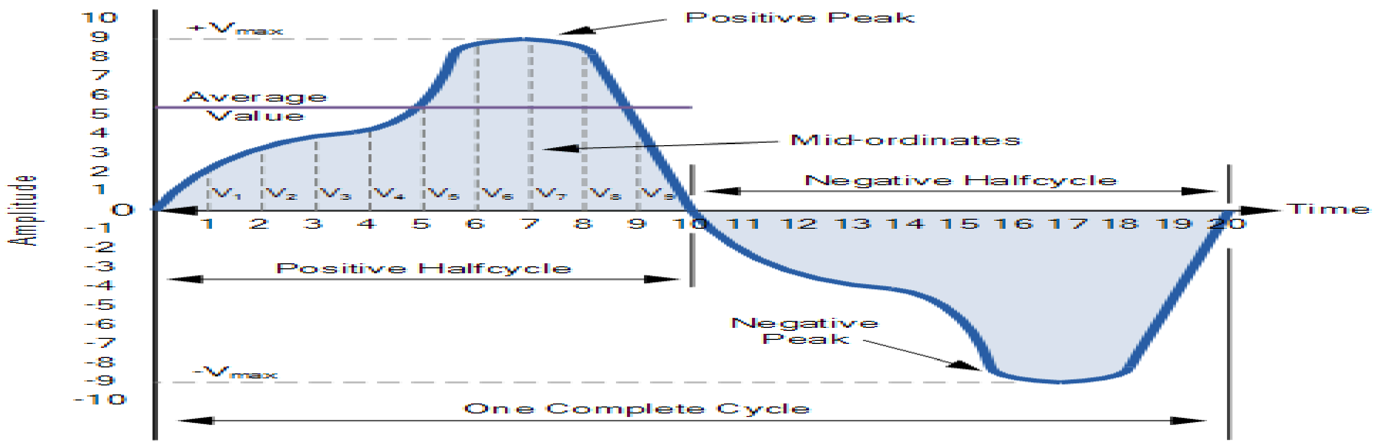


- The time taken for an **AC Waveform** to complete one full pattern from its positive half to its negative half and back to its zero baseline again is called a **Cycle** and one complete cycle contains both a positive half-cycle and a negative half-cycle.
- The time taken by the waveform to complete 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

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

- 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.

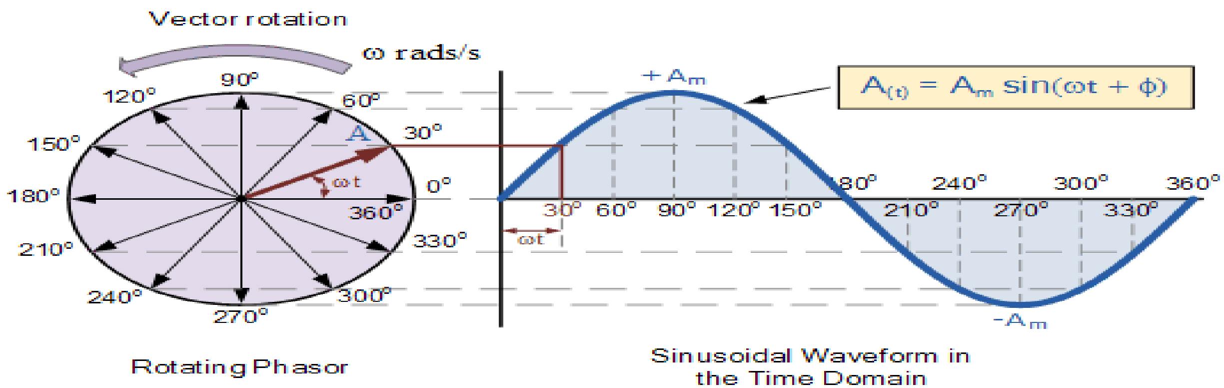
$$CrestFactor = \frac{\text{Peak Value}}{\text{R.M.S Value}} = \frac{V_{\max}}{0.707 \times V_{\max}}$$

- For a pure sinusoidal waveform the Crest Factor will always be equal to 1.414.

PHASOR DIAGRAMS AND PHASOR ALGEBRA

- Phasor Diagrams are a graphical way of representing the magnitude and directional relationship between two or more alternating quantities
- Sinusoidal waveforms of the same frequency can have a Phase Difference between themselves which represents the angular difference of the two sinusoidal waveforms. Also the terms “lead” and “lag” as well as “in-phase” and “out-of-phase” are commonly used to indicate the relationship of one waveform to the other with the generalized sinusoidal expression given as: $A_{(t)} = A_m \sin(\omega t \pm \Phi)$ representing the sinusoid in the time-domain form.

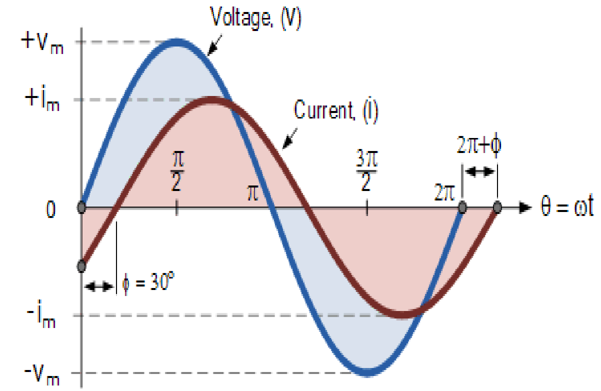
PHASOR DIAGRAM OF A SINUSOIDAL WAVEFORM



- As the single vector rotates in an anti-clockwise direction, its tip at point A will rotate one complete revolution of 360° or 2π representing one complete cycle. If the length of its moving tip is transferred at different angular intervals in time to a graph as shown above, a sinusoidal waveform would be drawn starting at the left with zero time.
- Each position along the horizontal axis indicates the time that has elapsed since zero time, t = 0. When the vector is horizontal the tip of the vector represents the angles at 0°, 180° and at 360°.

PHASE DIFFERENCE OF A SINUSOIDAL WAVEFORM

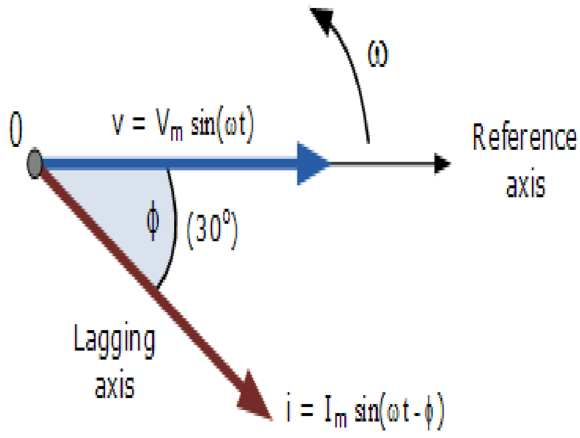
- The generalised mathematical expression to define these two sinusoidal quantities will be written as:
- The current, i is lagging the voltage, v by angle Φ and in our example above this is 30°. So the difference between the two phasors representing the two sinusoidal quantities is angle Φ and the resulting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

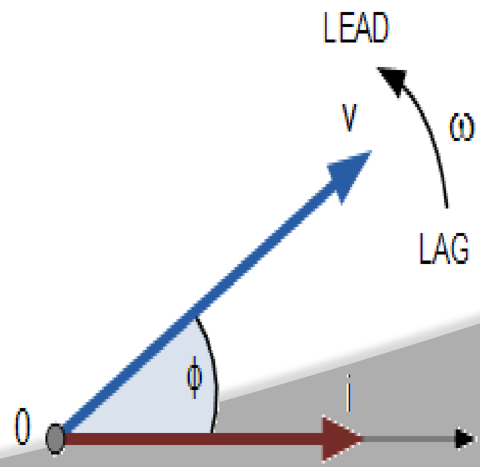


$$v_{(t)} = V_m \sin(\omega t)$$

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

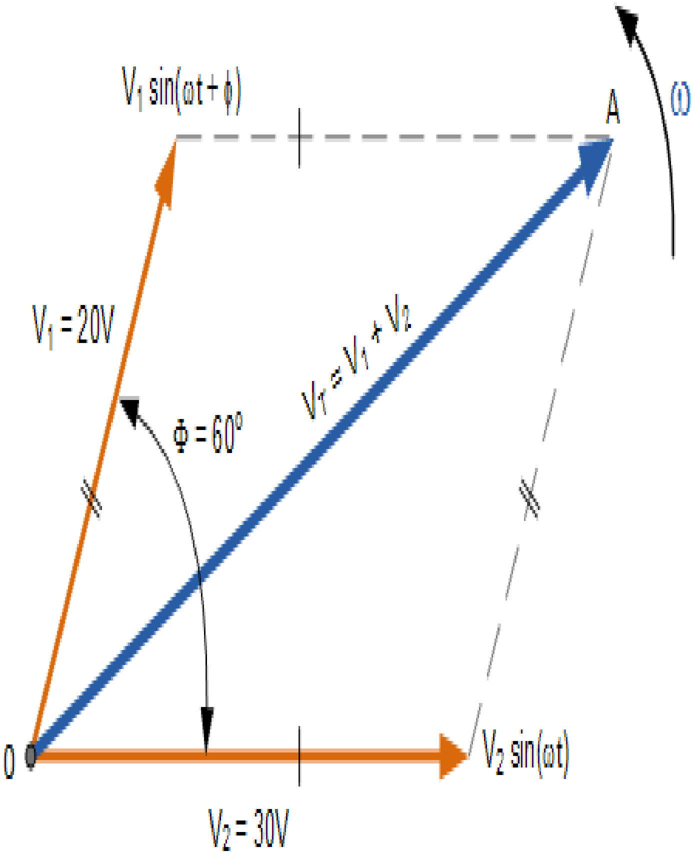
- The phasor diagram is drawn corresponding to time zero (t = 0) on the horizontal axis. The lengths of the phasors are proportional to the values of the voltage, (V) and the current, (I) at the instant in time that the phasor diagram is drawn. The current phasor lags the voltage phasor by the angle, Φ, as the two phasors rotate in an *anticlockwise*direction as stated earlier, therefore the angle, Φ is also measured in the same anticlockwise direction.





PHASOR ADDITION OF TWO PHASORS

- By drawing out the two phasors to scale onto graph paper, their phasor sum $V_1 + V_2$ can be easily found by measuring the length of the diagonal line, known as the "resultant r-vector", from the zero point to the intersection of the construction lines 0-A. The downside of this graphical method is that it is time consuming when drawing the phasors to scale.



AC INDUCTANCE AND INDUCTIVE REACTANCE

- The opposition to current flow through an AC Inductor is called Inductive Reactance and which depends lineally on the supply frequency
- Inductors and chokes are basically coils or loops of wire that are either wound around a hollow tube former (air cored) or wound around some ferromagnetic material (iron cored) to increase their inductive value called **inductance**.
- Inductors store their energy in the form of a magnetic field that is created when a voltage is applied across the terminals of an inductor. The growth of the current flowing through the inductor is not instant but is determined by the inductors own self-induced or back emf value. Then for an inductor coil, this back emf voltage V_L is proportional to the ***rate of change of the current*** flowing through it.

- The actual opposition to the current flowing through a coil in an AC circuit is determined by the AC Resistance of the coil with this AC resistance being represented by a complex number. But to distinguish a DC resistance value from an AC resistance value, which is also known as Impedance, the term **Reactance** is used.
- Like resistance, reactance is measured in Ohm's but is given the symbol "X" to distinguish it from a purely resistive "R" value and as the component in question is an inductor, the reactance of an inductor is called **Inductive Reactance**, (X_L) and is measured in Ohms. Its value can be found from the formula.

INDUCTIVE REACTANCE

$$X_L = 2\Pi fL$$

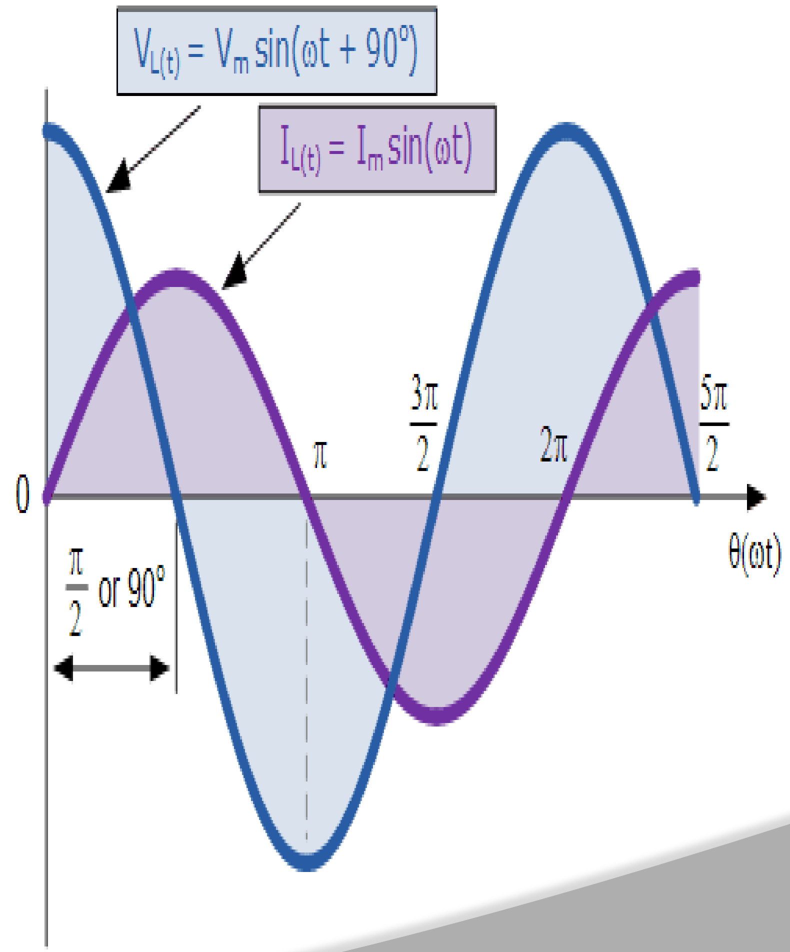
- Where: X_L is the Inductive Reactance in Ohms, ƒ is the frequency in Hertz and L is the inductance of the coil in Henries.
- We can also define inductive reactance in radians, where Omega, ω equals 2πf.

$$X_L = \omega L$$

- So whenever a sinusoidal voltage is applied to an inductive coil, the back emf opposes the rise and fall of the current flowing through the coil and in a purely inductive coil which has zero resistance or losses, this impedance (which can be a complex number) is equal to its inductive reactance. Also reactance is represented by a vector as it has both a magnitude and a direction (angle). Consider the circuit below.

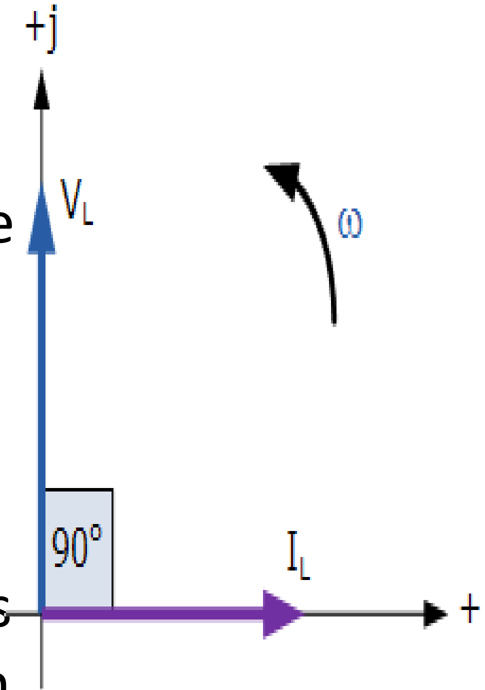
SINUSOIDAL WAVEFORMS FOR AC INDUCTANCE

- This effect can also be represented by a phasor diagram were in a purely inductive circuit the voltage "LEADS" the current by 90°. But by using the voltage as our reference, we can also say that the current "LAGS" the voltage by one quarter of a cycle or 90° as shown in the vector diagram below.



