AUM SAI INSTITUTE OF TECHNICAL EDUCATION

NARAYANPUR, BERHAMPUR (GM.)

DEPARTMENT OF ELECTRICAL ENGINEERING

BASIC ELECTRICAL ENGINEERING

2ND Semester

Lecture Note

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CHAPTER-1

FUNDAMENTALS

CONCEPT OF CURRENT FLOW:

Introduction:

Each substance in this universe is made of plenty of atoms and each atom has the same number of negative electrons and positive protons. As a result, we can say that each neutral substance has the same number of electrons and protons in it.

The protons are immovable and strongly attached to the nucleus of the atoms. Electrons are also bounded to atoms and orbiting around the nucleus in different distinct levels.

But some of the electrons can move freely or can come out from their orbit due to external influences. These free and as well as loosely bonded electrons cause **electricity**.

In neutral condition, the number of electrons and protons is the same in any piece of substance.

But if somehow the number of electrons in a substance becomes more than the number of protons, the substance becomes negatively charged as the net charge of each electron is negative.

If the number of electrons in a substance becomes less than the number of protons, the substance becomes positively charged.

Concept of current flow:

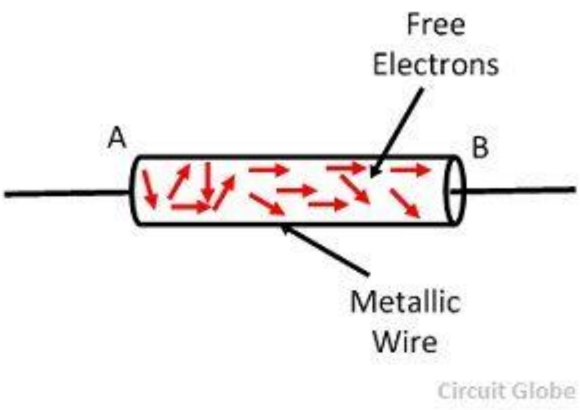
The smallest known quantity of electric charge is the charge of an electron. So, all quantities of charge are expressed in multiples of this basic or fundamental unit i.e. charge of an electron. The SI unit of charge is coulomb (Symbol C) which is equal to charge of 6.24 x 1018
electrons.

Definition: Electric current is defined as the rate of flow of negative charges of the conductor. In other words, the continuous flow of electrons in an electric circuit is called an electric current.The conducting material consists a large number of free electrons which move from one atom to the other at random.

The time rate of flow of electric charge is current I =dq / dt
The unit of current is "Ampere".
When a current is flowing in a conductor having non-uniform cross sectional area, the
current is same for all Cross-Sections of the conductor in accordance to the principle of
Conservation of charge.

Unit of Current

Since the charge is measured in coulombs and time in seconds, so the unit of electric current is coulomb/Sec (**C/s**) or amperes (**A**). The amperes is the **SI** unit of the conductor. The **I** is the symbolic representation of the current.



$Q = 1\ coloumb;\ t = 1\ second;$ then $I = 1A$

Thus, a wire is said to carry a current of one ampere when charge flows through it at the rate of one coulomb per second.

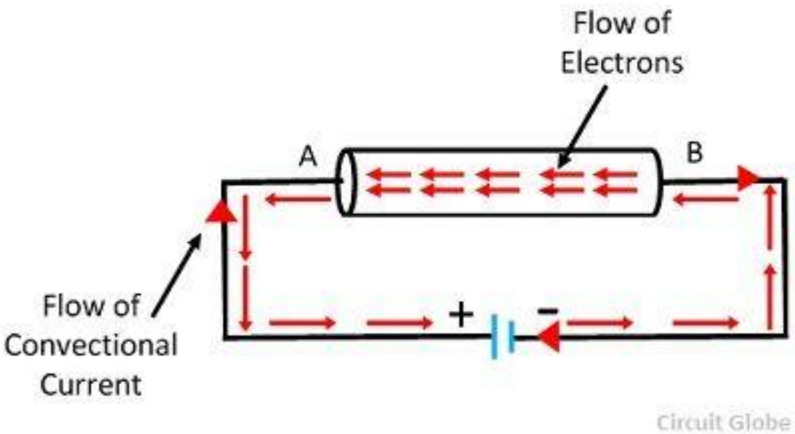
When an electrical potential difference is applied across the metallic wire, the loosely attached free electrons start moving towards the positive terminal of the cell shown in the figure below.

This continuous flow of electrons constitutes the electrical current. The flow of currents in the wire is from the negative terminal of the cell to the positive terminal through the external circuit.

Conventional Direction of Flow of Current

According to the electron theory, when the potential difference is applied across the conductor some matter flows through the circuit which constitutes the electric current.

It was considered that this matter flows from higher potential to lower potential, i.e. positive terminal to the negative terminal of the cell through the external circuit.



This convention of flow of current is so firmly established that it is still in use.Thus, the conventional direction of flow of current is from the positive terminal of the cell to the negative terminal of the cell through the external circuit.

The magnitude of flow of current at any section of the conductor is the rate of flow of electrons i.e. charge flowing per second.

Mathematically, it is represented by

$I = Q/t$ **On the basis of the flow of electric charge the current is mainly classified into two types, i.e. alternating current and direct current. In direct current, the charges flow through unidirectional whereas in alternating current the charges flows in both the direction.**

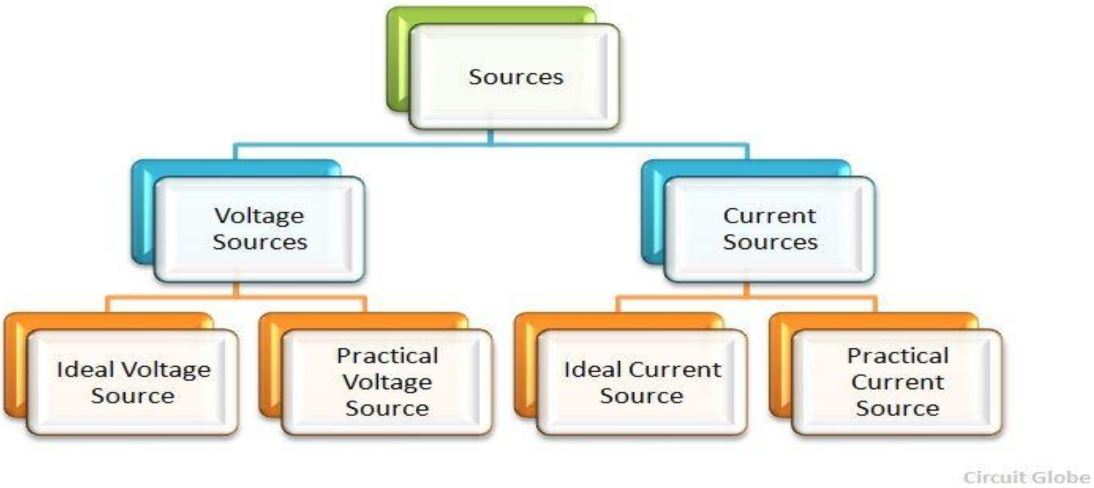
Conventional current is the concept of current in which it was believed that the current is caused by the motion of positive charges and therefore,the direction of current is taken from positive terminal to negative terminal of a battery in a circuit.

CONCEPT OF SOURCE AND LOAD

Source:

A **Source** is a device which converts mechanical, chemical, thermal or some other form of energy into electrical energy.

In other words, the source is an active network element meant for generating electrical energy. The various types of sources available in the electrical network are voltage source and current sources. A voltage source has a forcing function of emf whereas the current source has a forcing function of current.

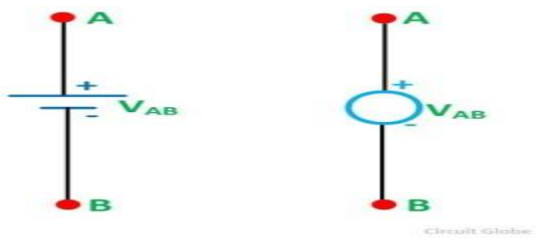


Voltage Source

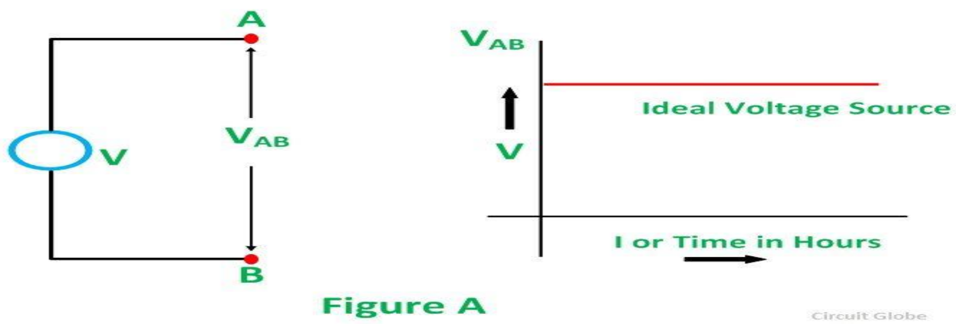
A **voltage source** is a two-terminal device whose voltage at any instant of time is constant and is independent of the current drawn from it. Such a voltage source is called an **Ideal Voltage Source** and have zero internal resistance. Practically an ideal voltage source cannot be obtained.

Sources having some amount of internal resistances are known as **Practical Voltage Source**.due to this internal resistance; voltage drop takes place, and it causes the terminal voltage to reduce.

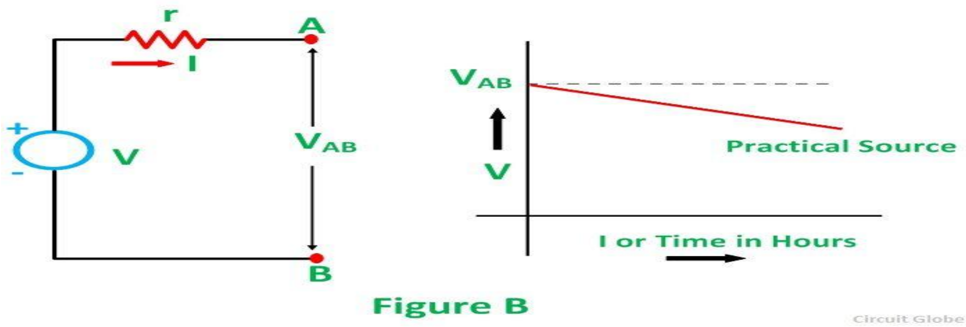
The smaller is the internal resistance (r) of a voltage source, the more closer it is to an Ideal Source. The symbolic representation of the ideal and practical voltage source is shown below.



The figure A shown below shows the circuit diagram and characteristics of an ideal voltage source.



The figure B shown below gives the circuit diagram and characteristics of Practical Voltage Source



The example of voltage sources is batteries and alternators.

Current Source

The current sources are further categorised as Ideal and Practical current source.