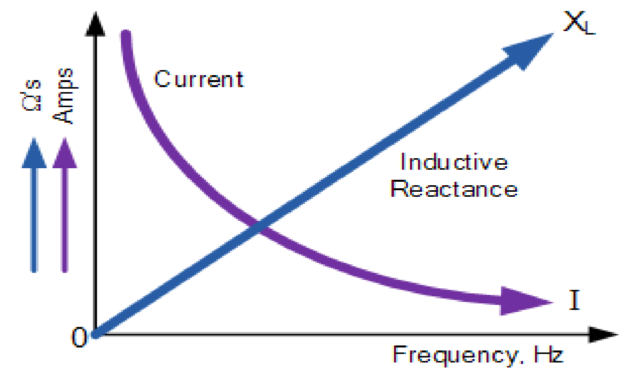
PHASOR DIAGRAM FOR AC INDUCTANCE

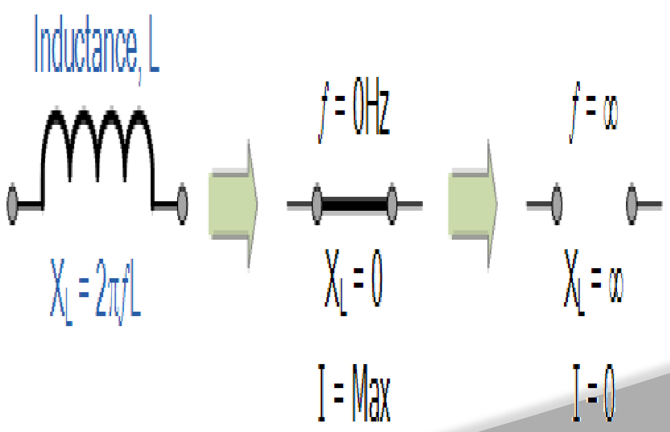
- So for a pure loss less inductor, V_L “leads” I_L by 90^o, or we can say that I_L “lags” V_L by 90^o.
- There are many different ways to remember the phase relationship between the voltage and current flowing through a pure inductor circuit, but one very simple and easy to remember way is to use the mnemonic expression “ELI” (pronounced *Ellie* as in the girls name). ELI stands for Electromotive force first in an AC inductance, L before the current I. In other words, voltage before the current in an inductor, E, L, I equals “ELI”, and whichever phase angle the voltage starts at, this expression always holds true for a pure inductor circuit.



INDUCTIVE REACTANCE AGAINST FREQUENCY

- The inductive reactance of an inductor increases as the frequency across it increases therefore inductive reactance is proportional to frequency ($X_L \propto f$) as the back emf generated in the inductor is equal to its inductance multiplied by the rate of change of current in the inductor.
- Also as the frequency increases the current flowing through the inductor also reduces in value.





- In an AC circuit containing pure inductance the following formula applies:

$$Current(I) = \frac{\text{Voltage}}{\text{Opposition of current flow}} = \frac{V}{X_L}$$

- So how did we arrive at this equation. Well the self induced emf in the inductor is determined by Faraday's Law that produces the effect of self-induction in the inductor due to the rate of change of the current and the maximum value of the induced emf will correspond to the maximum rate of change. Then the voltage in the inductor coil is given as:

$$V_{L(t)} = L\frac{di_{L(t)}}{dt}$$

$$if, i_{L(t)} = I_{\max}\sin(\omega t)$$

$$then: V_{L(t)} = L\frac{d}{dt}I_{\max}\sin(\omega t + \theta) \quad = \omega L I_{\max}\cos(\omega t + \theta) = \omega L I_{\max}\sin(\omega t + 90^0)$$

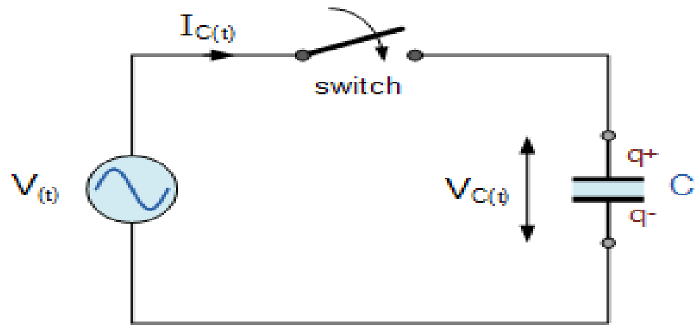
- then the voltage across an AC inductance will be defined as:

AC CAPACITANCE AND CAPACITIVE REACTANCE

- The opposition to current flow through an AC Capacitor is called Capacitive Reactance and which itself is inversely proportional to the supply frequency
- **Capacitors** store energy on their conductive plates in the form of an electrical charge. When a capacitor is connected across a DC supply voltage it charges up to the value of the applied voltage at a rate determined by its time constant.
- A capacitor will maintain or hold this charge indefinitely as long as the supply voltage is present. During this charging process, a charging current, i flows into the capacitor opposed by any changes to the voltage at a rate which is equal to the rate of change of the electrical charge on the plates. A capacitor therefore has an opposition to current flowing onto its plates.

- A pure capacitor will maintain this charge indefinitely on its plates even if the DC supply voltage is removed. However, in a sinusoidal voltage circuit which contains “AC Capacitance”, the capacitor will alternately charge and discharge at a rate determined by the frequency of the supply. Then capacitors in AC circuits are constantly charging and discharging respectively.
- When an alternating sinusoidal voltage is applied to the plates of an AC capacitor, the capacitor is charged firstly in one direction and then in the opposite direction changing polarity at the same rate as the AC supply voltage. This instantaneous change in voltage across the capacitor is opposed by the fact that it takes a certain amount of time to deposit (or release) this charge onto the plates and is given by $V = Q/C$. Consider the circuit below.

AC CAPACITANCE WITH A SINUSOIDAL SUPPLY

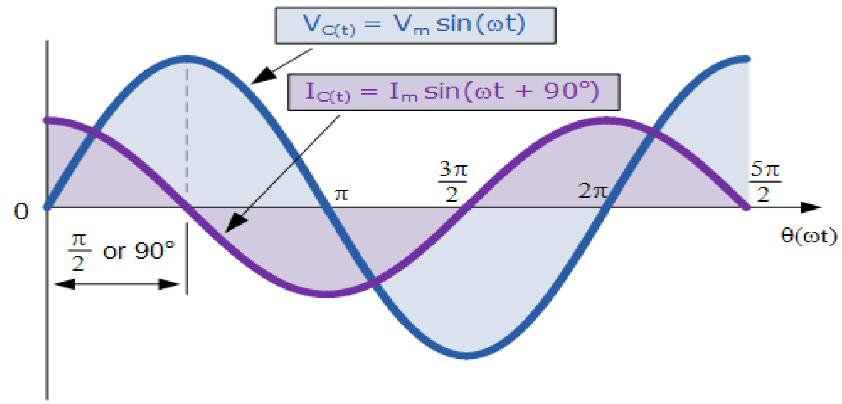


- When the switch is closed in the circuit above, a high current will start to flow into the capacitor as there is no charge on the plates at *t = 0*. The sinusoidal supply voltage, V is increasing in a positive direction at its maximum rate as it crosses the zero reference axis at an instant in time given as 0^o. Since the rate of change of the potential difference across the plates is now at its maximum value, the flow of current into the capacitor will also be at its maximum rate as the maximum amount of electrons are moving from one plate to the other.

- As the sinusoidal supply voltage reaches its 90^o point on the waveform it begins to slow down and for a very brief instant in time the potential difference across the plates is neither increasing nor decreasing therefore the current decreases to zero as there is no rate of voltage change. At this 90^o point the potential difference across the capacitor is at its maximum (V_{max}), no current flows into the capacitor as the capacitor is now fully charged and its plates saturated with electrons.

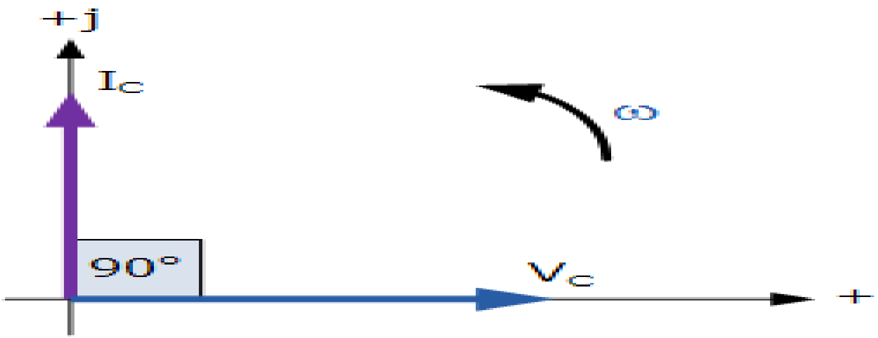
- At the end of this instant in time the supply voltage begins to decrease in a negative direction down towards the zero reference line at 180°. Although the supply voltage is still positive in nature the capacitor starts to discharge some of its excess electrons on its plates in an effort to maintain a constant voltage. This results in the capacitor current flowing in the opposite or negative direction.
- Then during this first half cycle 0° to 180° the applied voltage reaches its maximum positive value a quarter (1/4f) of a cycle after the current reaches its maximum positive value, in other words, a voltage applied to a purely capacitive circuit "LAGS" the current by a quarter of a cycle or 90° as shown below.

SINUSOIDAL WAVEFORMS FOR AC CAPACITANCE



- During the second half cycle 180º to 360º, the supply voltage reverses direction and heads towards its negative peak value at 270º. At this point the potential difference across the plates is neither decreasing nor increasing and the current decreases to zero. The potential difference across the capacitor is at its maximum negative value, no current flows into the capacitor and it becomes fully charged the same as at its 90º point but in the opposite direction.

PHASOR DIAGRAM FOR AC CAPACITANCE



- So for a pure capacitor, V_C "lags" I_C by 90º, or we can say that I_C "leads" V_C by 90º.
- There are many different ways to remember the phase relationship between the voltage and current flowing in a pure AC capacitance circuit, but one very simple and easy to remember way is to use the mnemonic expression called "ICE". ICE stands for current Ifirst in an AC capacitance, C before Electromotive force. In other words, current before the voltage in a capacitor, I, C, E equals "ICE", and whichever phase angle the voltage starts at, this expression always holds true for a pure AC capacitance circuit

CAPACITIVE REACTANCE

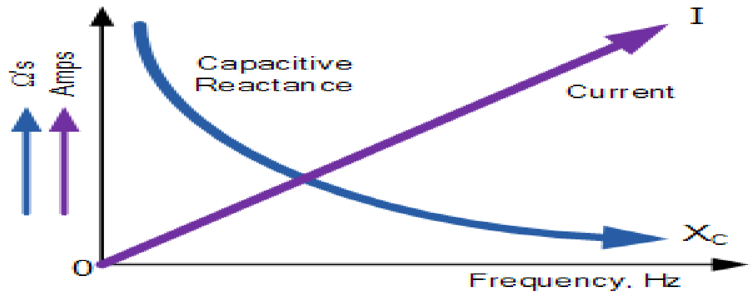
$$X_C = \frac{1}{2\Pi f C}$$

- Where: X_C is the Capacitive Reactance in Ohms, ƒ is the frequency in Hertz and C is the AC capacitance in Farads, symbol F.
- When dealing with AC capacitance, we can also define capacitive reactance in terms of radians, where Omega, ω equals 2πf.

$$X_C = \frac{1}{\omega C}$$

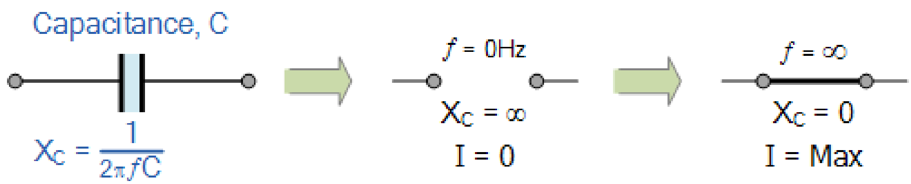
- From the above formula we can see that the value of capacitive reactance and therefore its overall impedance (in Ohms) decreases towards zero as the frequency increases acting like a short circuit. Likewise, as the frequency approaches zero or DC, the capacitors reactance increases to infinity, acting like an open circuit which is why capacitors block DC.
- The relationship between capacitive reactance and frequency is the exact opposite to that of inductive reactance, (X_L) we saw in the previous tutorial. This means then that capacitive reactance is “inversely proportional to frequency” and has a high value at low frequencies and a low value at higher frequencies as shown.

CAPACITIVE REACTANCE AGAINST FREQUENCY



- Capacitive reactance of a capacitor decreases as the frequency across its plates increases. Therefore, capacitive reactance is inversely proportional to frequency. Capacitive reactance opposes current flow but the electrostatic charge on the plates (its AC capacitance value) remains constant.
- This means it becomes easier for the capacitor to fully absorb the change in charge on its plates during each half cycle. Also as the frequency increases the current flowing into the capacitor increases in value because the rate of voltage change across its plates increases.

- We can present the effect of very low and very high frequencies on the reactance of a pure AC Capacitance as follows:



- In an AC circuit containing pure capacitance the current (electron flow) flowing into the capacitor is given as

$$I_{C(t)} = \frac{dq}{dt} \quad where: q = CV_C = CV_{\max}\sin(\omega t)$$

$$\therefore I_{C(t)} = \frac{d}{dt} CV_{\max}\sin(\omega t) = \omega CV_{\max}\cos(\omega t)$$

$$if: I_{\max} = \frac{V_{\max}}{X_C} \quad where: X_C = \frac{1}{2\Pi fC} = \frac{1}{\omega C}$$

$$then: I_{\max} = \omega CV_{\max}$$

- and therefore, the rms current flowing into an AC capacitance will be defined as:

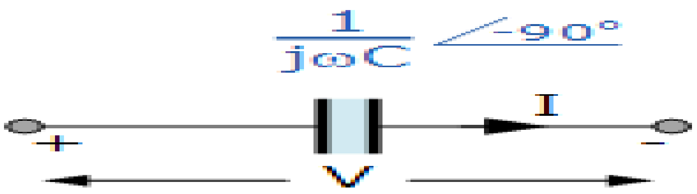
$$I_{C(t)} = I_{\max}\sin(\omega t + 90^0)$$

PHASOR DOMAIN

- In the phasor domain the voltage across the plates of an AC capacitance will be:

- and in Polar Form this would be written as: $X_C\angle\text{-}90^o$ where:

$$V_C = \frac{1}{j\omega C} \times I_C$$



$$where: \frac{1}{j\omega C} = jX_C = \frac{1}{2\Pi f C} = IMPEDENCE, Z$$

$$x_C\angle\theta = \frac{V_C\angle 0^0}{I_C\angle +90^0}$$

$$x_C\angle\theta = \frac{1}{j\omega C} = 0 - jX_C = \frac{1}{\omega C}\angle -90^0 = Z\angle -90^0$$

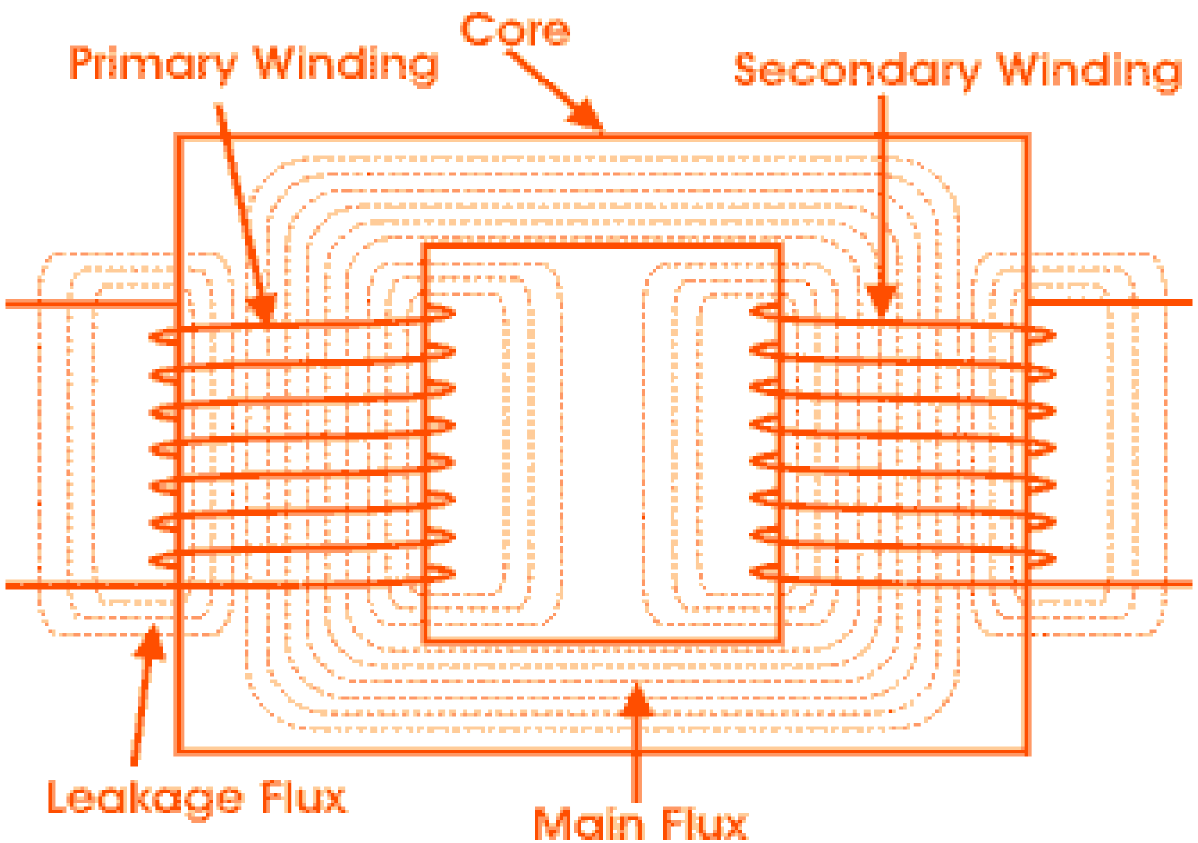
INTRODUCTION

- 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.

- WHAT IS TRANSFORMER
- A transformer is a static piece of apparatus by means of
- which an electrical power is transferred from one
- alternating current circuit to another electrical circuit
- There is no electrical contact between them
- The desire change in voltage or current without any
- change in frequency
- **It works on the principle of mutual induction**

- 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.

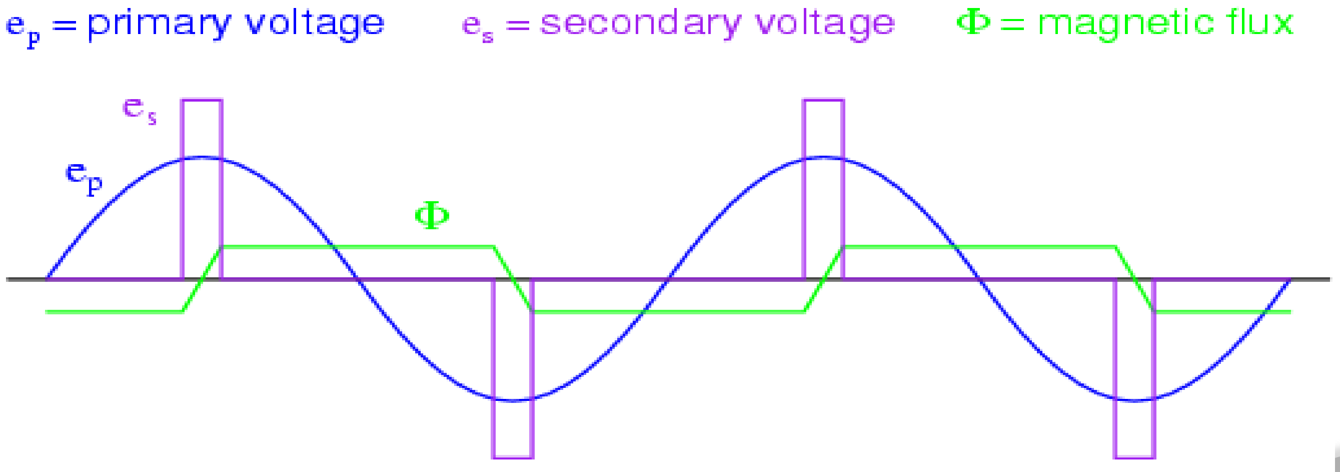
PRINCIPLE OF TRANSFORMER



- The primary and secondary coil wound on a ferromagnetic metal core.
- The function of the core is to transfer the changing magnetic flux from the primary coil to the secondary coil.
- The primary has N1 no of turns and the secondary has N2 no of turns the of turns plays major important role in the function of transformer.

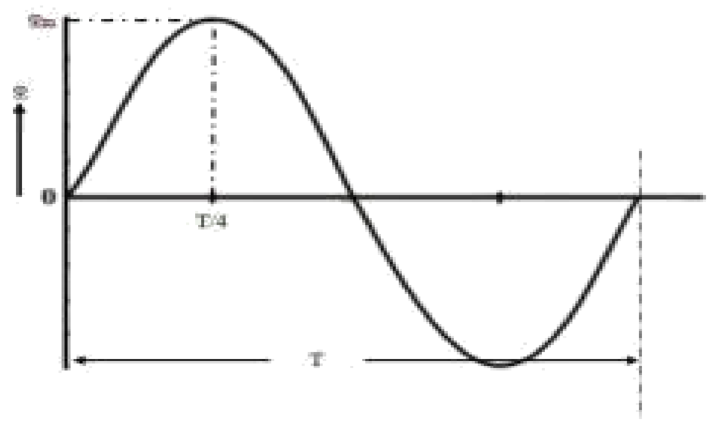
WORKING PRINCIPLE

The transformer works in the principle of mutual induction
“The principle of mutual induction states that when the two coils are
inductively coupled and if the current in coil change uniformly then the e.m.f. induced in the other coils. This e.m.f can drive a current when a closed path is provide to it.”



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 =4.44fϕm×N1 = 4.44fBm×A×N1

Similarly;

E2= 4.44 f ϕm × N2 = 4.44 f Bm × A × 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**

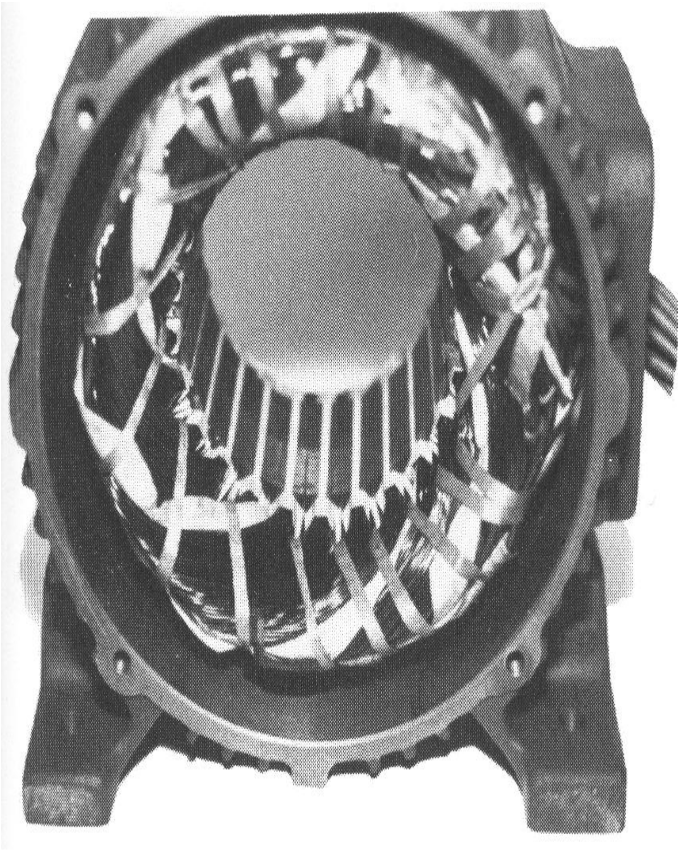
LOSSES

•Hysteresis loss :
During magnetization and demagnetization ,
due to hysteresis effect some energy losses in the core called hysteresis loss

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

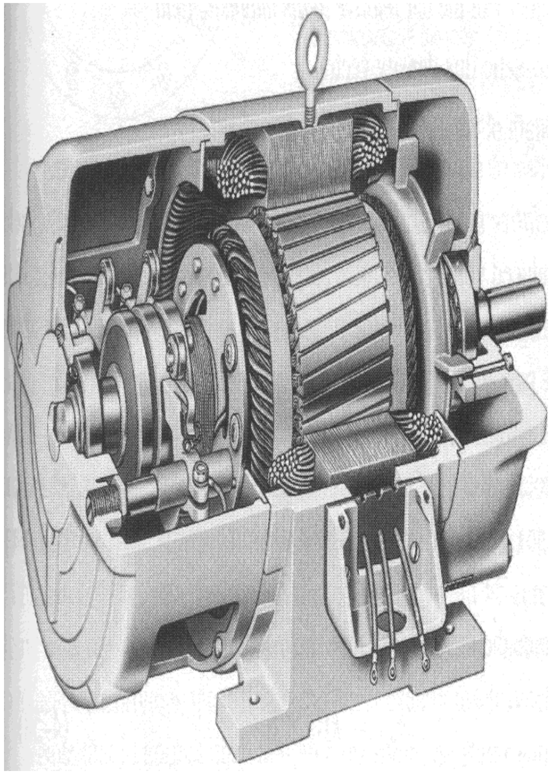
CONSTRUCTION

- 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



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)



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

PRINCIPLE OF OPERATION

- This rotating magnetic field cuts the rotor windings and produces an induced voltage in the rotor windings
- Due to the fact that the rotor windings are short circuited, for both squirrel cage and wound-rotor, and induced current flows in the rotor windings
- The rotor current produces another magnetic field
- So, the IM will always run at a speed lower than the synchronous speed
- The difference between the motor speed and the synchronous speed is called the Slip

SLIP

$$S = \frac{n_{sync} - n_m}{n_{sync}}$$

Where *s* is the *slip*

Notice that : if the rotor runs at synchronous speed

$s = 0$

if the rotor is stationary

$s = 1$

Slip may be expressed as a percentage by multiplying the above eq. by 100, notice that the slip is a ratio and doesn't have units

ROTOR FREQUENCY

- The frequency of the voltage induced in the rotor is given by

$$f_r = \frac{P \times n}{120}$$

Where f_r = the rotor frequency (Hz)

P = number of stator poles

n = slip speed (rpm)

$$f_r = \frac{P \times (n_s - n_m)}{120}$$

$$= \frac{P \times sn_s}{120} = sf_e$$

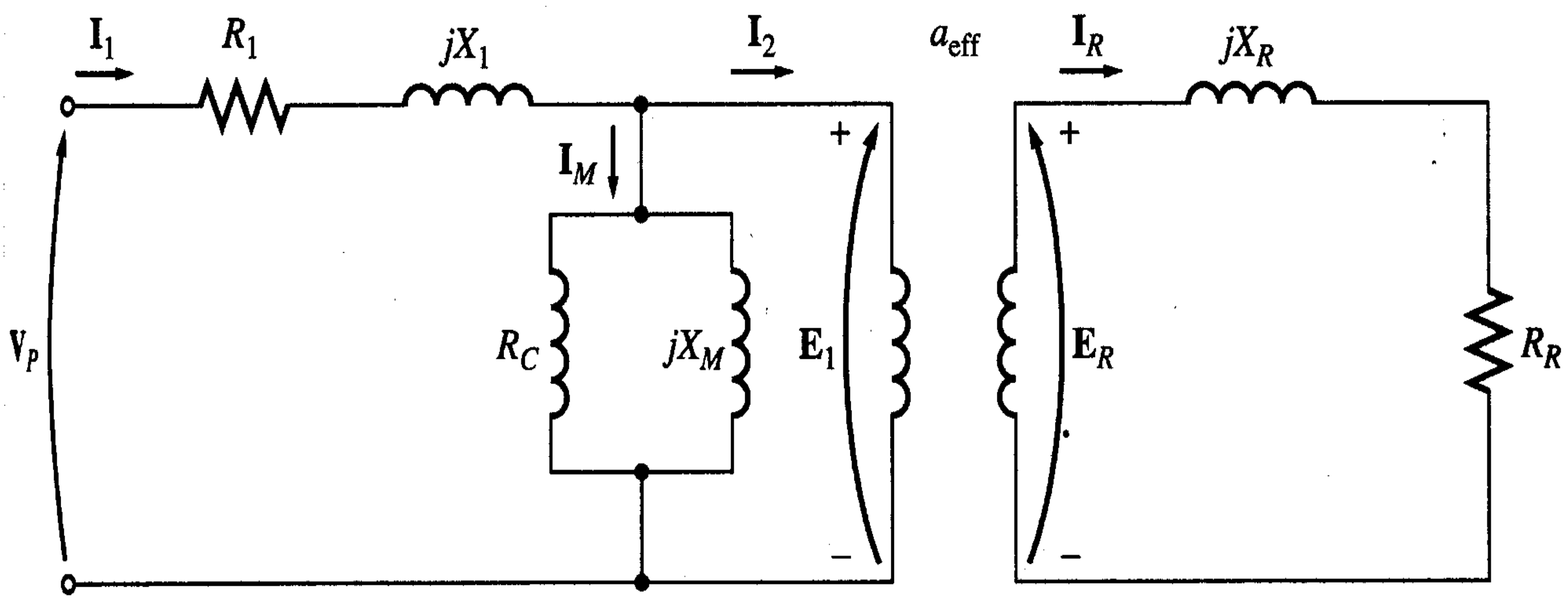
$$f_r = sf_e$$

When the rotor is blocked (*s*=1) , the frequency of the induced voltage is equal to the supply frequency

On the other hand, if the rotor runs at synchronous speed (*s* = 0), the frequency will be zero

EQUIVALENT CIRCUIT

- The induction motor is similar to the transformer with the exception that its secondary windings are free to rotate



- When the rotor is locked (or blocked), i.e. s =1, the largest voltage and rotor frequency are induced in the rotor, Why?
- On the other side, if the rotor rotates at synchronous speed, i.e. s = 0, the induced voltage and frequency in the rotor will be equal to zero, Why?

$$E_r = sE_{Ro}$$

Where E_{R0} is the largest value of the rotor's induced voltage obtained at s = 1(locked rotor)

- The same is true for the frequency, i.e.

$$f_r = sf_e$$

It is known that

$$X = \omega L = 2\prod fL$$

So, as the frequency of the induced voltage in the rotor changes, the reactance of the rotor circuit also changes

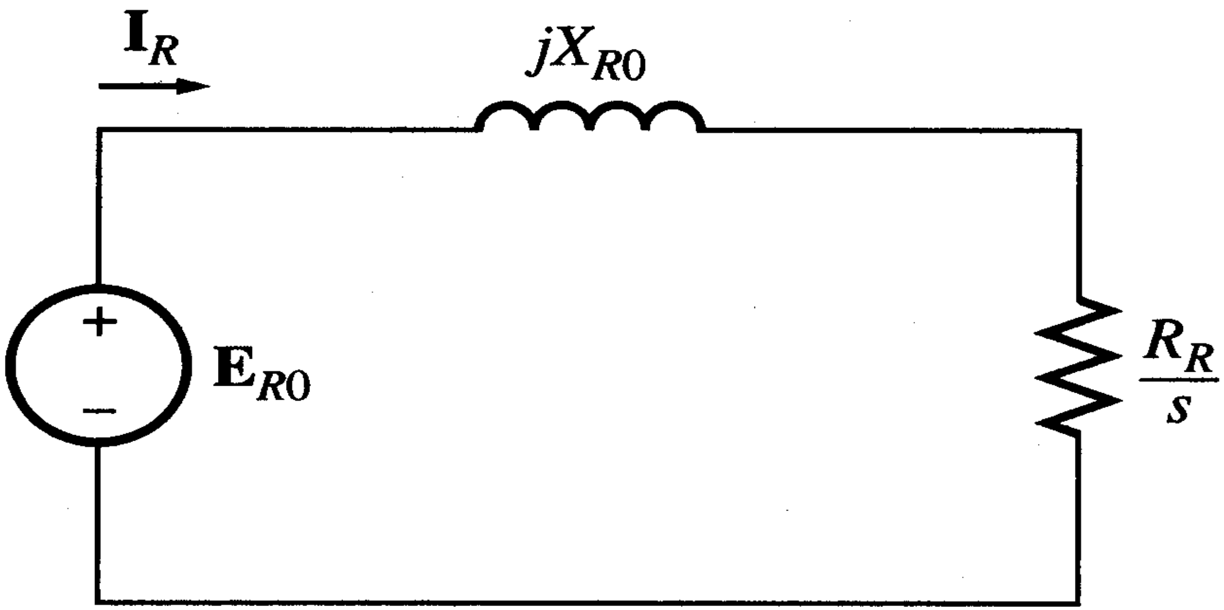
Where X_{r0} is the rotor reactance at the supply frequency (at blocked rotor)

$$X_r = \omega_r L_r = 2\prod f_r L_r$$

$$= 2\Pi s f_r L_r$$

$$= sX_{r0}$$

- Now we can have the rotor equivalent circuit



Now as we managed to solve the induced voltage and different frequency problems, we can combine the stator and rotor circuits in one equivalent circuit