An **Ideal current source** is a two-terminal circuit element which supplies the same current to any load resistance connected across its terminals.

It is important to keep in mind that the current supplied by the current source is independent of the voltage of source terminals. It has infinite resistance.

A **practical current source** is represented as an ideal current source connected with the resistance in parallel. The symbolic representation is shown below

Figure C shown below, show its characteristics.

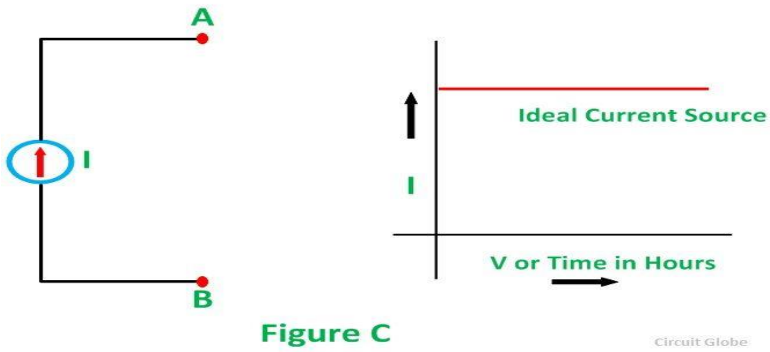


Figure C

Figure D shown below shows the characteristics of Practical Current Source.

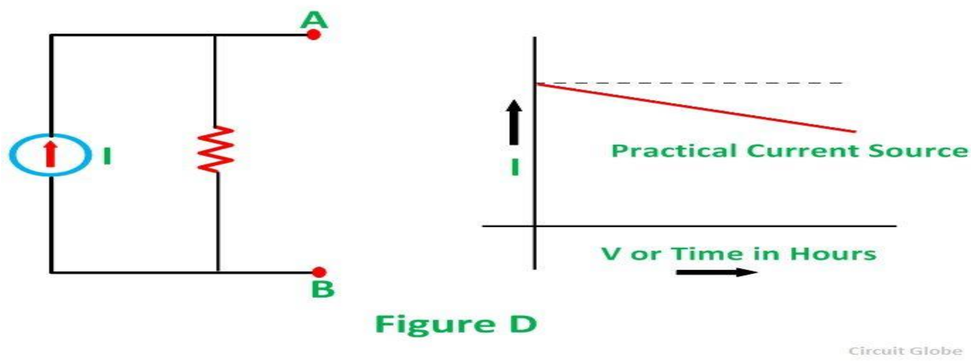


Figure D

The example of current sources is photoelectric cells, collector currents of transistors.

Independent Dependent Voltage and Current Source

The source which supplies the active power to the network is known as the electrical source. The electrical source is of two types namely independent source and dependent source. The **Independent and Dependent** source means, whether the voltage or current sources are either depending upon some other source, or they are acting independently.

Dependent Voltage and Current Source

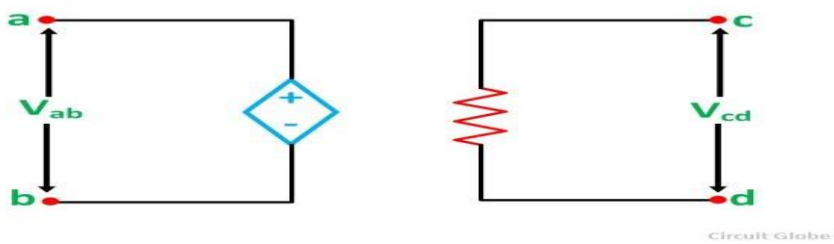
The sources whose output voltage or current is not fixed but depends on the voltage or current in another part of the circuit is called Dependent or Controlled source.

They are four terminal devices. When the strength of voltage or current changes in the source for any change in the connected network, they are called dependent sources. The dependent sources are represented by a diamond shape.

The dependent sources are further categorised as

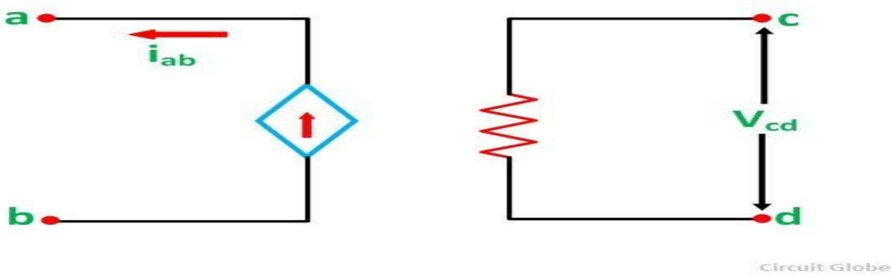
Voltage Controlled Voltage Source (VCVS):

In **voltage controlled voltage source** the voltage source is dependent on any element of the circuit.



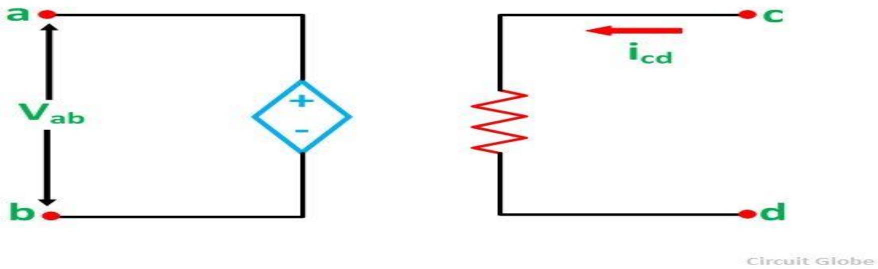
Voltage Controlled Current Source (VCCS)

In the **voltage controlled current source**, the current of the source i_{ab} depends on the voltage across the terminal cd (V_{cd}) as shown in the figure below.



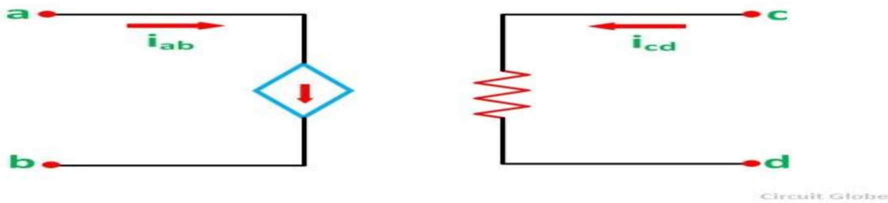
Current Controlled Voltage Source (CCVS)

In the **current controlled voltage source** voltage source of the network depends upon the current of the network as shown in the figure below



Current Controlled Current Source (CCCS);

In the **Current Controlled Current Source**, the current source is dependent on the current of the branch another branch as shown in the figure below



Load

The electrical load is an application consuming electrical power and is represented by R(Resistance),L(Inductance),C(Capacitance),E(back EMF) etc. or combination of these circuit elements.

Ohm's Law:

- It state that, "at a constant temperature, the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it."
- V α I

  V = RI

  Ohm's Law

  Or $I = \frac{V}{R}$ Electric current = Voltage / Resistance

  Where
- *I* is the current through the conductor in units of amperes,
- *V* is the voltage measured *across* the conductor in units of volts,
- and *R* is the resistance of the conductor in units of ohms

Limitations of Ohm's Law

- Ohm's law is not applicable in unilateral networks. Unilateral networks allow the current to flow in one direction. Such types of network consist elements like a diode, transistor, etc.

- It is not applicable for the non-linear network. In the nonlinear network, the parameter of the network is varied with the voltage and current. Their parameter likes resistance, inductance, capacitance and frequency, etc., not remain constant with the times. So ohms law is not applicable to the nonlinear network.

Ohm's law are used for finding the resistance of the circuit and also for knowing the voltage and current of the circuit.

Electrical Resistance

Definition: The electrical resistance is defined as the difficulty occurs in the flow of electrons.

The electrical resistance is provided to the circuit through the resistor. The resistance shows the relation between the applied voltage and the flow of charges. The resistance is inversely proportional to the flow of current

Unit: Resistance is measured in ohms (kilo-ohms) and is denoted by symbols Ω (or kΩ). A wire is said to have a resistance of one ohm If the one-ampere current is passed through it.

The resistance of the wire depends on the following factors. These factors are

- The resistance of a wire is directly proportional to its length, **l**, i.e., **R ∝ l.**
- The resistance of the wire is inversely proportional to its area of cross section (**a**).

$$R = \rho \frac{l}{a}$$

$$\rho = \frac{Ra}{l}$$

Where **ρ** is a constant of proportionality also called the resistivity of the wire material. The values of **ρ** depend on the nature (atomic structure) of the materials.

- The resistance of the wire depends on the nature (atomic structure) of the material of which the wire is made.
- The resistance of the wire depends on the temperature of the wire.

Resistivity of the Material

The resistivity of the material is defined as the resistance offered by the one-meter length of wire (of given area) having an area of cross section of one square meter. The resistance of the wire is given as $R \propto \frac{l}{a}$

If, l = 1 meter; a = 1 m^2 **then the resistance of the wire is R = ρ**

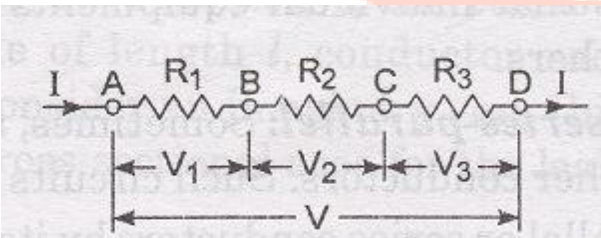
In place of wire, if a cube of the one-meter side of a given material is taken and their two opposite faces are considered, then the resistance is given by the relation shown below.

$$l = 1m; a = 1 \times 1 = 1m^2 \; and \; R = \rho$$

Relation of V and I in series circuit

Conductors are said to be connected in series if they are connected end to end , one after another so that one end of the first conductor and one end of the last conductor are free and same current flows through all conductors and potential difference across each one is different depending upon their resistances.

In figure S.1 below, A & D are free ends of three conductors AB, BC & CD connected in series and let R1,R2&R3 be the respective resistances.



[Figure S.1]

Let, R = Resistance of the combination

7

V = Total potential difference across resistances.

I = Strength of Current

Then V=IR ………………………………………………………………………1s

But V= sum of individual p.d. across R1,R2&R3

So,

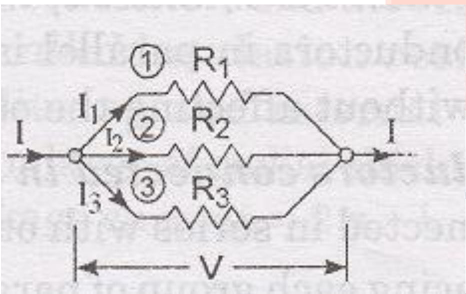
V = V1 + V2 + V3 =IR1+ IR2+ IR3……………………………………………2s

From equation 1s & 2s we get IR= I R1+ IR2+ IR3
Hence, R=IR1+ R2+ R3
It follows from the above that if a number of conductors are connected in series then the
combined resistance of the combination equals the sum of the individual resistances.

Relation of V and I in parallel circuit

Conductors are said to be connected in parallel if all of them are connected across two common points. In figure P.1 below three conductors of resistances R1,R2&R3 are connected between the common points A & B.

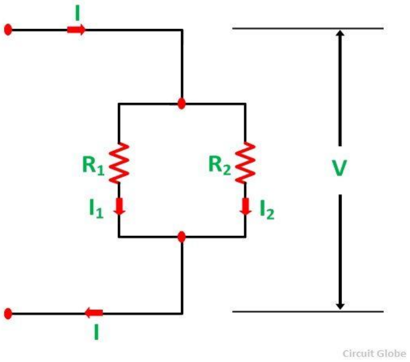
It will be observed that same potential difference exists between the ends of each conductor but the amount of current passing through each is different depending upon
their resistances.



V = potential difference
I = Strength of Current
Then , I =
....1P
By KCL , the main current entering this combination must come out as such & Hence,
[Figure P.1]
Suppose the main current I is divided into I1,I2&I3 through the resistors R1,R2&R3 respectively.
Let, R = Resistance of the combination between A & B

I = I1 + I2 + I3
Then I = v / R1+ V / R2 +V / R3..2P
From equations 1p & 2p we get
V / R= V/R1+V/R2+V/R3
Hence,1/R = 1/R1+1/ R2 +1/ R3
It follows from the above that if a number of conductors are connected in parallel then the
reciprocal of combined resistance is equal to the sum of the reciprocals of individual resistances

Expression of division current in parallel circuit



The current I has been divided into I_1 and I_2 in two parallel branches with the resistance R_1 and R_2 and V is the voltage drop across the resistance R_1 and R_2.

As we know

V = IR ……..(1)

Then the equation of the current is written as

$$I_1 = \frac{V}{R_1} \quad \text{and} \quad I_2 = \frac{V}{R_2}$$

Let the total resistance of the circuit be R and is given by the equation shown below

$$R = \frac{R_1 R_2}{R_1 + R_2} \ldots \ldots \ldots \ldots .(2)$$

Equation (1) can also be written as

I = V/R ……….(3)

Now, putting the value of R from the equation (2) in the equation (3) we will get

$$I = \frac{V\,(R_1 + R_2)}{R_1 R_2} \ldots \ldots \ldots .(4)$$

But

$$V = I_1R_1 = I_2R_2 \text{ ....(5)}$$

Putting the value of $V = I_1R_1$ from the equation (5) in the equation (4), we finally get the equation as

$$I = \frac{I_1R_1(R_1 + R_2)}{R_1R_2} = \frac{I_1}{R_2}(R_1 + R_2) \text{ ... . (6)}$$

And now considering $V = I_2R_2$ the equation will be

$$I = \frac{I_2R_2(R_1 + R_2)}{R_1R_2} = \frac{I_1}{R_1}(R_1 + R_2) \text{ ... . (7)}$$

Thus, from the equation (6) and (7) the value of the current I_1 and I_2 respectively is given by the equation below

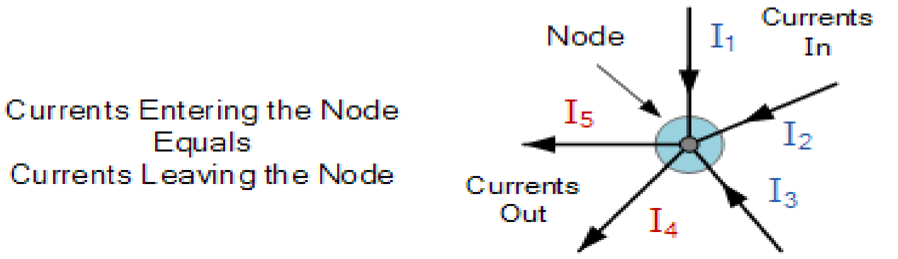
$$I_1 = I\frac{R_2}{R_1 + R_2} \quad \text{and} \quad I_2 = I\frac{R_1}{R_1 + R_2}$$

Thus, in the current division rule, it is said that the current in any of the parallel branches is equal to the ratio of opposite branch resistance to the total resistance, multiplied by the total current

KCL: (Kirchoff's current Law)

It state that the algebraic sum of ALL the currents entering and leaving a node must be equal to zero.

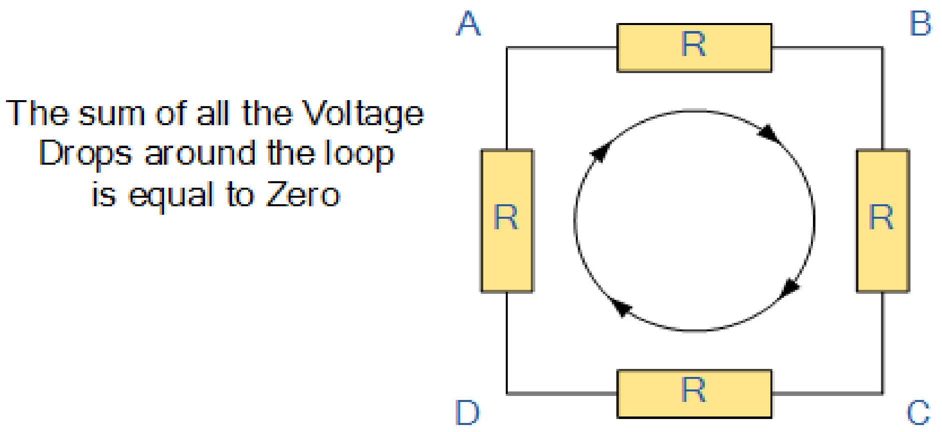
- **$I_{(exiting)} + I_{(entering)} = 0$.**
- **KCL deals with the Conservation of Charge.**



- $I_1 + I_2 + I_3 + (-I_4 + -I_5) = 0$

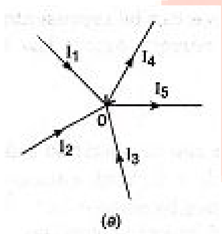
KVL: (Kirchoff's Voltage Law)

It states that "*in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop*"



$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

Find the values of I3assuming that I1=5A,I2=2A, I4=1A & I5=4A.



**Solution : Application of KCL to node A in figure with proper sign convention results in the
following equation:
I1 + I2 + I3- I4 - I5= 0
Or Replacing the current values ,we find
I3 = I4 + I5-I1-I2= 1+4-5-2= -2A(Ans)**

Given data :

$R_1 = 9\Omega$

$R_2 = 18\Omega$

$V = 27V$

$R = ?,\ I = ?,$

$I_1 = ?,\ I_2 = ?$

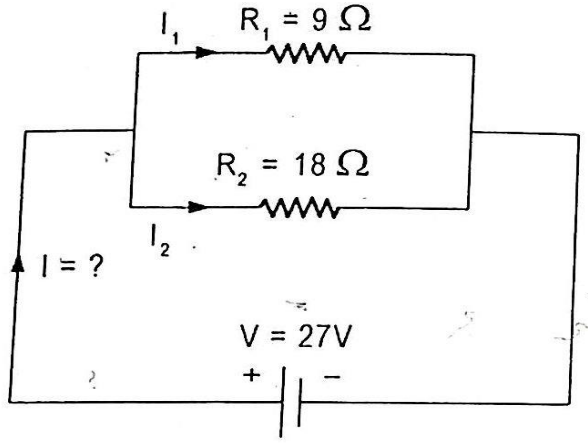


FIGURE 1.16 :

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{9 \times 18}{9 + 18} = 6\Omega$$

$$I = \frac{V}{R} = \frac{27}{6} = 4.5A \ \textit{Ans.}$$

$$I_1 = \frac{V}{R_1} = \frac{27}{9} = 3\Omega \ \textit{Ans.}$$

$$I_2 = \frac{V}{R_2} = \frac{27}{18} = 1.5\Omega$$

$$I_T = I_1 + I_2$$

$$4.5 = 3 + 1.5 = 4.5 = 4.5 \text{ (checks)}$$

Ex: find the current for the given circuit

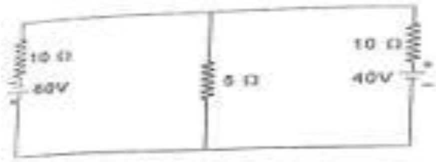


FIG 1.58 :

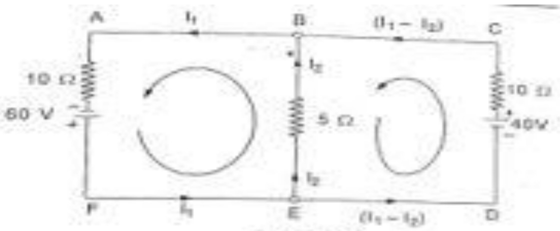


FIG 1.59 :

Solution :

The unknown quantities of currents in various branches are marked as shown in Fig. 1.59.