- Where

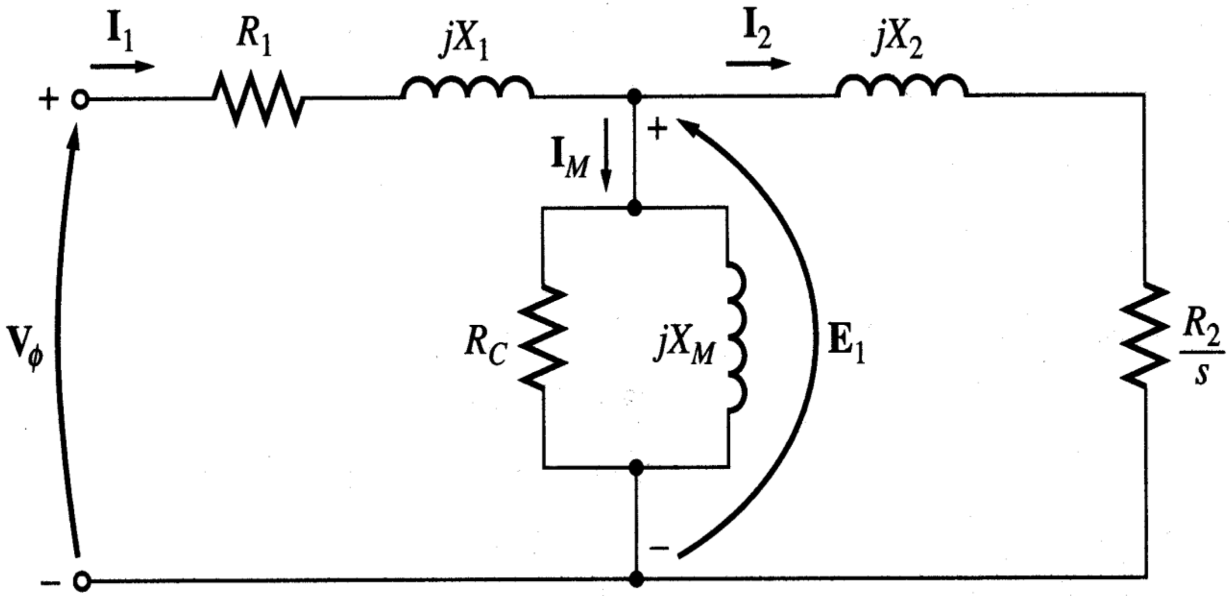
$$X_2 = a_{eff}^2 X_{R0}$$

$$R_2 = a_{eff}^2 R_R$$

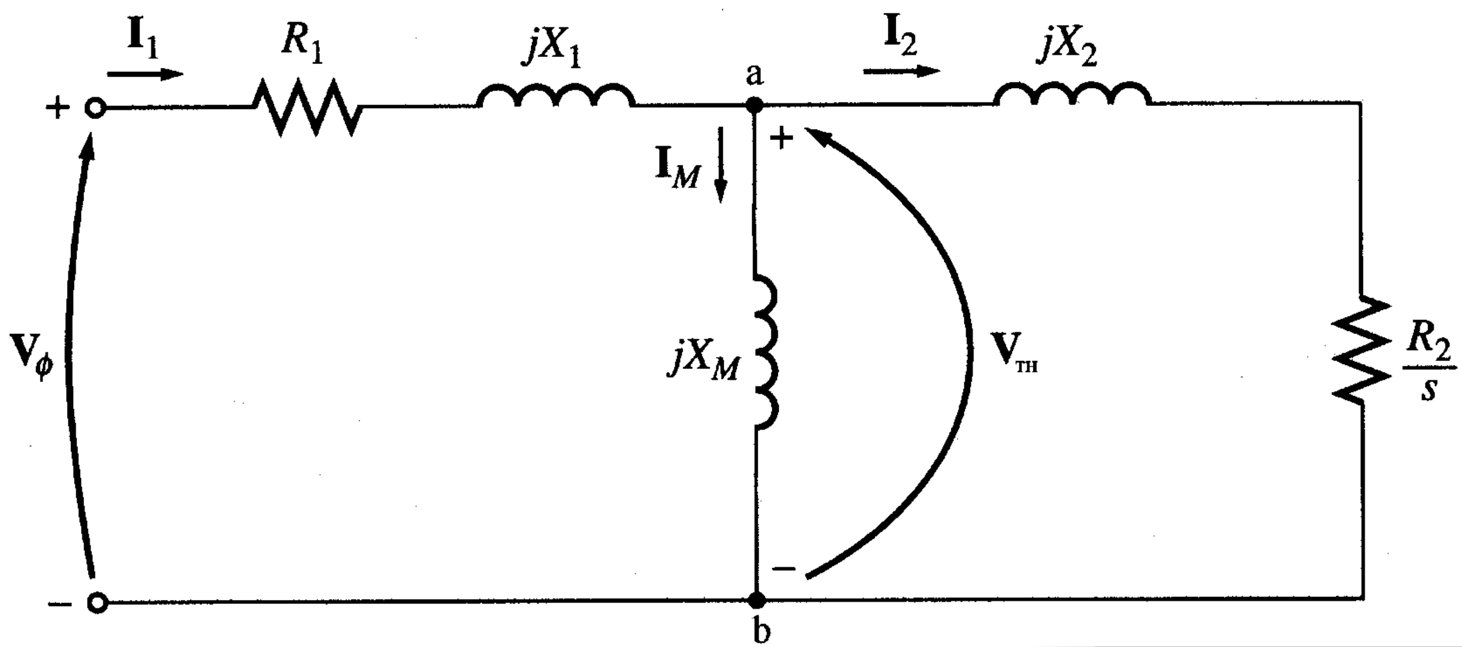
$$I_2 = \frac{I_R}{a_{eff}}$$

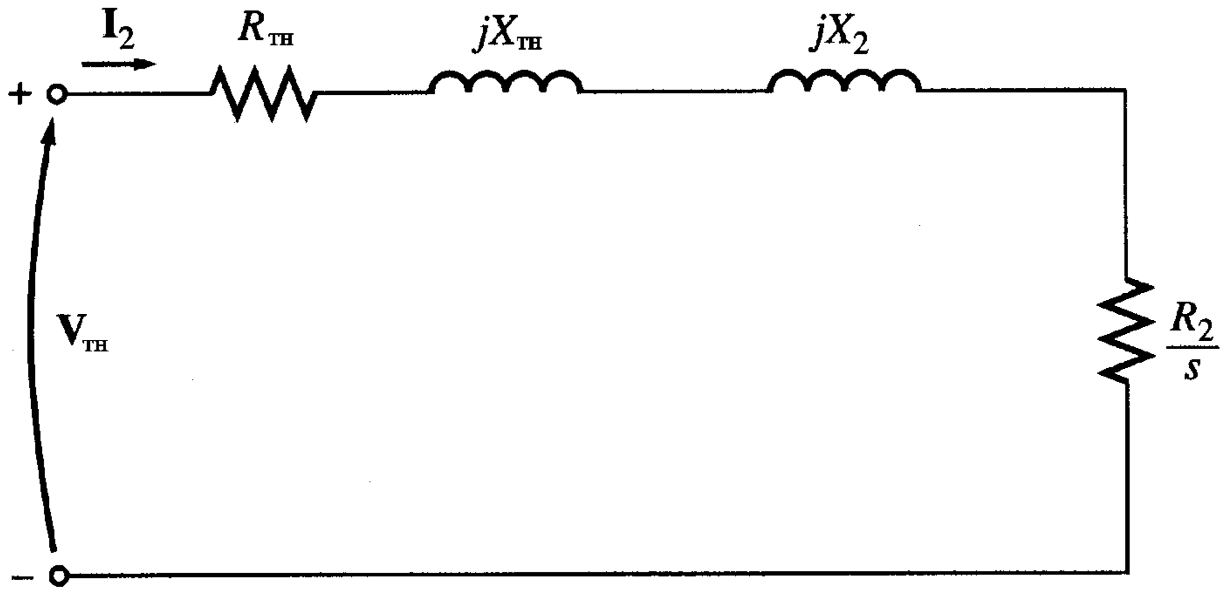
$$E_1 = a_{eff} E_{R0}$$

$$a_{eff} = \frac{N_S}{N_R}$$



- Thevenin's theorem can be used to transform the network to the left of points 'a' and 'b' into an equivalent voltage source V_{TH} in series with equivalent resistance





$$V_{TH} = V_\phi \frac{jX_M}{R_1 + j(X_1 + X_M)} \qquad |V_{TH}| = |V_\phi| \frac{X_M}{\sqrt{R_1^2 + (X_1 + X_M)^2}}$$

$$R_{TH} + jX_{TH} = (R_1 + jX_1) // jX_M$$

- Since $X_M >> X_1$ and $X_M >> R_1$

$$V_{TH} \approx V_{\phi} \frac{X_M}{X_1 + X_M}$$

Because $X_M >> X_1$ and $X_M + X_1 >> R_1$

$$R_{TH} \approx R_1 \left(\frac{X_M}{X_1 + X_M} \right)^2$$

$$X_{TH} \approx X_1$$

$$I_2 = \frac{V_{TH}}{Z_T} = \frac{V_{TH}}{\sqrt{\left(R_{TH} + \frac{R_2}{s}\right)^2 + (X_{TH} + X_2)^2}}$$

Then the power converted to mechanical (P_{conv})

$$P_{conv} = 3I_2^2 \frac{R_2(1-s)}{s}$$

And the internal mechanical torque (T_{conv})

$$\tau_{ind} = \frac{P_{conv}}{\omega_m} = \frac{P_{conv}}{(1-s)\omega_s} = \frac{3I_2^2 \frac{R_2}{s}}{\omega_s} = \frac{P_{AG}}{\omega_s}$$

$$\tau_{ind} = \frac{3}{\omega_s}\left(\frac{V_{TH}}{\sqrt{\left(R_{TH}+\frac{R_2}{s}\right)^2+(X_{TH}+X_2)^2}}\right)^2\left(\frac{R_2}{s}\right)$$

$$\mathrm{T}_{ind} = \frac{1}{\omega_S}\frac{3V_{TH}^2\left(\frac{R_2}{s}\right)}{\left(R_{TH}+\frac{R_2}{s}\right)^2+\left(X_{TH}+X_2\right)^2}$$

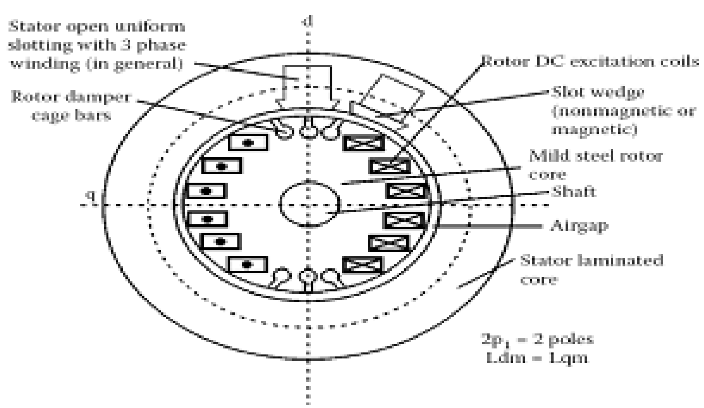
TYPES OF SYNCHRONOUS MACHINES

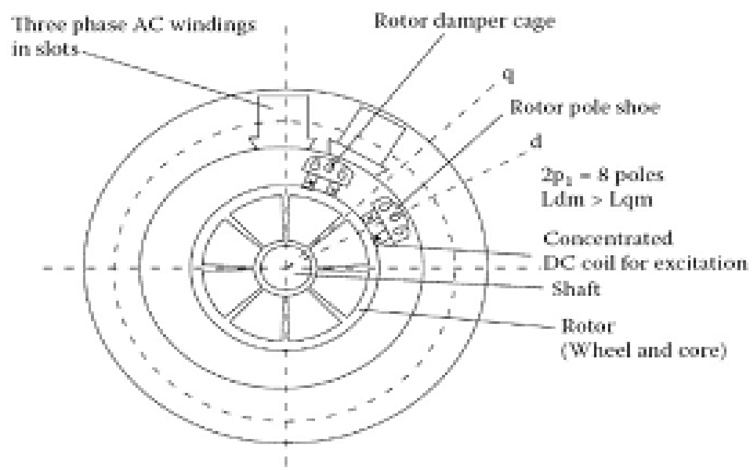
- According to the arrangement of armature and field winding, the synchronous machines are classified as rotating armature type or rotating field type.
- In rotating armature type the armature winding is on the rotor and the field winding is on the stator. The generated emf or current is brought to the 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.

- 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:**





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.

- 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.

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.

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

REGULATION OF ALTERNATOR

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

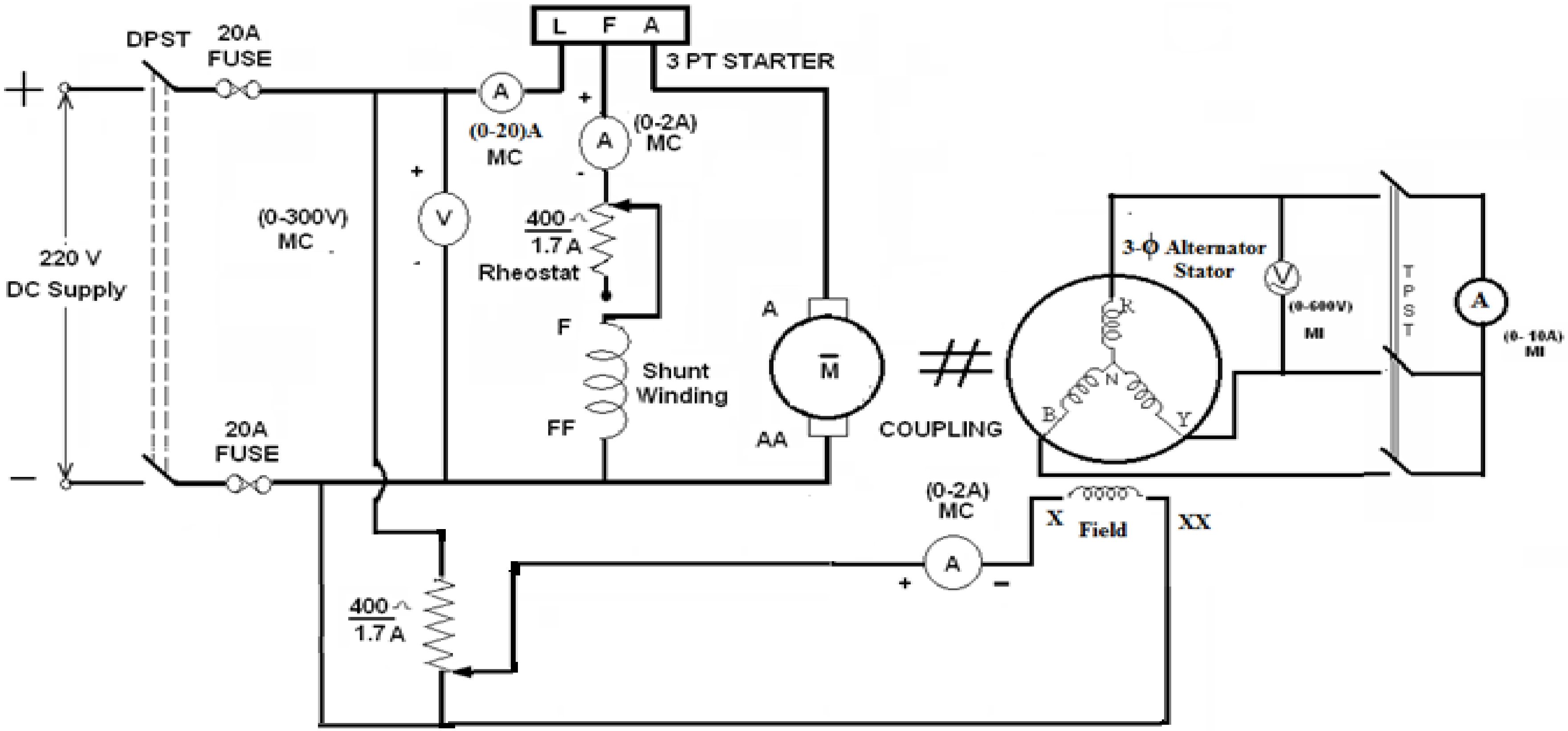
different methods used for predetermination of regulation of alternators.

- 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

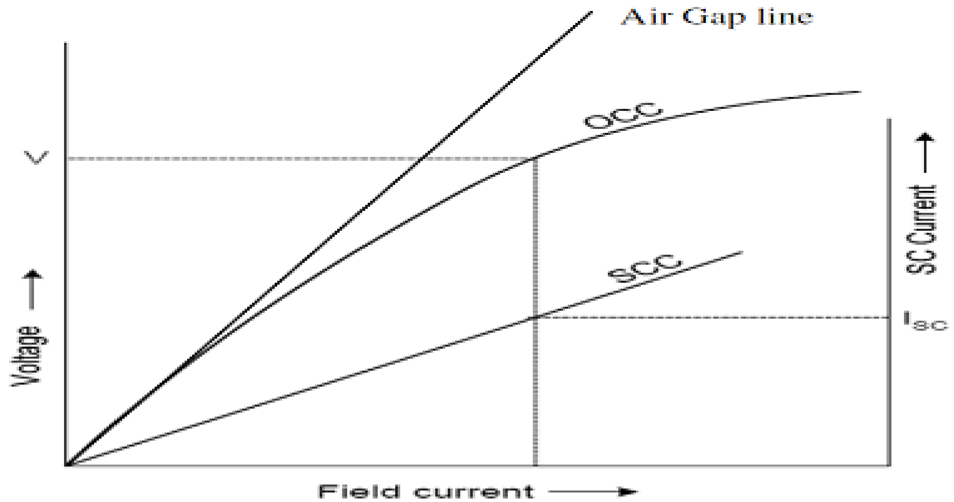


Procedure to conduct OC test:

- 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.