Applying KVL to loop ABEFA, we get

$$-5I_2 - 10\,I_1 + 60 = 0$$

$$10\,I_1 + 5I_2 = 60 \qquad \ldots\ldots\ldots\ldots (1)$$

Applying KVL to loop BCDEB, we get

$$-10\,(I_1 - I_2) + 5\,I_2 + 40 = 0$$

$$-10\,I_1 + 15\,I_2 + 40 = 0$$

$$10\,I_1 - 15\,I_2 = 40 \qquad \ldots\ldots\ldots\ldots (2)$$

Subtracting Equ. (2) from equ. (1), we get

$$10\,I_1 + 5\,I_2 = 60$$

$$10\,I_1 - 15\,I_2 = 40$$

$$- \qquad + \qquad -$$

$$20\,I_2 = 20 \Rightarrow I_2 = \frac{20}{20} = 1\,A \qquad \textbf{Ans}$$

CHAPTER-2

AC THEORY

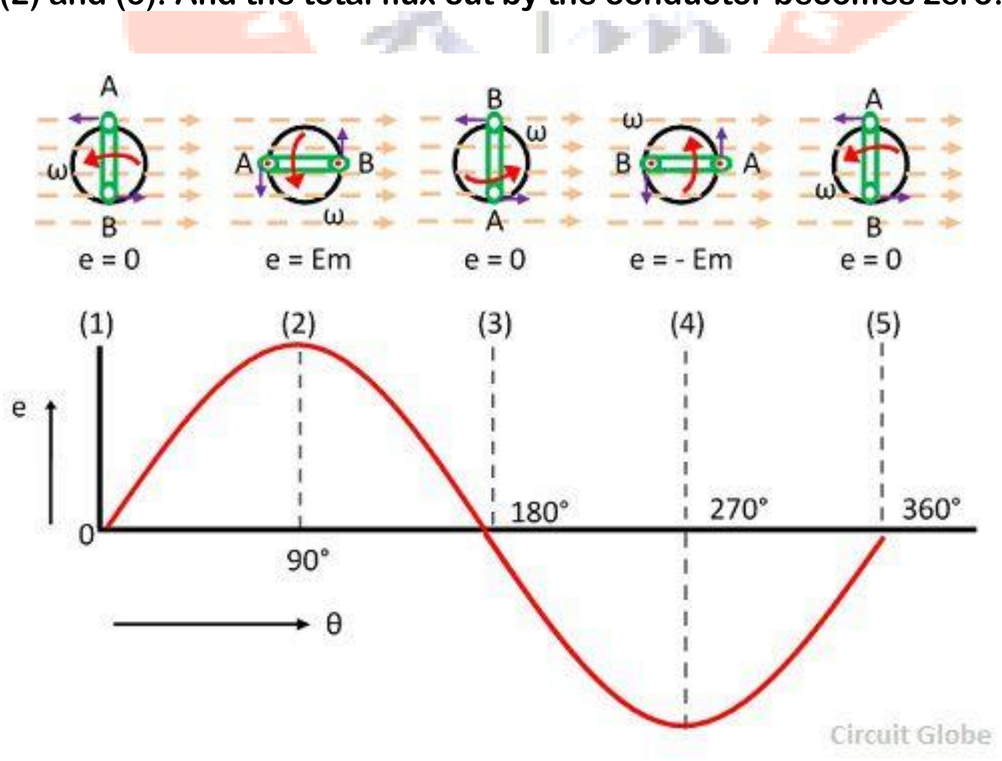
Generation of Alternating Emf

- Ans: The voltage which changes polarity at regular interval of time is known as the alternating voltage.
- The alternating voltage is generated in two ways.

- By rotating the coil inside the uniform magnetic field at constant speed
- By rotating the magnetic field around the stationary coil at the constant speed.

Generation of alternating emf

- Consider the stationary coil places inside the uniform magnetic field. The load is connected across the coil with the help of brushes and the slip rings.
- When the coil rotates in the anticlockwise direction at constant angular velocity ω the electromotive force induces in the coil.
- The magnitude of the emf induced in the coil depends on the rate of the flux cut by the conductor.
- The figure below shows that the no current induces in the coil when they are parallel to the magnetic line of forces. i.e., at the position (1), (2) and (3). And the total flux cut by the conductor becomes zero.



- The magnitude of the induces emf becomes maximum when the conductor becomes perpendicular to the magnetic line of force.
- The conductor cuts the maximum flux at this position.

- he direction of the emf induces in the conductor is determined by Fleming's right-hand rule.

- When the coil is at position (2) the emf induces in the outward direction of the conductor whereas at position (4) the direction of the inducing emf becomes inward.

- In other words, the direction of emf induces in the conductor at position (2) and (4) becomes opposite to each other.

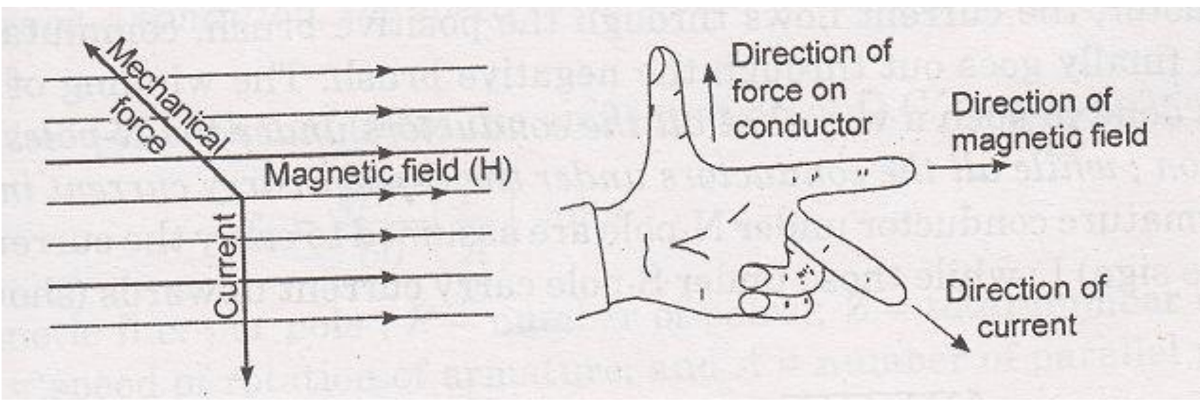
LENZ's law

Faraday's laws provide no idea regarding the direction of induced EMF. The direction of induced
EMF is however, given by Lenz's Law which states that "the direction of the induced current(or
EMF) is such that it opposes the very cause producing this current(or EMF)" i.e. it opposes the
change in magnetic flux.

FLEMMING 's LEFT-HAND RULE

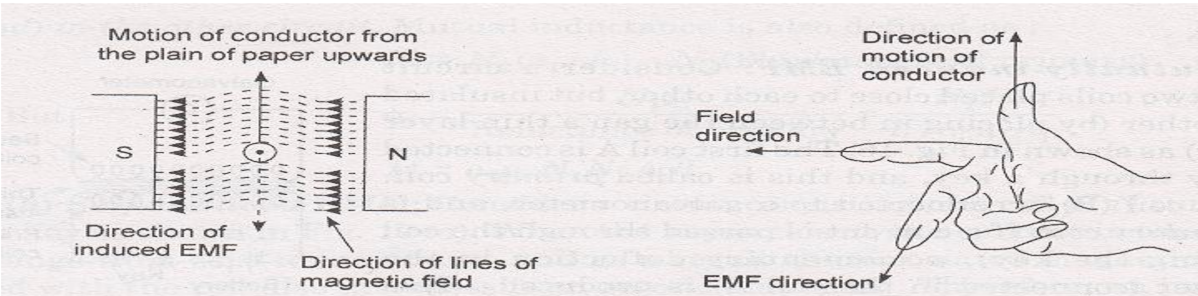
Flemming's left hand rule states that If we stretch out the thumb, the fore-finger & the middle
finger of the left hand so that they are at right angles to each other then if the fore-finger points
in the direction of magnetic field,the middle finger in the direction of current then the thumb

- points in the direction motion or the mechanical force experienced.

- 

- Direction of force experienced on a conductor carrying current, when placed in a magnetic field is given by Fleming's left-hand rule.

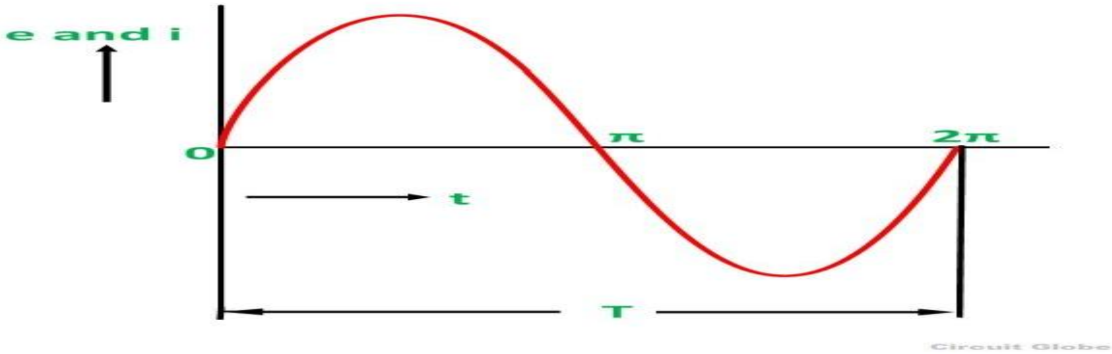
- **FLEMMING'S RIGHT-HAND RULE**
- **Flemming's right hand rule states that If we stretch out the thumb, the fore-finger & the middle**
- **finger of the right hand so that they are at right angles to each other and if the fore-finger points**
- **in the direction of magnetic field, the thumb points in the direction motion of the conductor then**
- **the middle finger points in the direction of current.**



DIFFERENCE BETWEEN AC & DC:

	Alternating Current	Direct Current
Amount of energy that can be carried	Safe to transfer over longer city distances and can provide more power.	Voltage of DC cannot travel very far until it begins to lose energy.
Cause of the direction of flow of electrons	Rotating magnet along the wire.	Steady magnetism along the wire.
Frequency	The frequency of alternating current is 50Hz or 60Hz depending upon the country.	The frequency of direct current is zero.
Direction	It reverses its direction while flowing in a circuit.	It flows in one direction in the circuit.
Current	It is the current of magnitude varying with time	It is the current of constant magnitude.
Flow of Electrons	Electrons keep switching directions - forward and backward.	Electrons move steadily in one direction or 'forward'.
Obtained from	A.C Generator and mains.	Cell or Battery.
Passive Parameters	Impedance.	Resistance only
Power Factor	Lies between 0 & 1.	it is always 1.
Types	Sinusoidal, Trapezoidal, Triangular, Square.	Pure and pulsating.

IMPORTANT TERMS



- **Amplitude**

  The maximum positive or negative value attained by an alternating quantity in one complete cycle is called Amplitude or peak value or maximum value. The maximum value of voltage and current is represented by E_m or V_m and I_m respectively.

- **Alternation**

  One-half cycle is termed as alternation. An alternation span is of 180 degrees electrical.

- **Cycle**

  When one set of positive and negative values completes by an alternating quantity or it goes through 360 degrees electrical, it is said to have one complete Cycle.

- **Instantaneous Value**

  The value of voltage or current at any instant of time is called an instantaneous value. It is denoted by (i or e).

- **Frequency**

  The number of cycles made per second by an alternating quantity is called frequency. It is measured in cycle per second (c/s) or hertz (Hz) and is denoted by (f).

- **Time Period**

The time taken in seconds by a voltage or a current to complete one cycle is called Time Period. It is denoted by (T).

- **Wave Form**

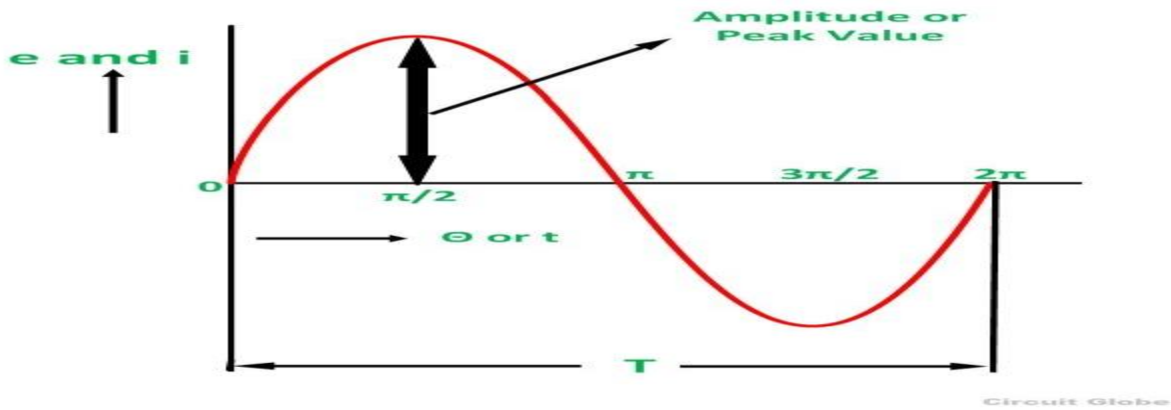
The shape obtained by plotting the instantaneous values of an alternating quantity such as voltage and current along the y-axis and the time (t) or angle (θ=wt) along the x-axis is called a waveform.