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



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

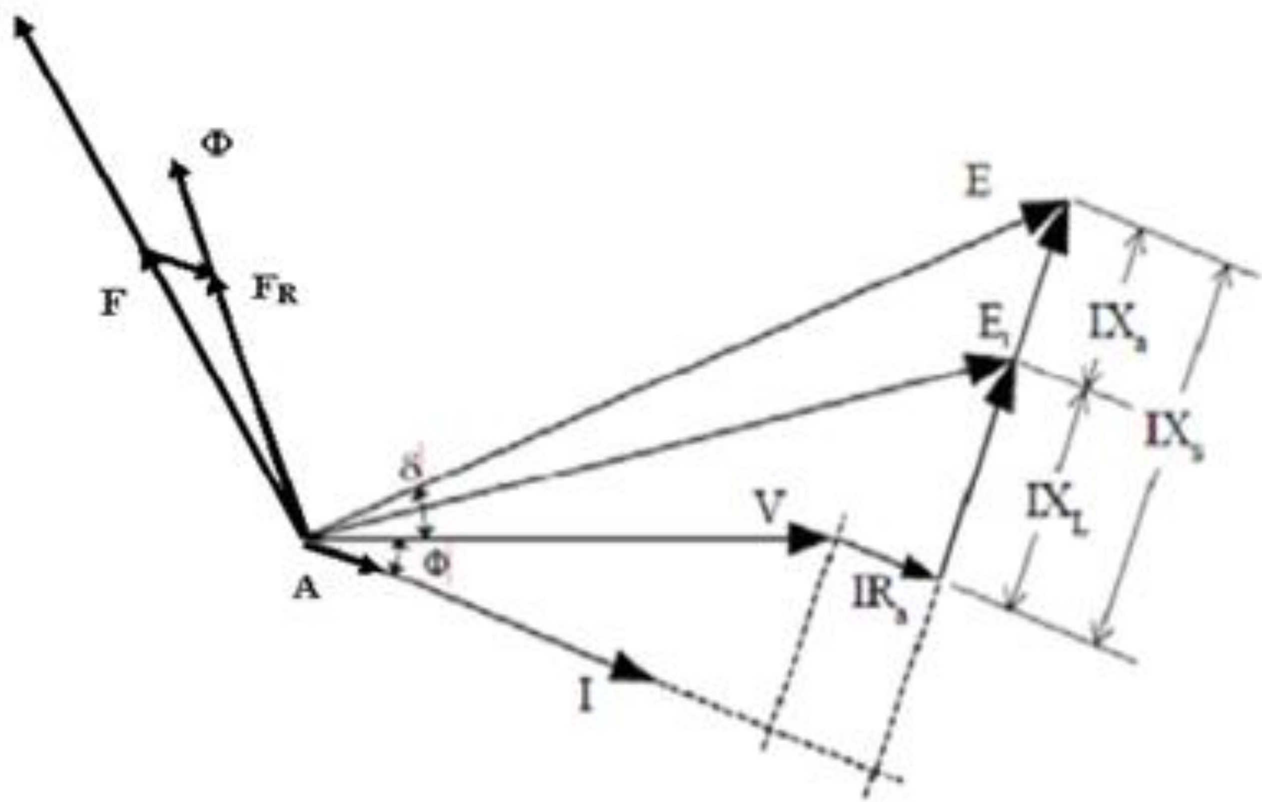
- $Z_s = \sqrt{(R_a)^2 + (X_S)^2}$ and Synchronous reactance $X_s = \sqrt{(Z_s)^2 - (R_a)^2}$

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

- 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



Φ
E
F
FR
E1
IXa
IXs
δ
V
IXL
A
Φ
IRa
I

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.

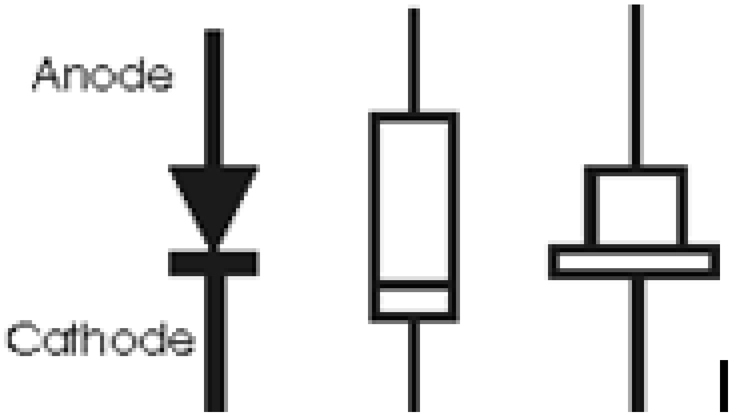
P-N JUNCTION DIODE

- 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.

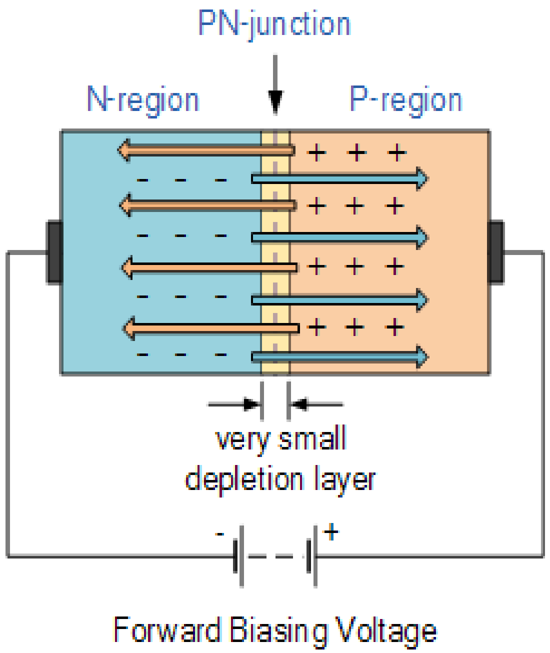
P-N JUNCTION DIODE

- 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.

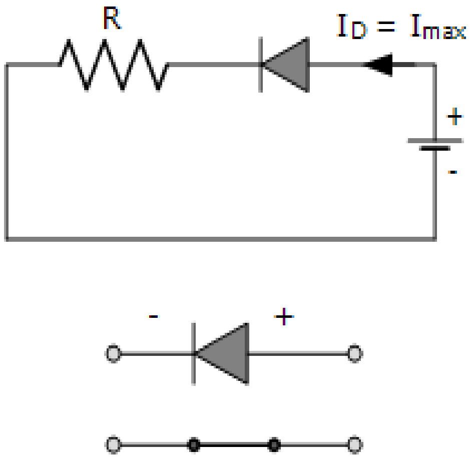
SYMBOL



DIODE

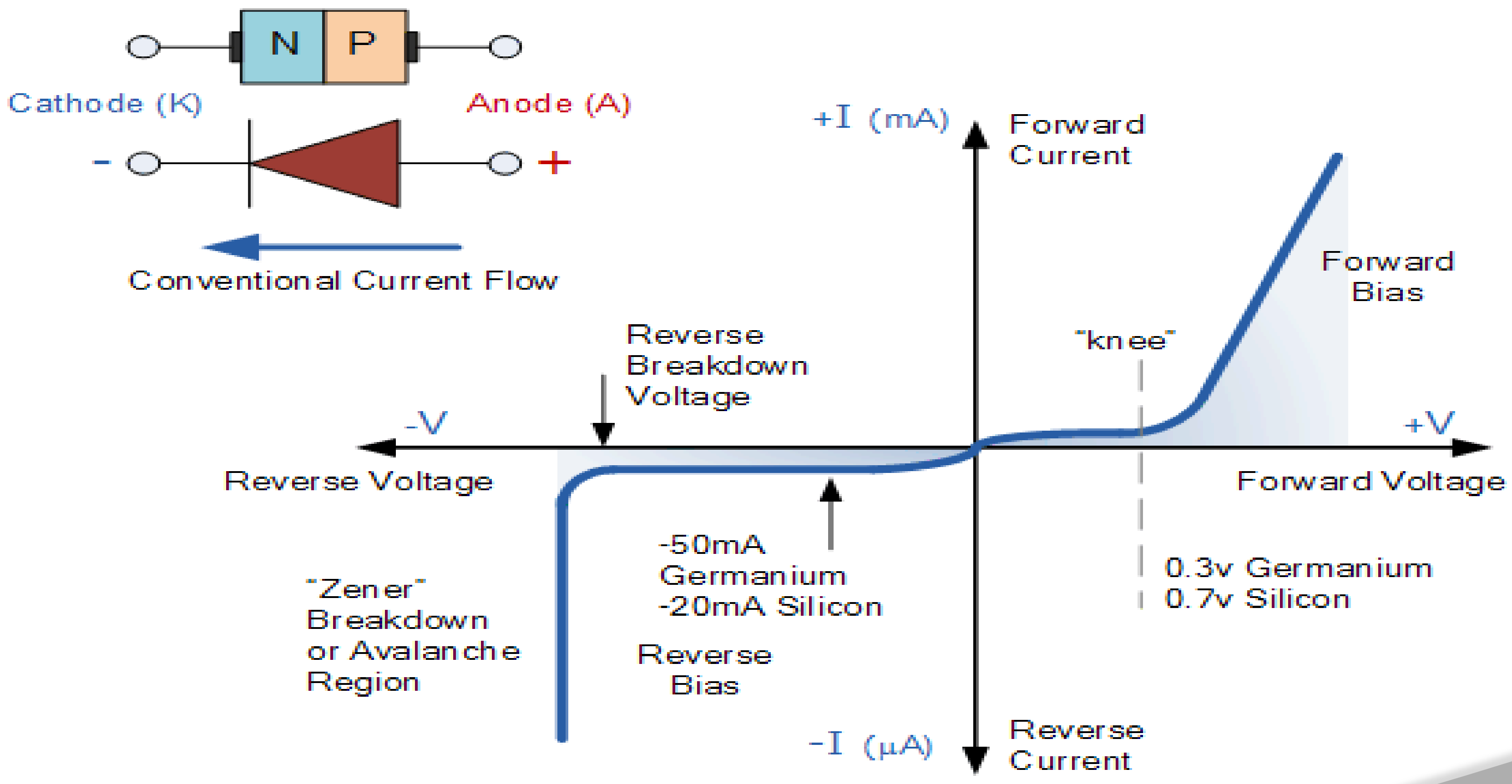


PN-junction
N-region
P-region
very small
depletion layer
-
+
Forward Biasing Voltage



R
ID = Imax
+
-

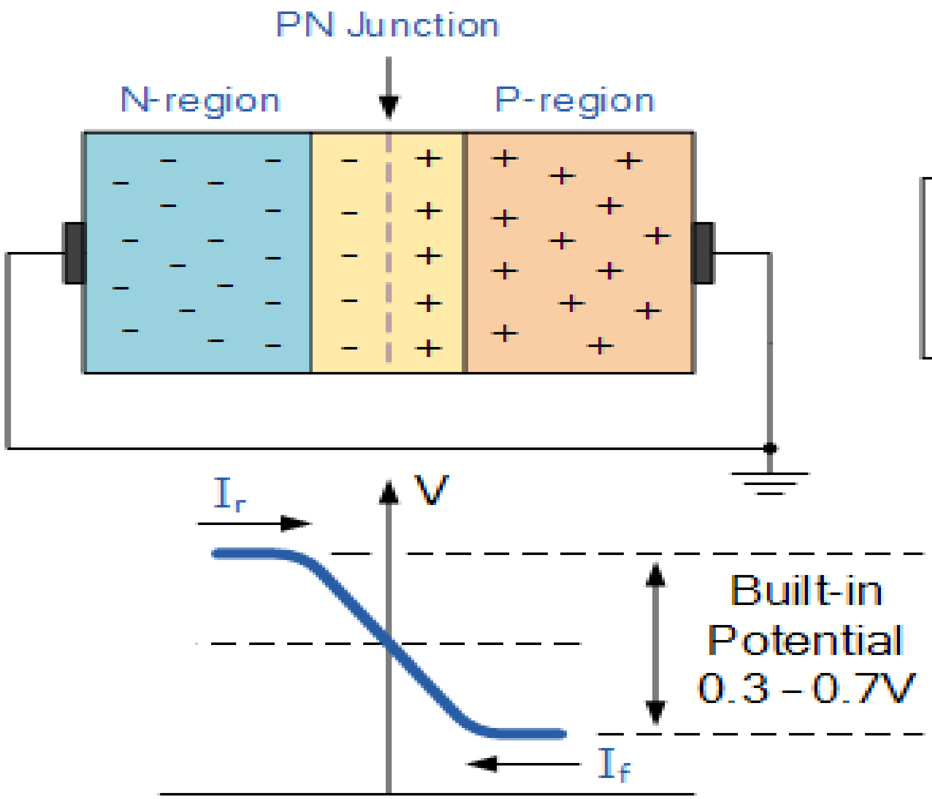
JUNCTION DIODE SYMBOL AND STATIC I-V CHARACTERISTICS

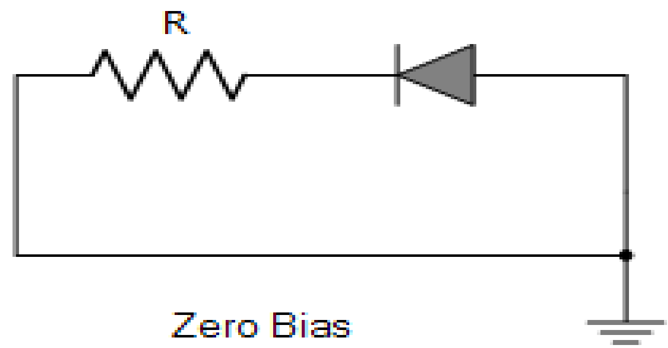


FORWARD BIASED PN JUNCTION DIODE

- 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.

ZERO BIASED PN JUNCTION DIODE





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.

IMPORTANT POINTS OF THIS LECTURE

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).

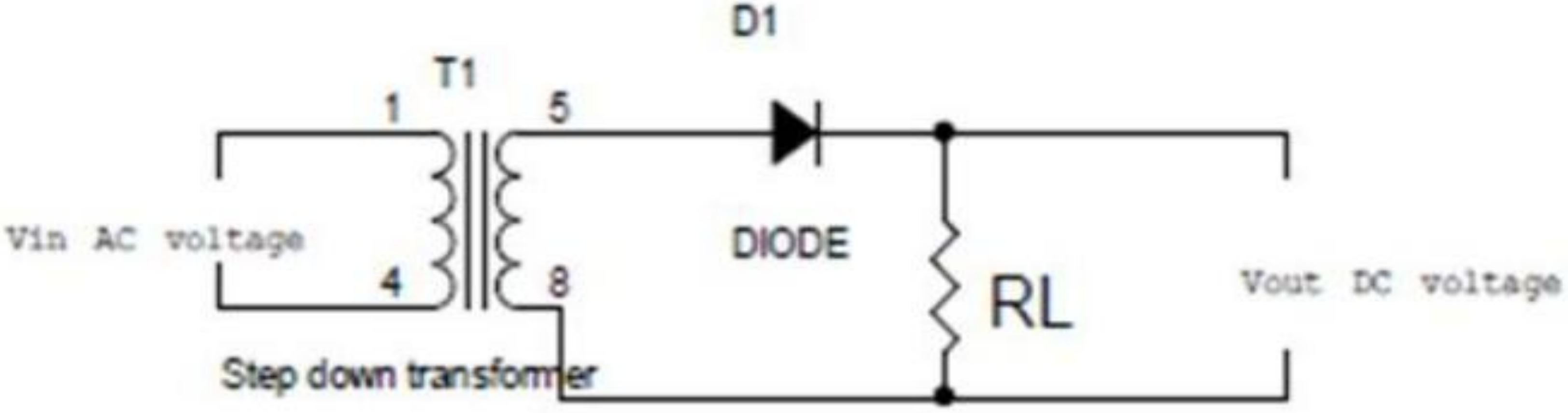
Calculation of output voltage using

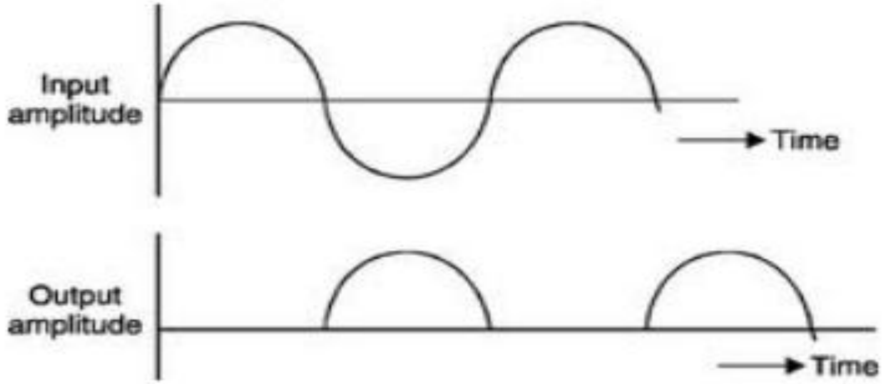
appropriate piecewise models for diode for simple (unfiltered) half wave rectifier

- Diode selection criteria
- Filtered half wave rectifier Ripple voltage

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.