Peak Value, Average Value and RMS Value

Peak Value

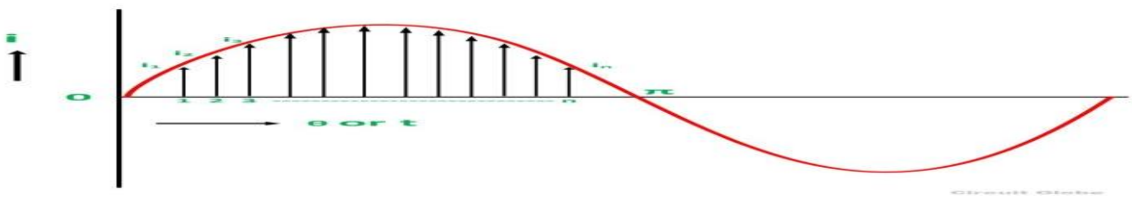
Definition: The maximum value attained by an alternating quantity during one cycle is called its **Peak value**. It is also known as the maximum value or amplitude or crest value. The sinusoidal alternating quantity obtains its peak value at 90 degrees as shown in the figure below.

The peak values of alternating voltage and current is represented by E_m and I_m respectively.



Average Value

Definition: The average of all the instantaneous values of an alternating voltage and currents over one complete cycle is called **Average Value.**



Let i_1, i_2, i_3........ i_n be the mid ordinates

The Average value of current I_{av} = mean of the mid ordinates

$$I_{av} = \frac{i_1 + i_2 + i_3 + \dots\dots\dots + i_n}{n} = \frac{\text{Area of alternation}}{\text{Base}}$$

R.M.S Value

Definition: That steady current which, when flows through a resistor of known resistance for a given period of time than as a result the same quantity of heat is produced by the alternating current when flows through the same resistor for the same period of time is called **R.M.S** or effective value of the alternating current.

$$\frac{I_{eff}^2 Rt}{J} = \frac{Rt}{J}\left(\frac{i_1^2 + i_2^2 + i_3^2 + \dots\dots + i_n^2}{n}\right) \quad \text{or}$$

$$I_{eff} = \sqrt{\frac{i_1^2 + i_2^2 + i_3^2 + \dots\dots.. + i_n^2}{n}}$$

$$I_{eff} = \sqrt{\text{mean of squares of instantaneous values}}$$

Form Factor:

The ratio of the root mean square value to the average value of an alternating quantity (current or voltage) is called **Form Factor.**

The average of all the instantaneous values of current and voltage over one complete cycle is known as the **average value** of the alternating quantities

Mathematically, it is expressed as:

$$\text{Form Factor} = \frac{I_{r.m.s}}{I_{av}} \text{ or } \frac{E_{r.m.s}}{E_{av}}$$

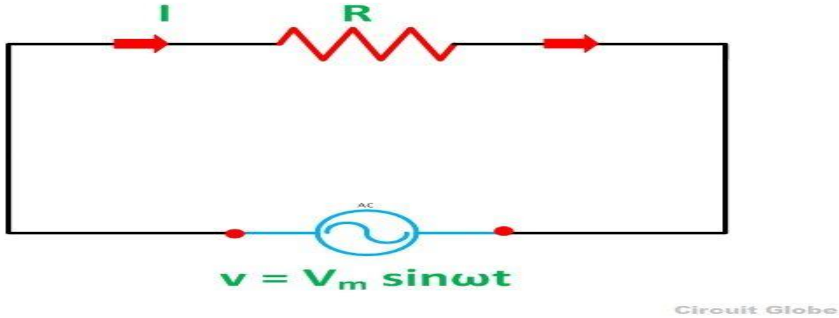
Explanation of Resistive Circuit;

In an AC circuit, the ratio of voltage to current depends upon the supply frequency, phase angle, and phase difference. In an AC resistive circuit, the value of resistance of the resistor will be same irrespective of the supply frequency.

Let the alternating voltage applied across the circuit be given by the equation

$$v = V_m \text{Sin}\omega t \,\ldots\ldots\ldots\ldots\ldots(1)$$

Then the instantaneous value of current flowing through the resistor shown in the figure below will be:



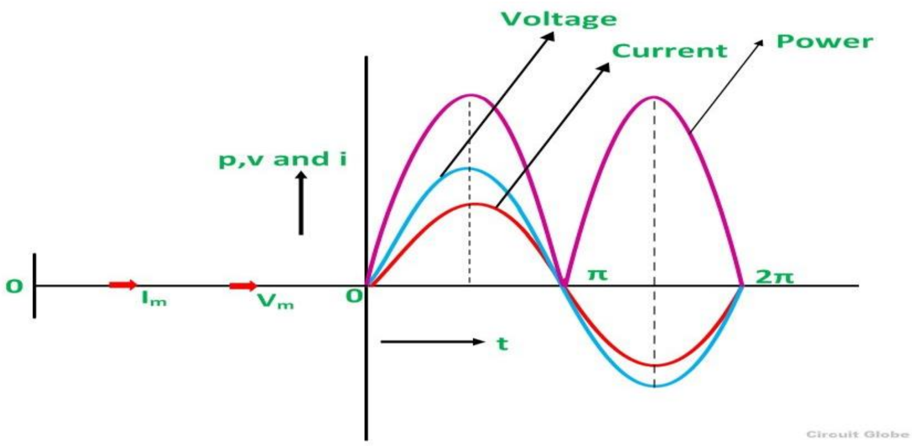
$$i = \frac{v}{R} = \frac{V_m}{R}\ \sin\omega t \ldots \ldots \ldots (2)$$

The value of current will be maximum when ωt= 90° or sinωt = 1

Putting the value of sinωt in equation (2) we will get

Phase Angle and Waveform of Resistive Circuit

From equation (1) and (3), it is clear that there is no phase difference between the applied voltage and the current flowing through a purely resistive circuit, i.e. phase angle between voltage and current is **zero**. Hence, in an AC circuit containing pure resistance, the current is in phase with the voltage as shown in the waveform figure below.



Power in Pure Resistive Circuit

The three colours red, blue and pink shown in the power curve or the waveform indicate the curve for current, voltage and power respectively. From the phasor diagram, it is clear that the current and voltage are in phase with each other that means the value of current and voltage attains its peak at the same instant of time, and the power curve is always positive for all the values of current and voltage.

Therefore, the instantaneous power in a purely resistive circuit is given by the equation shown below:

Instantaneous power, p= vi

$$p = (V_m \sin\omega t)(I_m \sin\omega t)$$

$$p = \frac{V_m I_m}{2} 2\sin^2\omega t = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}(1 - \cos 2\omega t)$$

$$p = \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}} - \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos 2\omega t$$

The average power consumed in the circuit over a complete cycle is given by

$$P = \text{average of } \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}} - \text{average of } \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}} \cos\omega t \ldots\ldots\ldots(4)$$

As the valve of cosωt is zero.

So, putting the value of cosωt in equation (4) the value of power will be given by

$$P = V_{r.m.s} I_{r.m.s} - 0$$

Where,

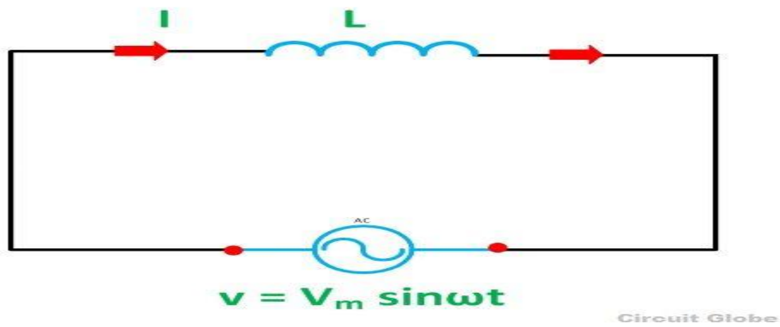
- **P – average power**
- **$V_{r.m.s}$ – root mean square value of supply voltage**
- **$I_{r.m.s}$ – root mean square value of the current**

Hence, the power in a purely resistive circuit is given by:

$P = VI$ The voltage and the current in the purely resistive circuit are in phase with each other having **no phase difference** with phase angle zero. The alternating quantity reaches their peak value at the interval of the same time period that is the rise and fall of the voltage and current occurs at the same time.

AC Through Pure Inductance Circuit:

The circuit containing pure inductance is shown below:



Circuit Diagram of pure Inductive Circuit

Let the alternating voltage applied to the circuit is given by the equation:

$$v = V_m \text{Sin}\omega t \ldots\ldots\ldots\ldots\ldots(1)$$

As a result, an alternating current i flows through the inductance which induces an emf in it. The equation is shown below:

$$e = -L\frac{di}{dt}$$

The emf which is induced in the circuit is equal and opposite to the applied voltage. Hence, the equation becomes,

$$v = -e \ \ldots\ldots\ldots..(2)$$

Putting the value of e in equation (2) we will get the equation as

$$v = -\left(-L\,\frac{di}{dt}\right) \quad \text{or}$$

$$V_m \mathrm{Sin}\omega t \;=\; L\,\frac{di}{dt} \qquad \text{or}$$

$$di = \frac{V_m}{L}\,\sin\omega t\, dt \;\;\dots\dots\dots\dots(3)$$

Integrating both sides of the equation (3), we will get

$$\int di = \int \frac{V_m}{L}\,\sin\omega t\, dt \qquad \text{or}$$

$$i = \frac{V_m}{\omega L}\,(-\cos\omega t) \qquad \text{or}$$

$$i = \frac{V_m}{\omega L}\,\sin\left(\omega t - {}^{\pi}/_{2}\right) = \frac{V_m}{X_L}\,\sin\left(\omega t - {}^{\pi}/_{2}\right) \;\;\dots\dots\dots..(4)$$

where, $X_L = \omega L$ is the opposition offered to the flow of alternating current by a pure inductance and is called inductive reactance.