D1
T1
1
5
4
8
Vin AC voltage
DIODE
RL
Vout DC voltage
Step down transformer


Input amplitude
Time
Output amplitude
Time

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,

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

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

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

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

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

  $= I_m / 2$

- 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,

η_{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

OBJECTIVES

- Power Diodes can be connected together to form a full wave rectifier that convert AC voltage into pulsating DC voltage for use in power supplies

FULL WAVE RECTIFIER

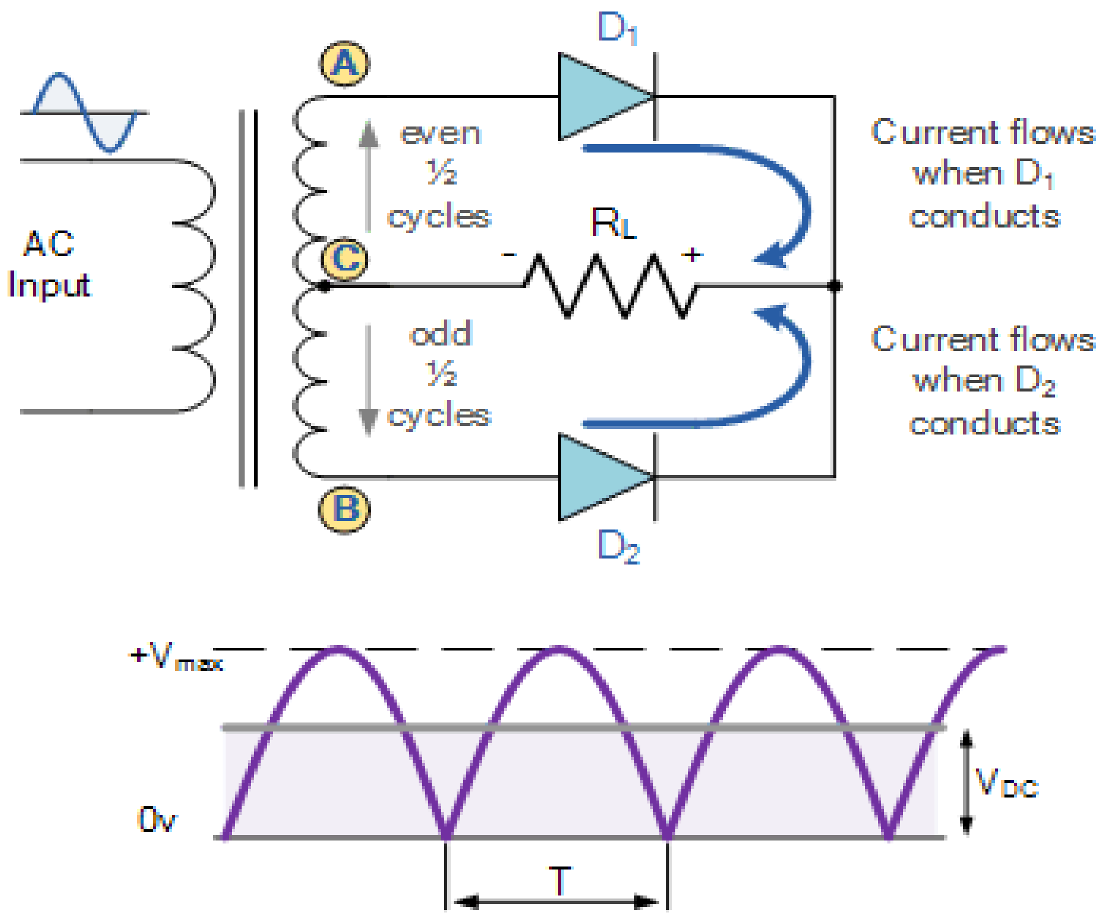
- While this method may be suitable for low power applications it is unsuitable to applications which need a “steady and smooth” DC supply voltage. One method to improve on this is to use every half-cycle of the input voltage instead of every other half-cycle. The circuit which allows us to do this is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



Resultant Output Waveform

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,

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

As we know,

Rectifier Efficiency (η) = 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,

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

FILTERS

- **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.

LC 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.

CLC OR Π 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.

VI CHARACTERISTICS OF ZENER DIODE

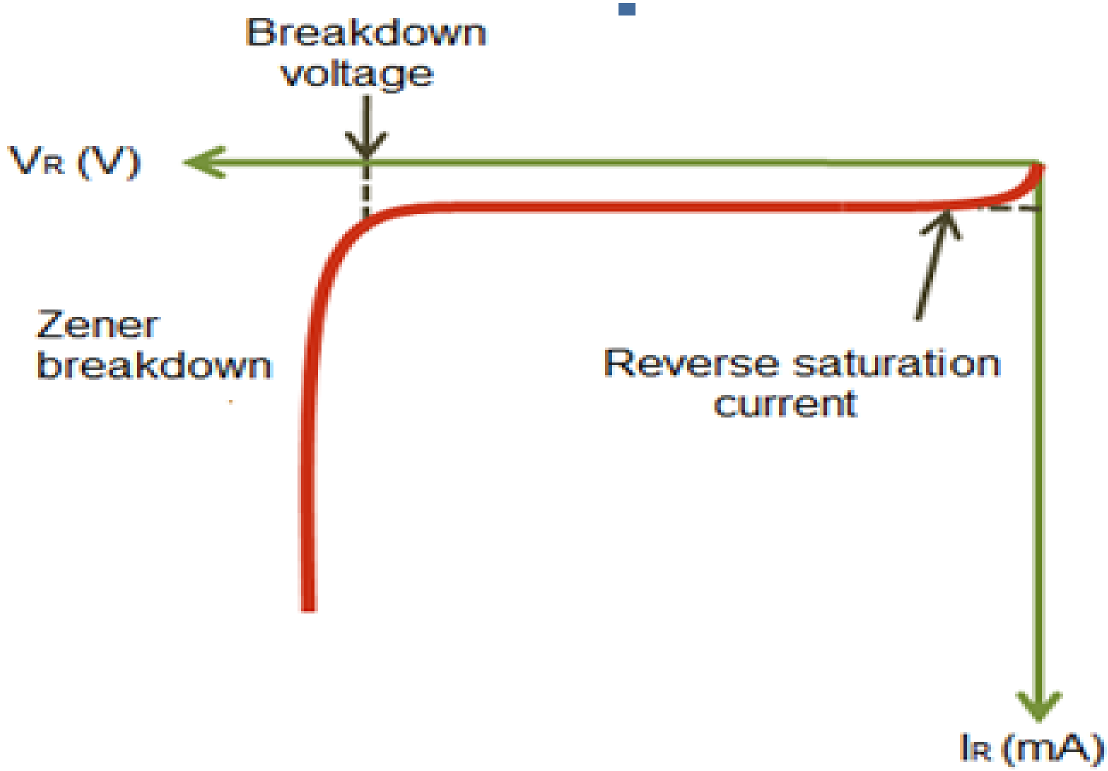


Fig: Zener breakdown

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.

ZENER DIODE

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.

ADVANTAGES OF ZENER DIODE:

- Power dissipation capacity is very high
- High accuracy
- Small size
- Low cost

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

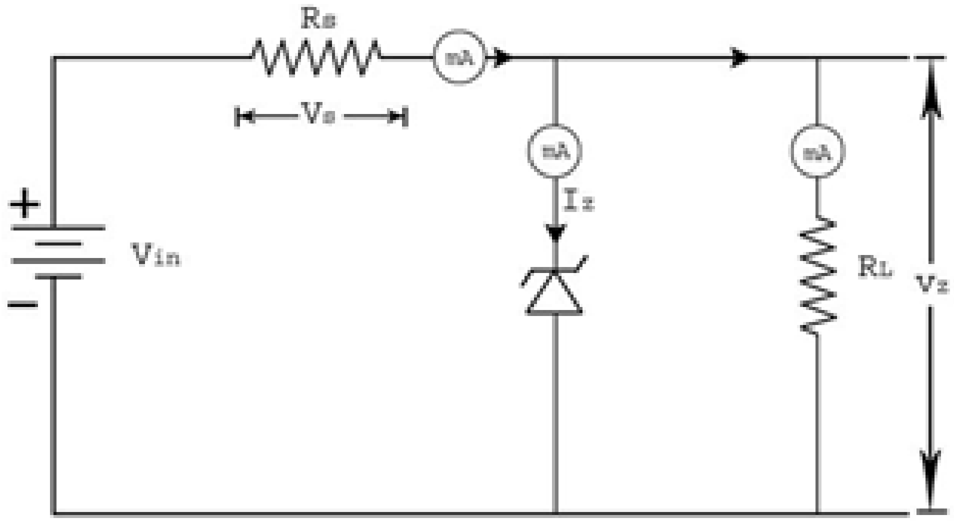


Fig 3: Zener diode shunt regulator

$Is = I_z min + I_L max$

$I_z min$ = 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).

$Is = I_z max + I_L min$

$I_z max = Pmax/Vz$

$Vs = V_{in} max – Vz$

$R_s max = Vs/Is$

- 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

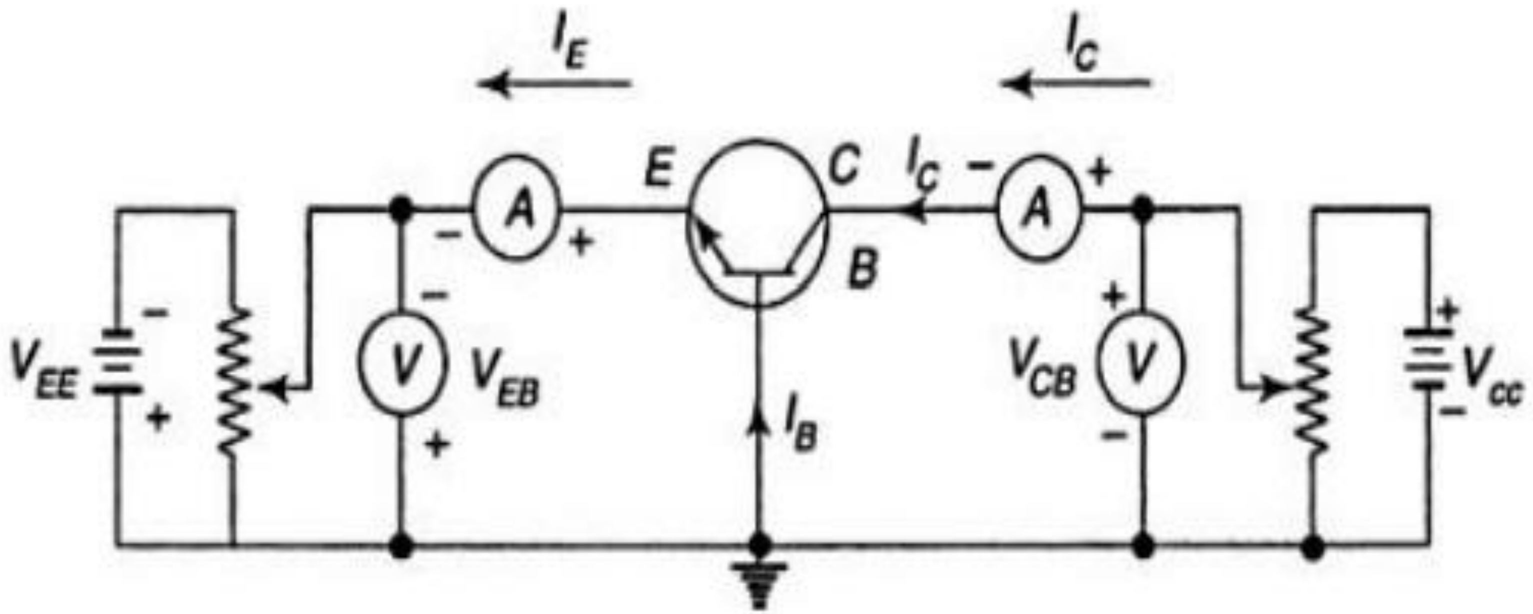
BIPOLAR JUNCTION TRANSISTOR AND APPLICATIONS

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.

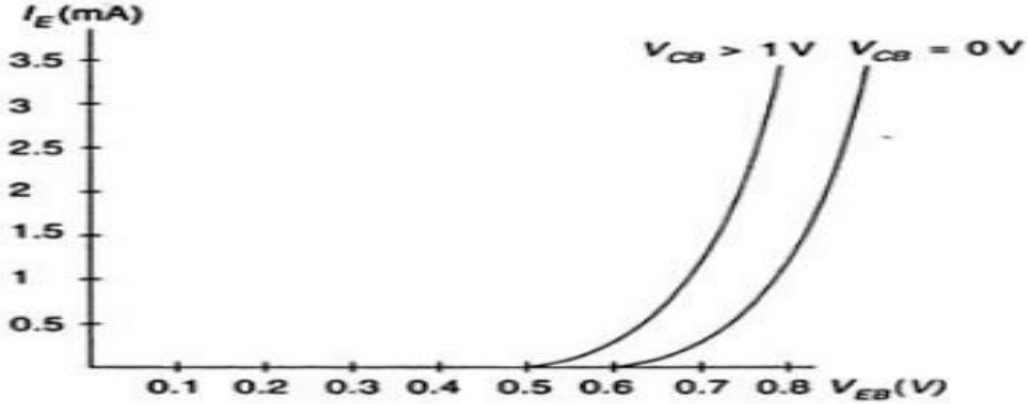
COMMON-BASE(CB) CONFIGURATION

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



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.