The value of current will be maximum when sin ($\omega t - \pi/2$) = 1

Therefore,

$$I_m = \frac{V_m}{X_L} \dots\dots\dots\dots(5)$$

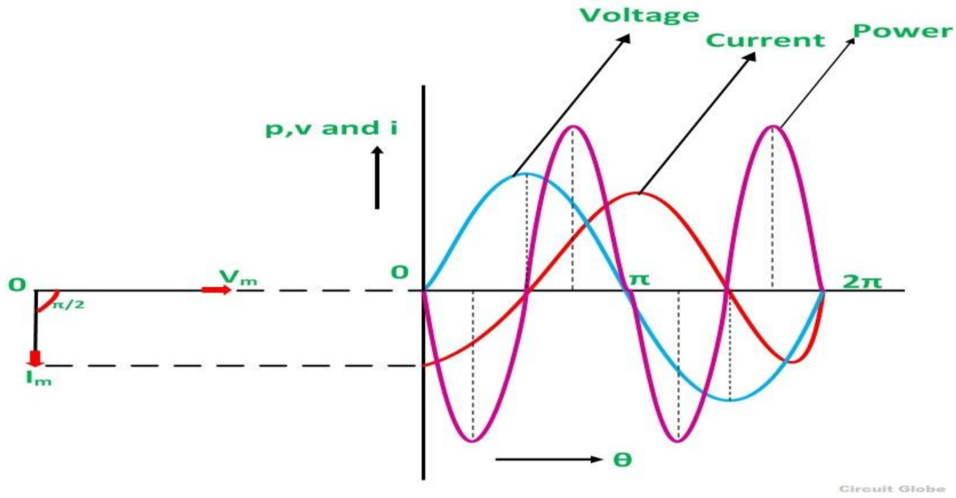
Substituting this value in I_m from the equation (5) and putting it in equation (4)

$$i = \; I_m \sin\left(\omega t - {}^{\pi}/_{2}\right)$$

we will get

Phasor Diagram and Power Curve of Inductive Circuit

The current in the pure inductive AC circuit lags the voltage by 90 degrees. The waveform, power curve and phasor diagram of a purely inductive circuit is shown below



Phasor Diagram and Waveform of Pure Inductive Circuit

The voltage, current and power waveform are shown in blue, red and pink colours respectively. When the values of voltage and current are at its peak as a positive value, the power is also positive and similarly, when the voltage and current give negative waveform the power will also become negative. This is because of the phase difference between voltage and current.

When the voltage drops, the value of the current changes. When the value of current is at its maximum or peak value of the voltage at that instance of time will be zero, and therefore, the voltage and current are out of phase with each other by an angle of 90 degrees.

The phasor diagram is also shown on the left-hand side of the waveform where current (I_m) lag voltage (V_m) by an angle of $\pi/2$.

Power in Pure Inductive Circuit

Instantaneous power in the inductive circuit is given by

$$p = vi$$

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

$$P = V_m I_m \sin\omega t \cos\omega t$$

$$P = \frac{V_m I_m}{2} 2 \sin\omega t \cos\omega t$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \sin 2\omega t \text{ or}$$

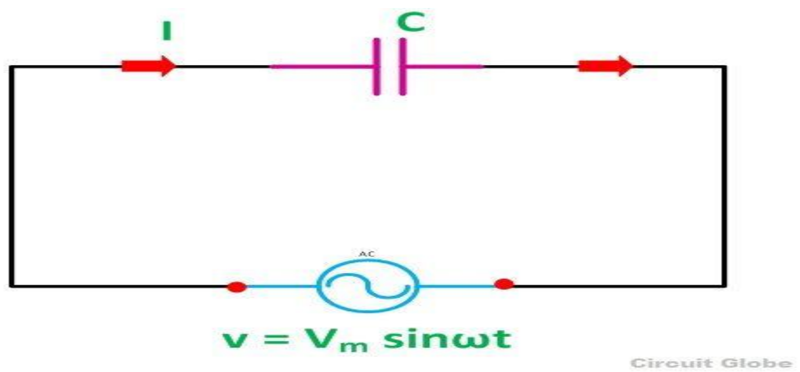
$$P = 0$$

Hence, the average power consumed in a purely inductive circuit is zero.

AC Through Pure Capacitor Circuit

A capacitor consists of two insulating plates which are separated by a dielectric medium. It stores energy in electrical form.

The capacitor works as a storage device, and it gets charged when the supply in ON and gets discharged when the supply is OFF. If it is connected to the direct supply, it gets charged equal to the value of the applied voltage.



Circuit Diagram of pure Capacitor Circuit

Let the alternating voltage applied to the circuit is given by the equation:

$$v = V_m \text{Sin}\omega t \ldots\ldots\ldots\ldots\ldots(1)$$

Charge of the capacitor at any instant of time is given as:

$$q = Cv \ \ldots\ldots\ldots\ldots (2)$$

Current flowing through the circuit is given by the equation:

$$i = \frac{d}{dt} q$$

Putting the value of q from the equation (2) in equation (3) we will get

$$i = \frac{d}{dt} (Cv) \ \ldots\ldots\ldots\ldots. (3)$$

Now, putting the value of v from the equation (1) in the equation (3) we will get

$$i = \frac{d}{dt} C\, V_m \mathrm{Sin}\omega t = C\, V_m \frac{d}{dt} \sin\omega t \quad \text{or}$$

$$i = \omega\, C\, V_m \cos\omega t = \frac{V_m}{1/_{\omega C}} \sin\left(\omega t + {}^{\pi}/_{2}\right) \quad \text{or}$$

$$i = \frac{V_m}{X_C} \sin\left(\omega t + {}^{\pi}/_{2}\right) \ \ldots\ldots\ldots\ldots. (4)$$

Where $X_c = 1/\omega C$ is the opposition offered to the flow of alternating current by a pure capacitor and is called **Capacitive Reactance.**

The value of current will be maximum when $\sin(\omega t + \pi/2) = 1$. Therefore, the value of maximum current I_m will be given as:

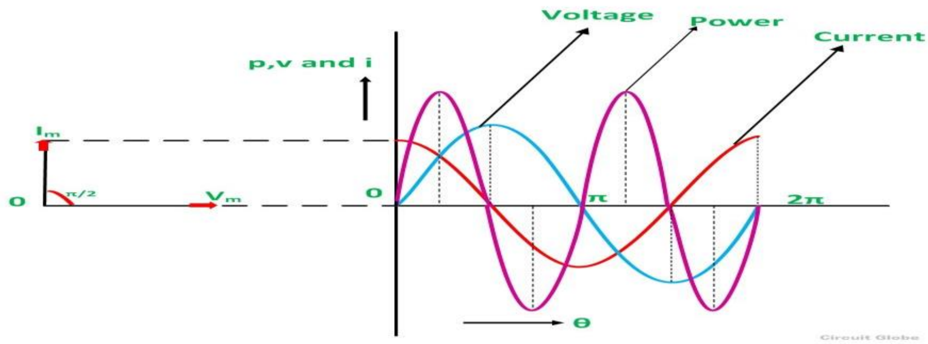
$$I_m = \frac{V_m}{X_C}$$

Substituting the value of I_m in the equation (4) we will get:

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

Phasor Diagram and Power Curve

In the pure capacitor circuit, the current flowing through the capacitor leads the voltage by an angle of 90 degrees. The phasor diagram and the waveform of voltage, current and power are shown below:



Phasor Diagram and Waveform of Pure Capacitor Circuit

The red colour shows current, blue colour is for voltage curve, and the pink colour indicates a power curve in the above waveform.

When the voltage is increased, the capacitor gets charged and reaches or attains its maximum value and, therefore, a positive half cycle is obtained. Further when the voltage level decreases the capacitor gets discharged, and the negative half cycle is formed.

If you examine the curve carefully, you will notice that when the voltage attains its maximum value, the value of the current is zero that means there is no flow of current at that time.

When the value of voltage is decreased and reaches a value π, the value of voltage starts getting negative, and the current attains its peak value. As a result, the capacitor starts discharging. This cycle of charging and discharging of the capacitor continues.

The values of voltage and current are not maximised at the same time because of the phase difference as they are out of phase with each other by an angle of 90 degrees.

The phasor diagram is also shown in the waveform indicating that the current (I_m) leads the voltage (V_m) by an angle of $\pi/2$.

Power in Pure Capacitor Circuit

Instantaneous power is given by p = vi

$$P = (V_m \sin\omega t)(I_m \sin(\omega t + {}^{\pi}/_{2})$$

$$P = V_m I_m \sin\omega t \cos\omega t$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \sin 2\,\omega t \quad \text{or}$$

$$P = 0$$

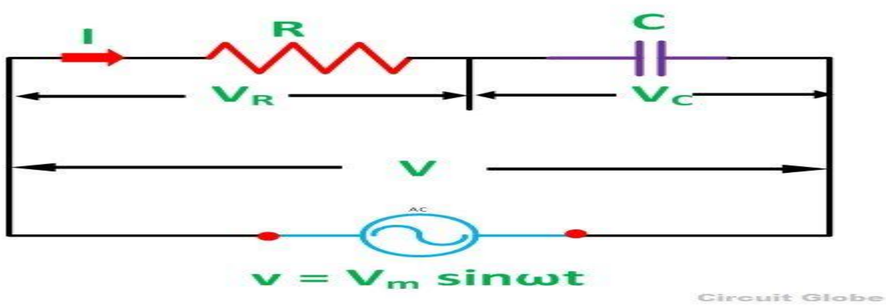
Hence, from the above equation,

it is clear that the average power in the capacitive circuit is zero.

Ac Through RC Series Circuit

A circuit that contains pure resistance R ohms connected in series with a pure capacitor of capacitance C farads is known as **RC Series Circuit.** A sinusoidal voltage is applied and current I flows through the resistance (R) and the capacitance (C) of the circuit.

The RC Series circuit is shown in the figure below:

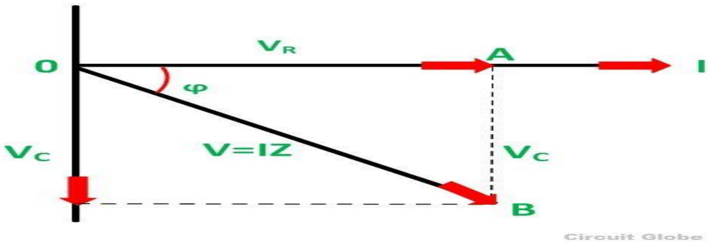


Where,

- V_R – voltage across the resistance R
- V_C – voltage across capacitor C
- V – total voltage across the RC Series circuit

Phasor Diagram of RC Series Circuit

The phasor diagram of the RC series circuit is shown below:



Steps to draw a Phasor Diagram

The following steps are used to draw the phasor diagram of RC Series circuit

- **Take the current I (r.m.s value) as a reference vector**
- **Voltage drop in resistance VR = IR is taken in phase with the current vector**
- **Voltage drop in capacitive reactance VC = IXC is drawn 90 degrees behind the current vector, as current leads voltage by 90 degrees (in the pure capacitive circuit)**
- **The vector sum of the two voltage drops is equal to the applied voltage V (r.m.s value).**

Now,

$$V_R = I_R \text{ and } V_C = IX_C$$

Where $X_C = I/2\pi fC$

RC Series Circuit

A circuit that contains pure resistance R ohms connected in series with a pure capacitor of capacitance C farads is known as RC Series Circuit. A sinusoidal voltage is applied and current I flows through the resistance (R) and the capacitance (C) of the circuit.

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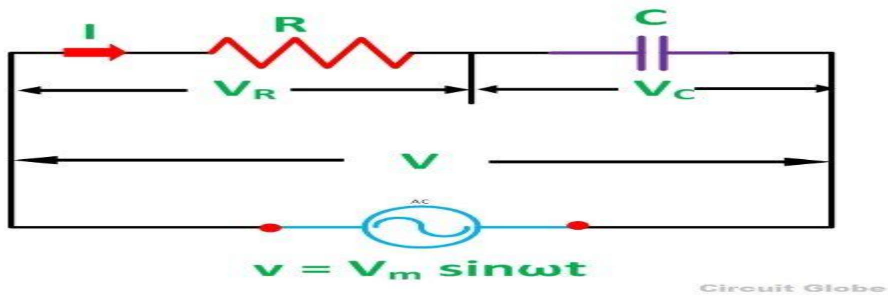

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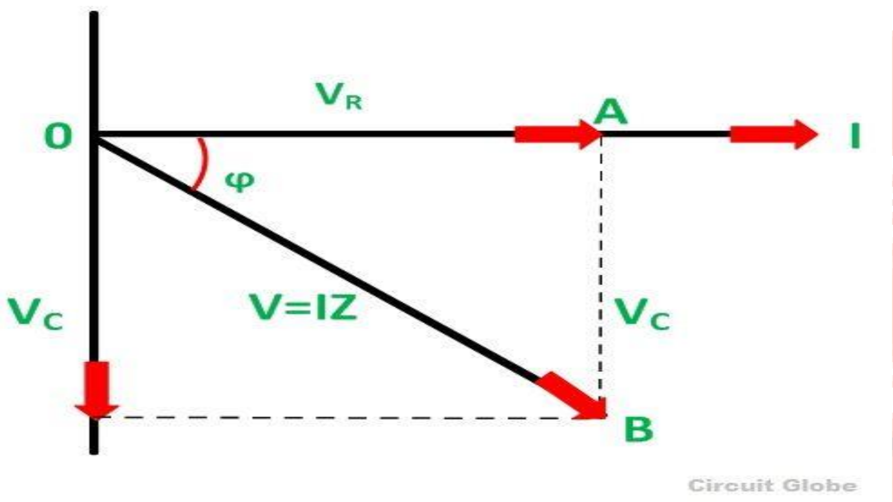
- V – total voltage across the RC Series circuit

Contents:

- Phasor Diagram of RC Series Circuit
- Steps to draw a Phasor Diagram
- Phase angle
- Power in RC Series Circuit
- Waveform and Power Curve of the RC Series Circuit

Phasor Diagram of RC Series Circuit

The phasor diagram of the RC series circuit is shown below:



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- The vector sum of the two voltage drops is equal to the applied voltage V (r.m.s value).

Now,

$$V_R = I_R \text{ and } V_C = IX_C$$

Where $X_C = I/2\pi fC$

In right triangle OAB,

$$V = \sqrt{(V_R)^2 + (V_C)^2} = \sqrt{(IR)^2 + (IX_C)^2}$$

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

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

Where,

$$Z = \sqrt{R^2 + X_C^2}$$

Z is the total opposition offered to the flow of alternating current by an RC series circuit and is called impedance of the circuit. It is measured in ohms (Ω).

Phase angle

From the phasor diagram shown above, it is clear that the current in the circuit leads the applied voltage by an angle ϕ and this angle is called the phase angle.

$$\tan\varphi = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{X_C}{R} \qquad \text{or}$$

$$\varphi = \tan^{-1}\frac{X_C}{R}$$

Power in RC Series Circuit

If the alternating voltage applied across the circuit is given by the equation

$$v = V_m \mathrm{Sin}\omega t \ldots\ldots\ldots\ldots\ldots(1)$$

Then,

$$i = I_m \sin(\omega t + \varphi) \ldots \ldots \ldots . . (2)$$

Therefore, the instantaneous power is given by p = vi

Putting the value of v and i from the equation (1) and (2) in p = vi

$$P = (V_m \mathrm{Sin}\omega t) \mathrm{x}\, I_m \sin(\omega t + \varphi)$$

$$p = \frac{V_m I_m}{2} 2\sin(\omega t + \varphi) \sin\omega t$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} [\cos\varphi - \cos(2\omega t + \varphi)]$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\varphi - \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos(2\omega t + \varphi)$$

The average power consumed in the circuit over a complete cycle is given by:

$$P = \text{average of } \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\varphi - \text{average of } \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos(2\omega t + \varphi) \quad \text{o}$$

$$P = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\varphi - \text{Zero} \quad \text{or}$$

$$P = V_{r.m.s} I_{r.m.s} \cos\varphi = V\, I \cos\varphi$$

Where $\cos\phi$ is called the **power factor** of the circuit.

$$\cos\varphi = \frac{V_R}{V} = \frac{IR}{IZ} = \frac{R}{Z} \ldots \ldots \ldots \ldots . (3)$$

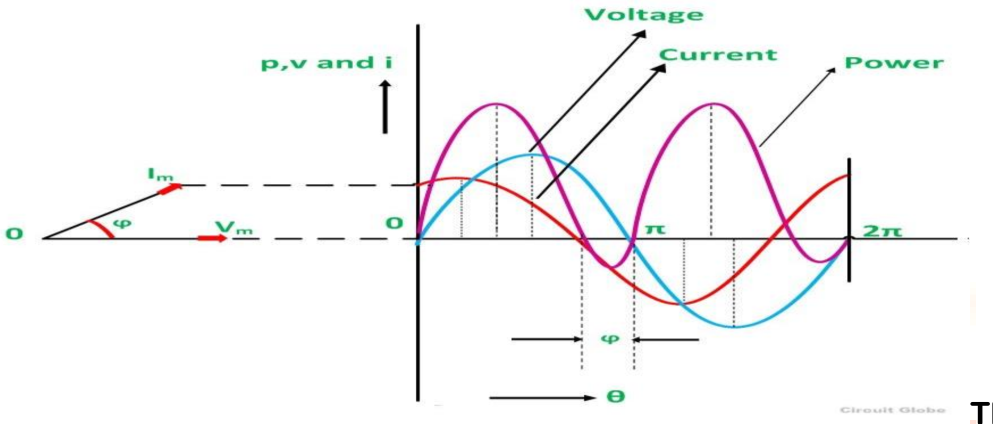
Putting the value of V and $\cos\phi$ from the equation (3) the value of power will be

$$P = (IZ)(I)(R/Z) = I^2 R \ldots \ldots \ldots (4)$$

From the equation (4) it is clear that the power is actually consumed by the resistance only and the capacitor does not consume any power in the circuit.

Waveform and Power Curve of the RC Series Circuit

The waveform and power curve of the RC circuit is shown below:



The various points on the power curve are obtained from the product of the instantaneous value of voltage and current.

The power is negative between the angle (180° – ϕ) and 180° and between (360° -ϕ) and 360° and in the rest of the cycle, the power is positive. Since the area under the positive loops is greater than that under the negative loops, therefore the net power over a complete cycle is positive.

Examples:

1.resistance of 10 Ω, inductance of 0.1 H & capacitance 50 micro farad are connected in series across a 230v, 50Hz supply. Find (a) XL , XC & Z, (b) I & Power factor (C) Active, reactive and apparent power

SOLUTION:

(a) $wL = 2\pi fL = X_L$ = INDUCTIVE REACTANCE

$2\pi fL = 2\pi\, 50 \times 0.1 = 31.41\ \Omega$

$X_C = (1 / wc) = (1 / 2\pi 50 \times 50 \times 10^{-6}) = 63.66\ \Omega$

$Z = R + j(X_L - X_C) = 10 + j(31.41-63.66) = 10 - j32.25 = 33.76 \angle -72.77^0$

(b) I = CURRENT = $(V / Z) = (230\angle 0^0 / 33.76\angle -72.77^0 = 6.8 \angle 72.77^0$ Amp

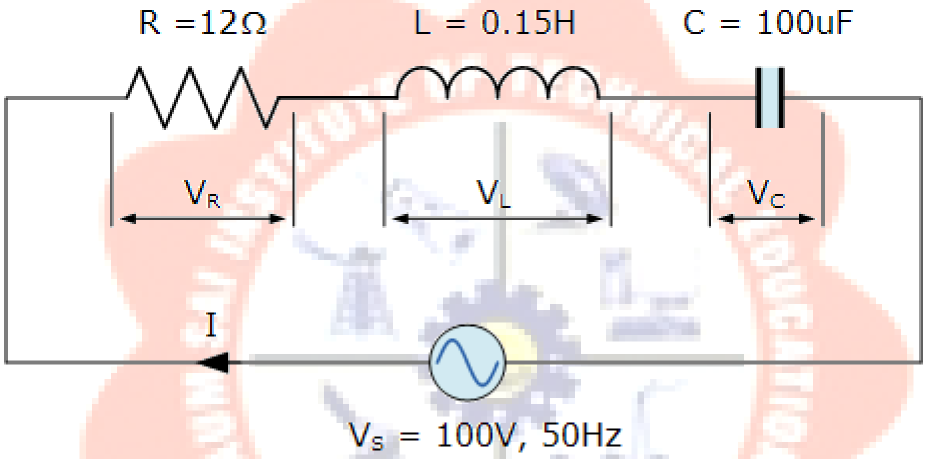
Power factor = Cos (72.77^0) = 0.296 leading

(c) App Power = S = VI = 230 x 6.8 = 1564 VA

Active power = P = VI Cos θ = (1564 x 0.296) = 462.9 watt

Reactive power = Q = VI Sin θ = (1564 x Sin -72.77^0) = -1496.80 Vars

1.A series RLC circuit containing a resistance of 12Ω, an inductance of 0.15H and a capacitor of 100uF are connected in series across a 100V, 50Hz supply. Calculate the total circuit impedance, the circuits current, power factor and draw the voltage phasor diagram.



Ans:I

Inductive Reactance, X_L.

$$X_L = 2\pi f L = 2\pi \times 50 \times 0.15 = 47.13\Omega$$

Capacitive Reactance, X_C.