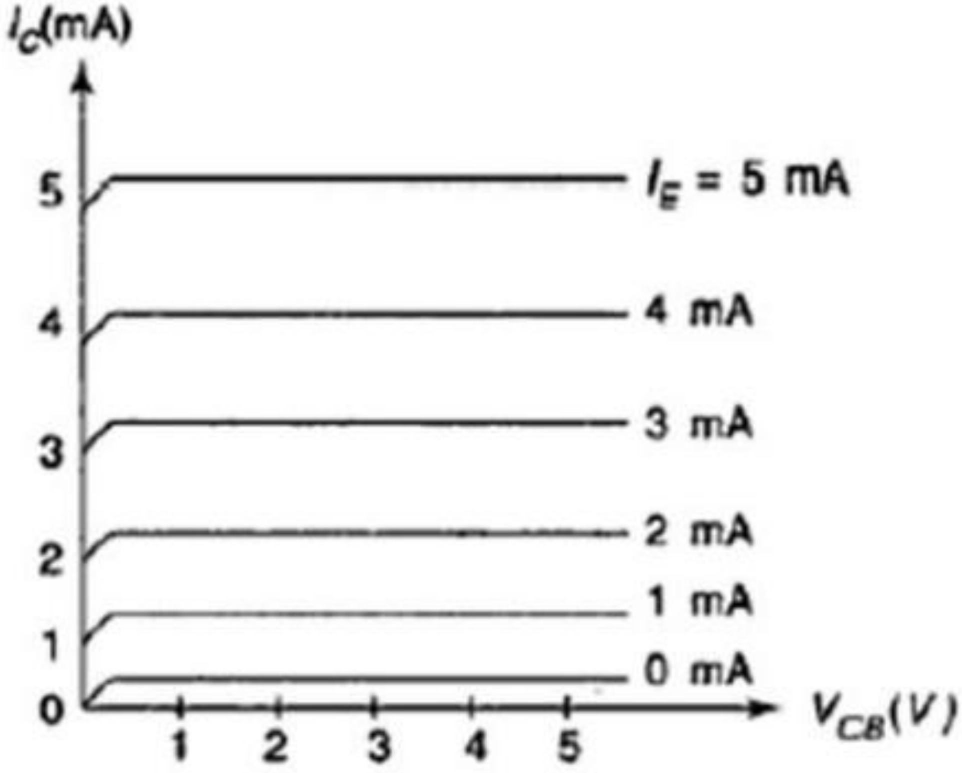


CB OUTPUT CHARACTERISTICS

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

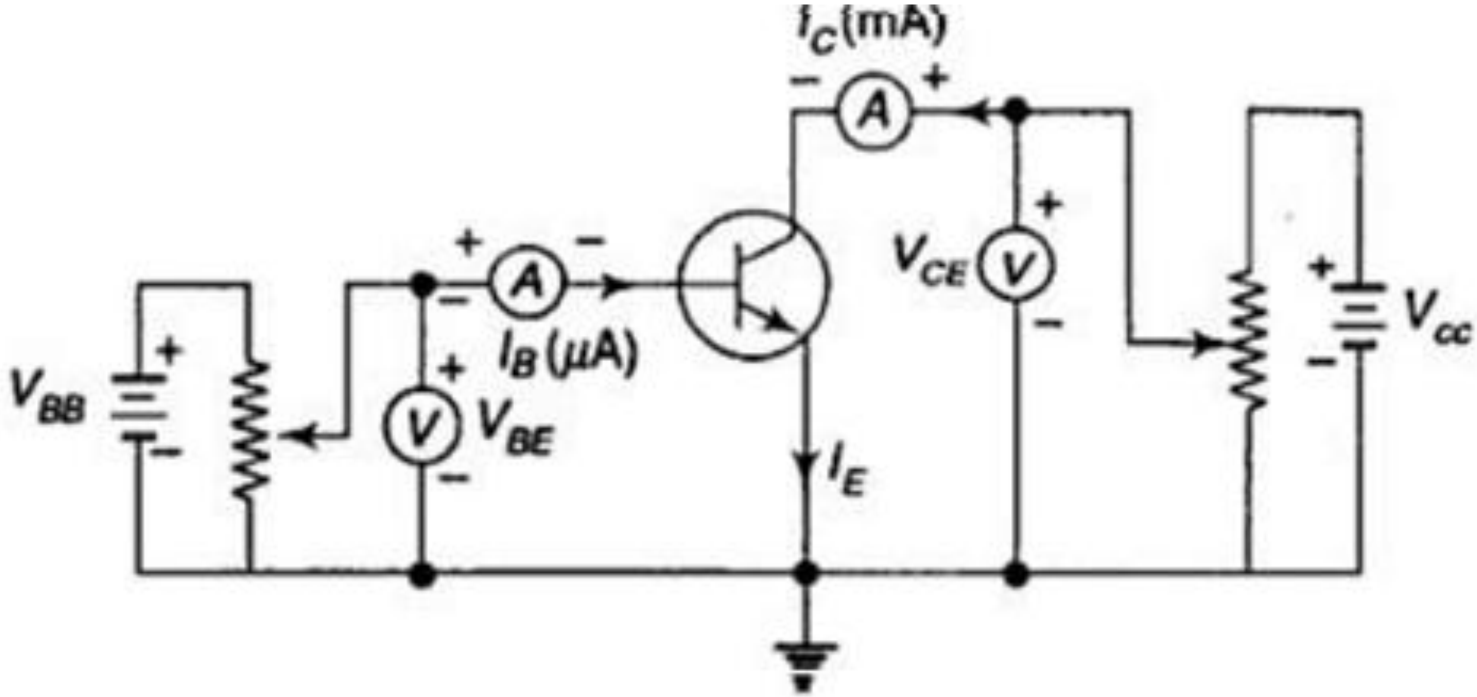
- To determine output characteristics, the emitter current IE is kept constant at zero and collector current Ic is increased from zero by increasing VCB.This is repeated for higher fixed values of IE

CB OUTPUT CHARACTERISTICS



COMMON-EMITTER CONFIGURATION

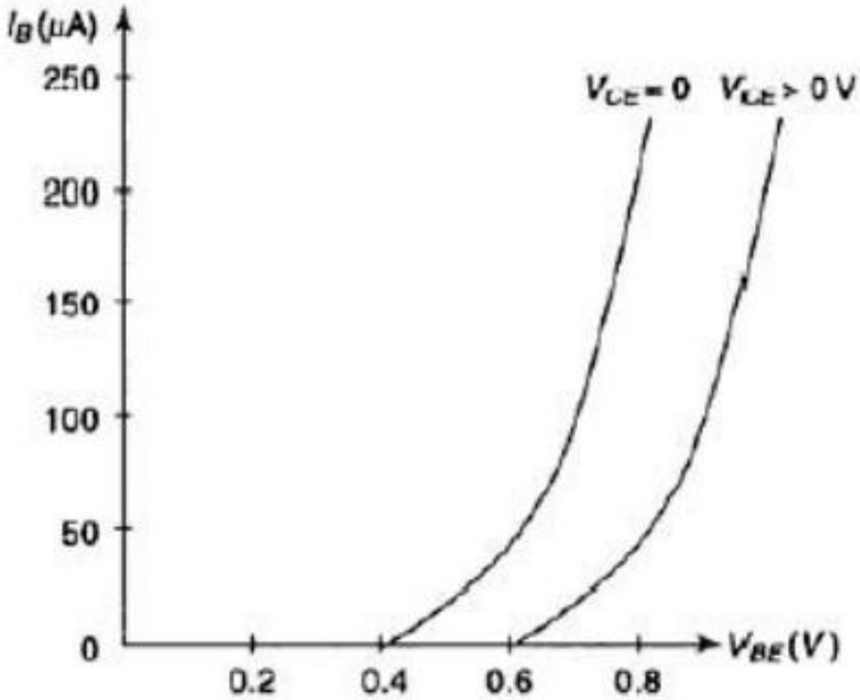
- The term common-emitter is derived from the fact that the emitter is reference to both the input and output terminals.



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

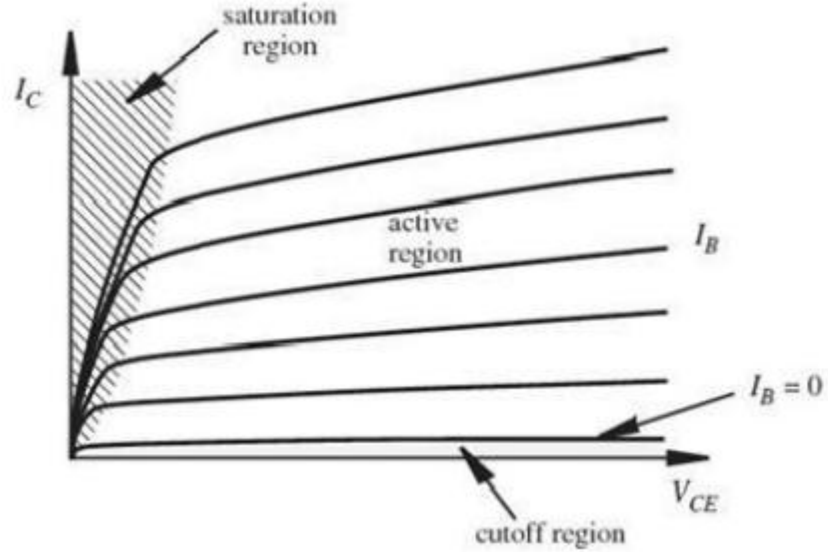


CE input characteristics

OUTPUT CHARACTERISTICS

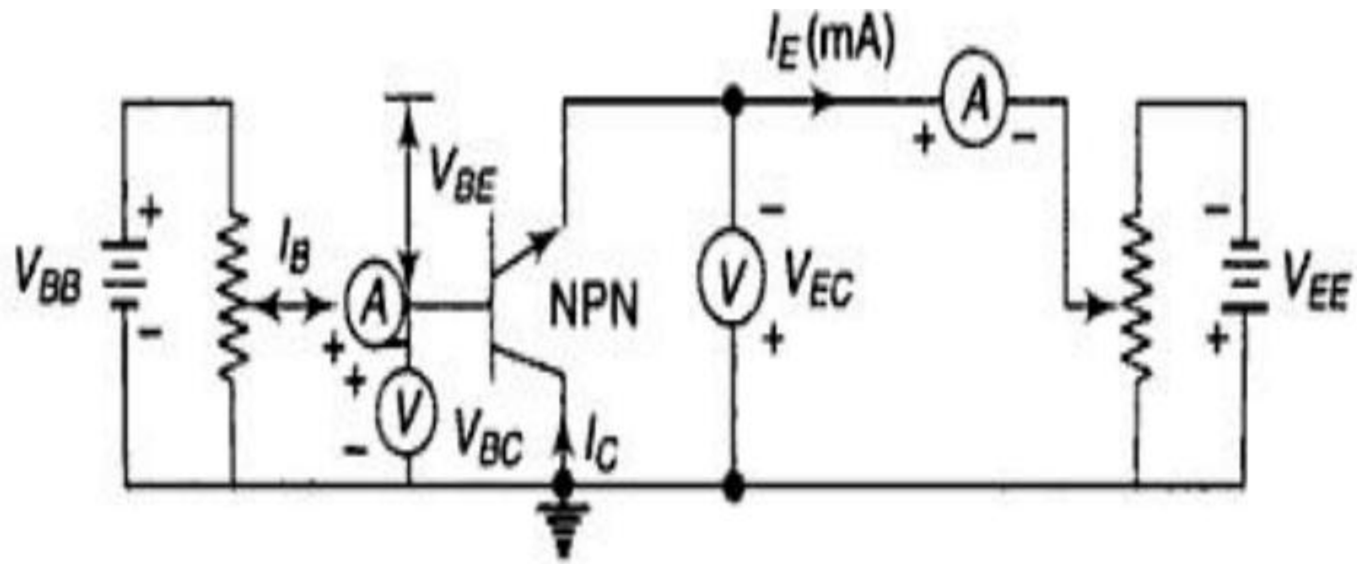
- It is defined as the characteristic curve drawn between output voltage to output current whereas input, the base current IB i s kept constant at zero current is constant
- To determine output characteristics and collector current Ic is increased from zero by increasing VCE. This is repeated for higher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

OUTPUT CHARACTERISTICS



COMMON COLLECTOR CONFIGURATION

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



CB INPUT CHARACTERISTICS

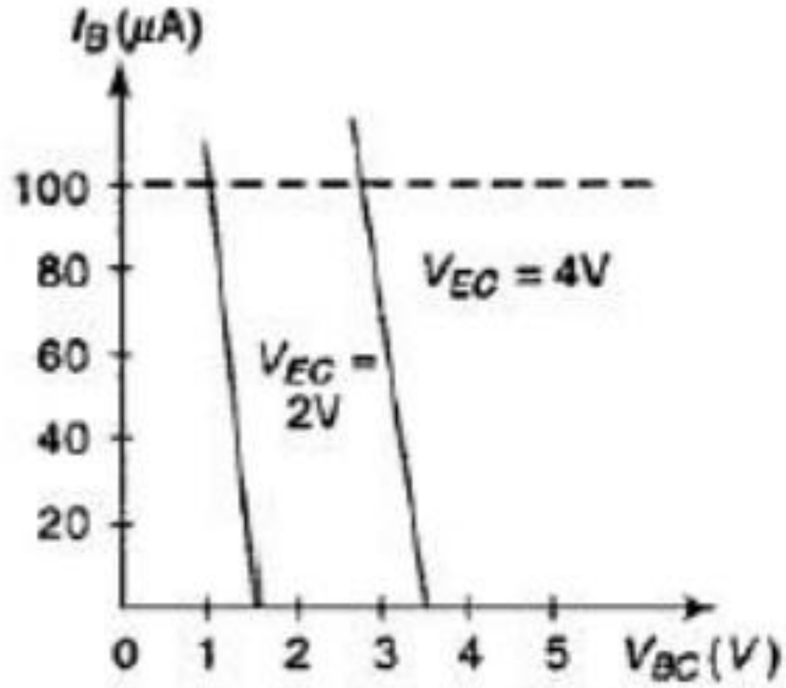
- It is defined as the characteristic curve drawn between input voltage to input current whereas output voltage is constan
- To determine input characteristics, the collector base voltage VCB is kept constant at zero and emitter current IE is increased from zero by increasing VEB. This is repeated for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

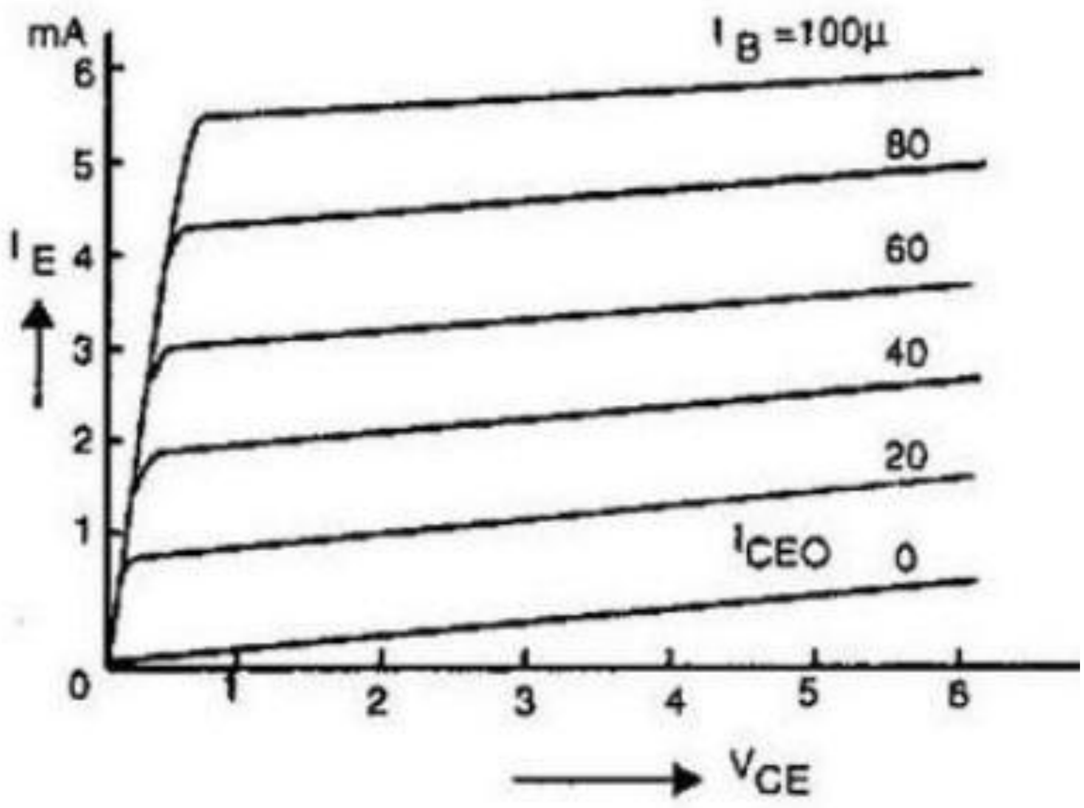


CC input characteristics

OUTPUT CHARACTERISTICS

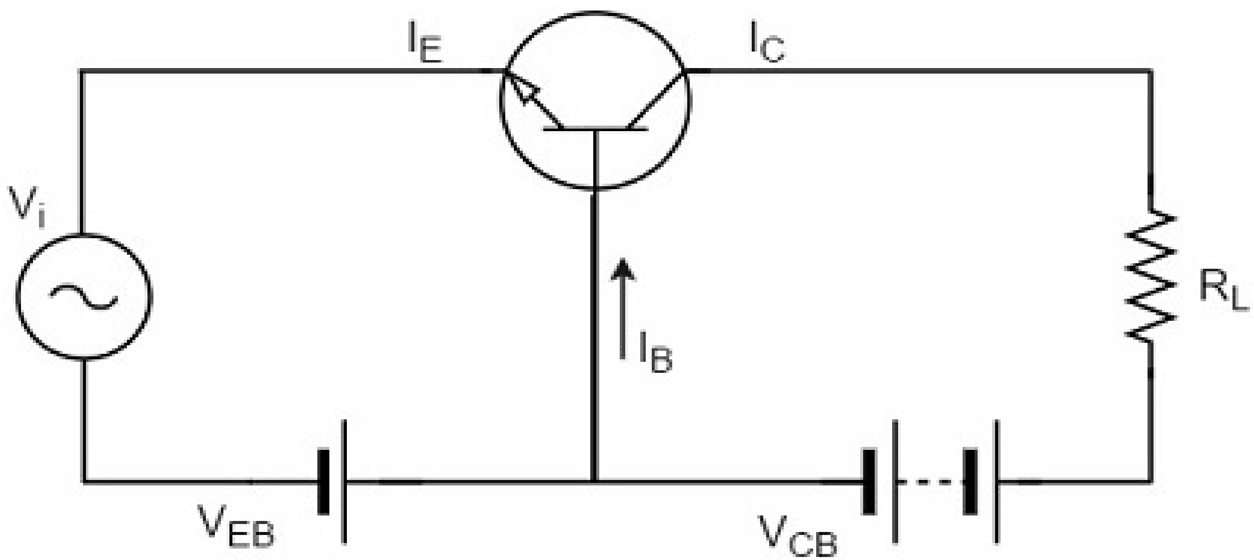
- To determine output characteristics, the base current IB is kept constant at zero and emitter current IE is increased from zero by increasing VEC. This is repeated for higher fixed values of IB

OUTPUT CHARACTERISTICS



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.



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

FIXED BASE BIAS/FIXED RESISTANCE BIAS

- The biasing circuit shown by Figure 1 has a base resistor R_B connected between the base and the V_{CC}. Here the base-emitter junction of the transistor is forward biased by the voltage drop across R_B which is the result of I_B flowing through it. From the figure, the mathematical expression for I_B is obtained as

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

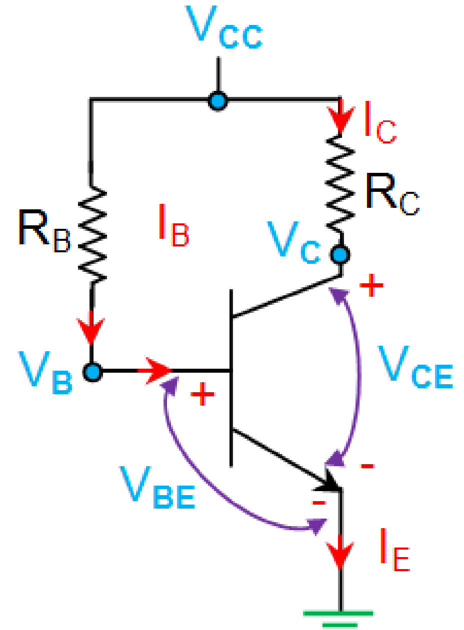


Figure 1 Fixed Base Bias Circuit

FIXED BASE BIAS/FIXED RESISTANCE BIAS

The expressions for other voltages and currents are given as

$$V_B = V_{BE} = V_{CC} - I_B R_B$$
$$V_C = V_{CC} - I_C R_C = V_{CC} - V_{CE}$$
$$I_C = \beta I_B$$
$$I_E \approx I_C$$

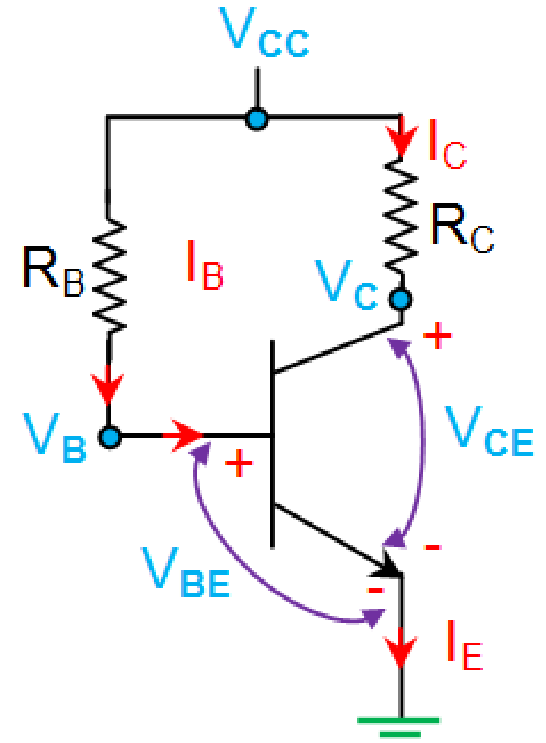


Figure 1 Fixed Base Bias Circuit

COLLECTOR FEEDBACK BIAS

- In this circuit (Figure 2), the base resistor R_B is connected across the collector and the base terminals of the transistor. This means that the base voltage, V_B and the collector voltage, V_C are inter-dependent due to the fact that

$$V_B = V_C - I_B R_B$$

$$V_C = V_{CC} - (I_B + I_C) R_C$$

$$V_B = V_{BE}$$
$$I_C = \beta I_B$$
$$I_E \approx I_C$$

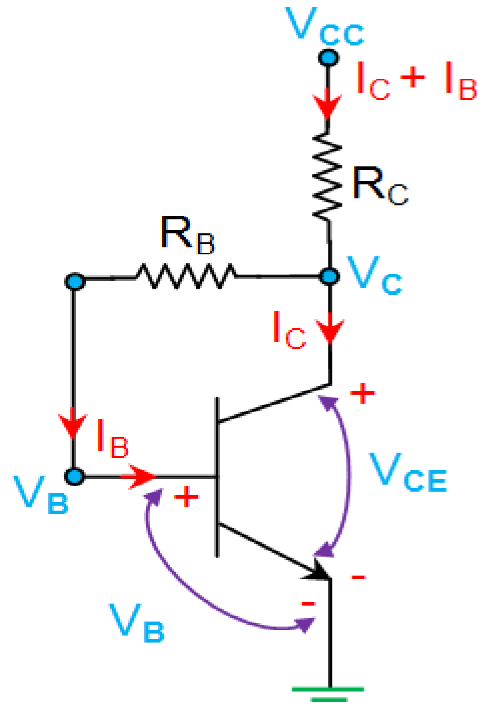
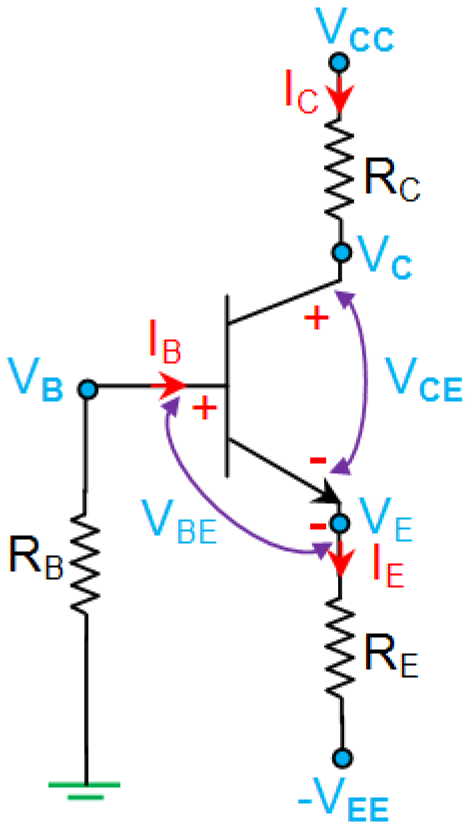


Figure 2 Collector Feedback Bias Circuit

EMITTER BIAS

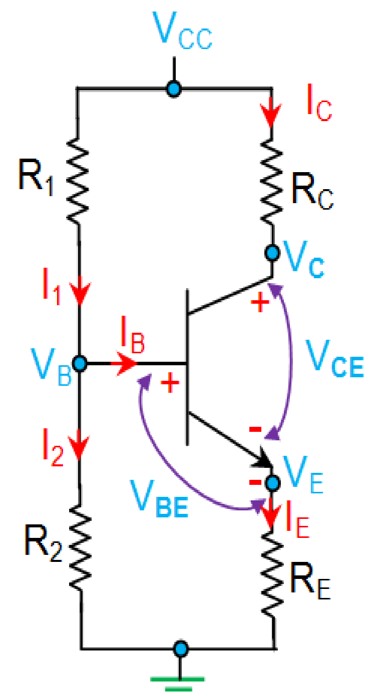
- This biasing network uses two supply voltages, V_{CC} and V_{EE}, which are equal but opposite in polarity. Here V_{EE} forward biases the base-emitter junction through R_E while V_{CC} reverse biases the collector-base junction.

$$V_E = -V_{EE} + I_E R_E$$
$$V_C = V_{CC} - I_C R_C$$
$$V_B = V_{BE} + V_E$$
$$I_C = \beta I_B$$
$$I_E \approx I_C$$



VOLTAGE DIVIDER BIAS

- This type of biasing network employs a Voltage Divider formed by the resistors R_1 and R_2 to bias the transistor.
- This means that here the voltage developed across R_2 will be the base voltage of the transistor which forward biases its base-emitter junction.
- In general, the current through R_2 will be fixed to be 10 times required base current, I_B (i.e. $I_2 = 10I_B$). This is done to avoid its effect on the voltage divider current or on the changes in β. Further, from the circuit, one gets



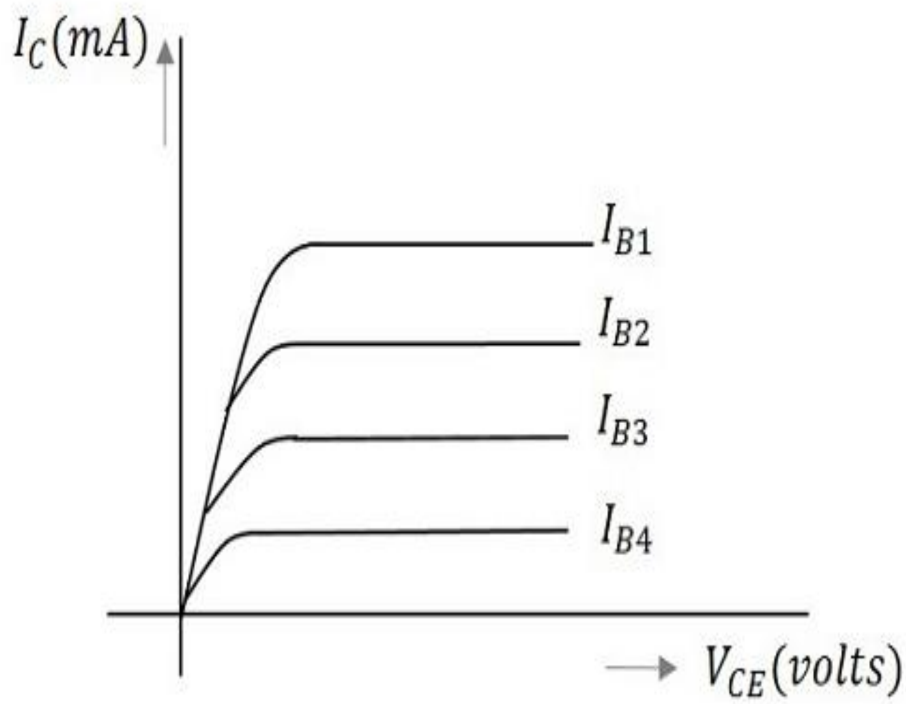
$$I_B = V_{CC}\frac{R_2}{R_1 + R_2}$$
$$V_E = I_E R_E$$
$$V_B = I_2 R_2 = V_{BE} + V_E$$

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.



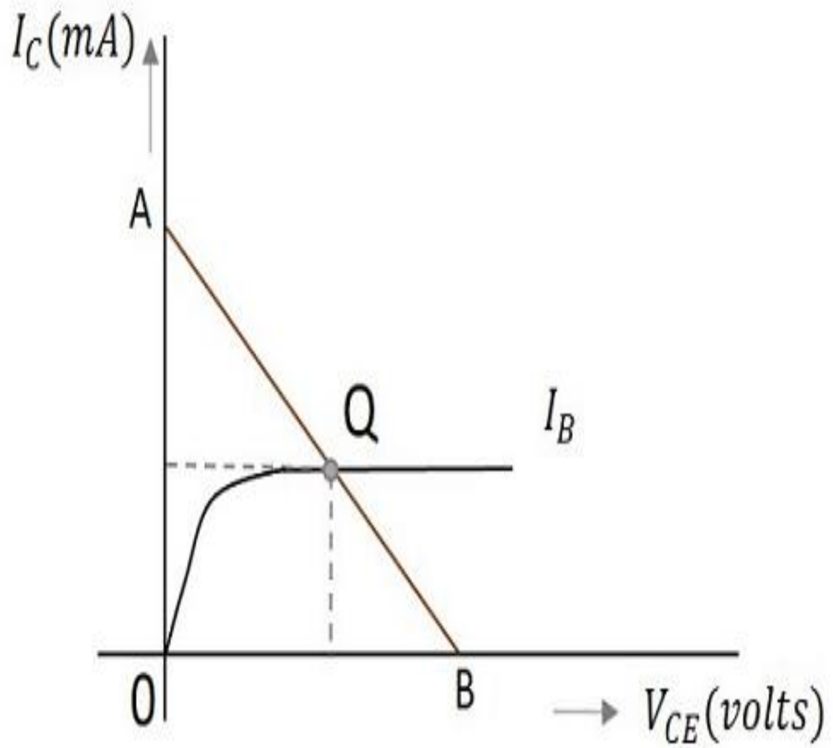
OPERATING POINT

- 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**.
- This 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.



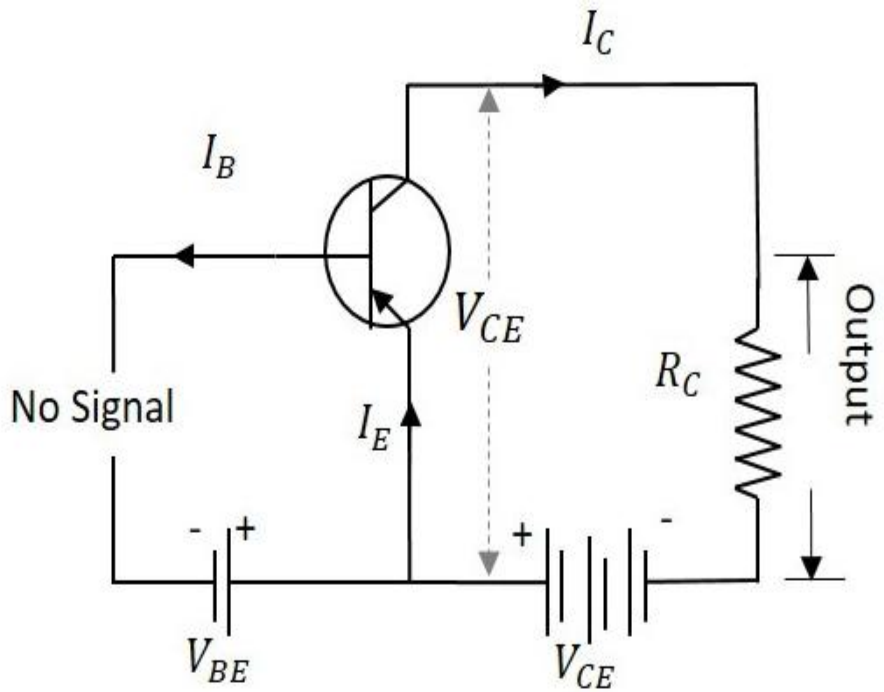
DC LOAD LINE

- 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

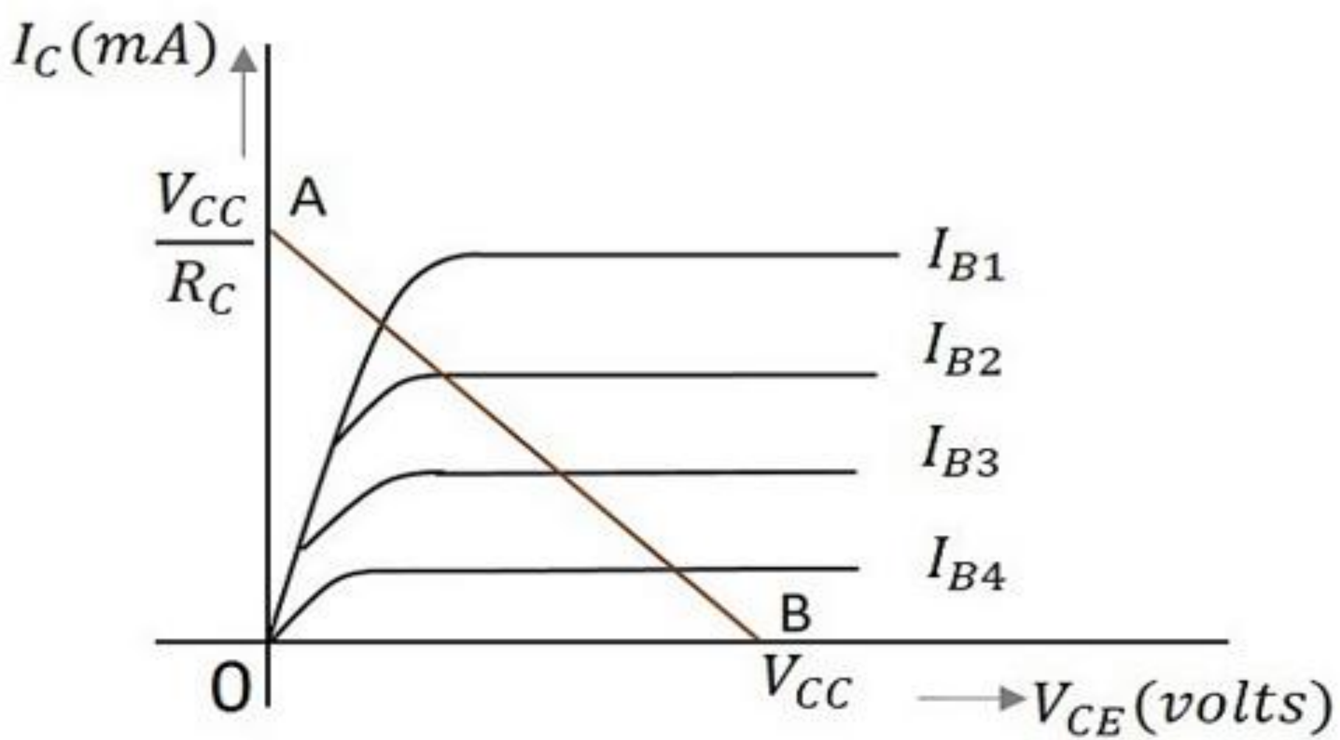
$$V_{CE} = V_{CC} - I_C R_C$$

- 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**.



DC LOAD LINE

The figure below shows the 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