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 100 \times 10^{-6}} = 31.83\Omega$$

Circuit Impedance, Z.

$$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$$

$$Z = \sqrt{12^2 + \left(47.13 - 31.83\right)^2}$$

$$Z = \sqrt{144 + 234} = 19.4\Omega$$

Circuits Current, I.

$$I = \frac{V_S}{Z} = \frac{100}{19.4} = 5.14\,\text{Amps}$$

Voltages across the Series RLC Circuit, V_R, V_L, V_C.

$$V_R = I \times R = 5.14 \times 12 = 61.7\ \text{volts}$$

$$V_L = I \times X_L = 5.14 \times 47.13 = 242.2\ \text{volts}$$

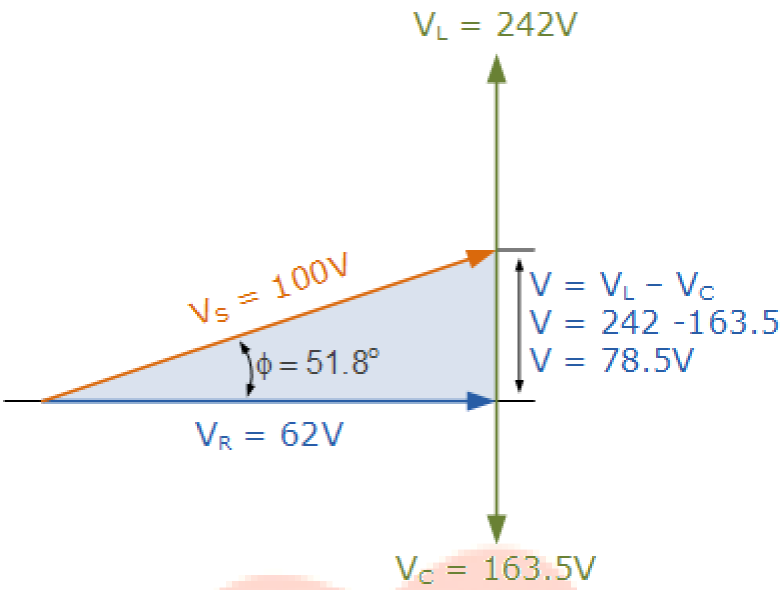
$$V_C = I \times X_C = 5.14 \times 31.8 = 163.5\ \text{volts}$$

Circuits Power factor and Phase Angle, θ.

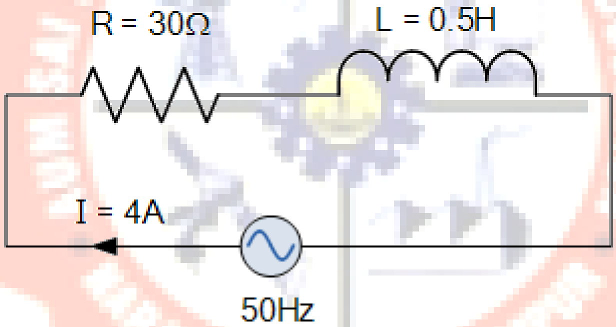
$$\cos\phi = \frac{R}{Z} = \frac{12}{19.4} = 0.619$$

$$\therefore \cos^{-1} 0.619 = 51.8^0\ \text{lagging}$$

Phasor Diagram.



2.A coil has a resistance of 30Ω and an inductance of 0.5H. If the current flowing through the coil is 4amps. What will be the rms value of the supply voltage if its frequency is 50Hz.



The impedance of the circuit will be:

$$X_L = 2\pi f L = 2\pi \times 50 \times 0.5 = 157\Omega$$

$$Z = \sqrt{R^2 + X_L^2}$$
$$Z = \sqrt{30^2 + 157^2}$$
$$Z = 159.8\Omega$$

Then the voltage drops across each component is calculated as:

$$V_S = I.Z = 4 \times 159.8 = 640v$$

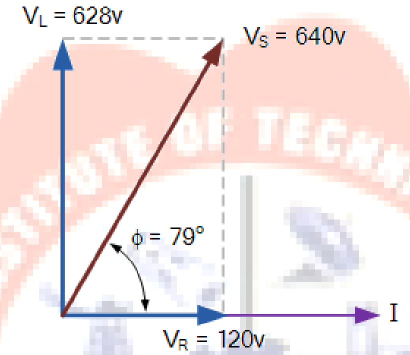
$$V_R = I.R = 4 \times 30 = 120v$$

$$V_L = I.X_L = 4 \times 157 = 628v$$

The phase angle between the current and supply voltage is calculated as:

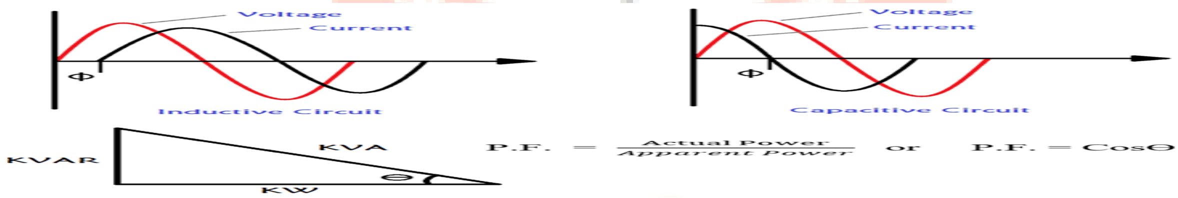
$$\tan^{-1}\phi = \frac{X_L}{R} = \frac{157}{30} = 79.2^o$$

The phasor diagram will be.

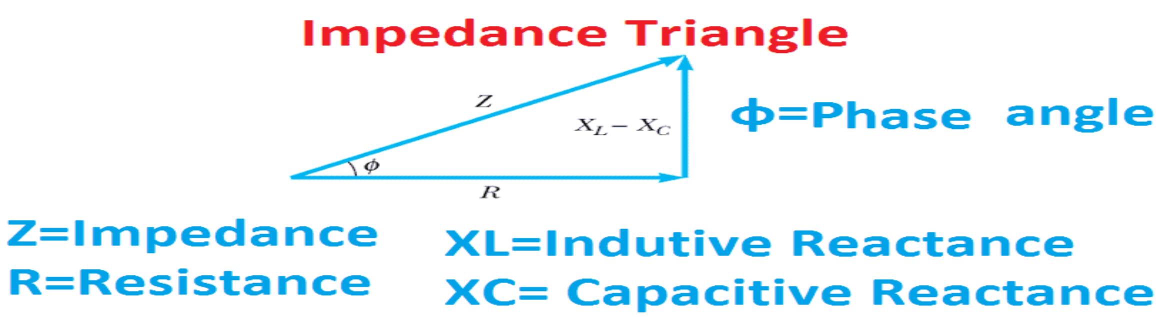


Power Factor:

the ratio of the actual electrical power dissipated by an AC circuit to the product of the r.m.s. values of current and voltage.



Impedance Triangle:



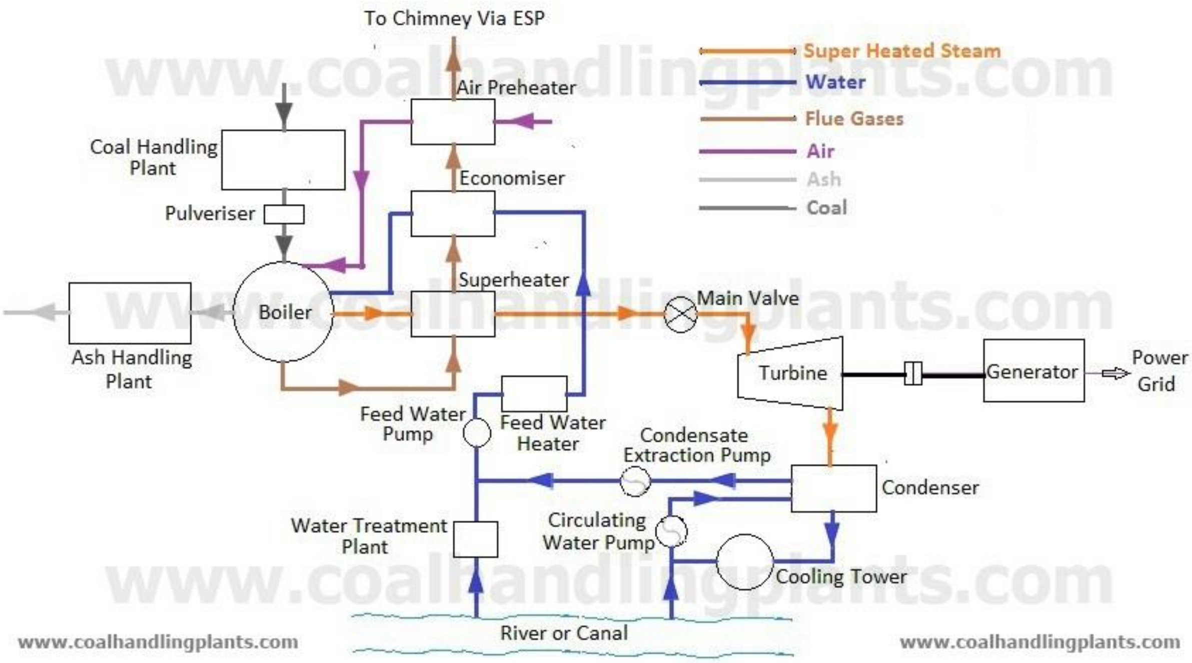
CHAPTER-3

GENERATION OF ELCTRIC POWER

ELEMENTARY IDEA ON GENERATION OF POWER STATION:

Thermal Power Station:

A generating station which converts heat energy of coal combustion into electrical energy is known as a steam power station or thermal power plant.



**1.COAL STORAGE PLANT :- Coal is transported to the power station by road or rail and is
stored in coal storage plant.**
**2. COAL HANDLING PLANT:- : From the coal storage plant coal is delivered to the coal
handling plant where it is pulverized for rapid combustion with out using excess amount of air.**

**3. ASH STORAGE PLANT:- The coal is burnt in the boiler & the ash produced after the
complete combustion of coal is removed to the ash handling plant.**

4. ASH HANDLING PLANT:- the ash from ash handling plant is then delivered to the ash storage plant for subsequent use as fertilizer etc.

5. BOILER:- The heat of combustion of coal in the boiler is utilized to convert water into steam at very high temperature and pressure.The flue gases from the boiler makes their journey through superheater,economizer, air pre-heater & are finally exhausted to the atmosphere through the chimney.

6. SUPERHEATER:- The steam produced in the boiler is wet and is passed through super heater where it is dried and super heated.

7. ECONOMISER:- An economizer is essentially a feed water heater & derives heat from the flue gases for the purpose.

8. AIR PREHEATER:- Air pre-heater increases the temperature of the air supplied for coal burning by deriving heat from flue gases.

9. FORCED DRAUGHT FAN :-It draws air from atomosphere which is supplied to the boiler for effective combustion.

10. INDUCED DRAUGHT FAN : it draws the flue gas and sends to chimney.

11. CHIMNEY:- The hot flue gases go to the atmosphere though chimney.

12. STEAM TURBINE:- The dry and super heated steam from the super heater is fed to the steam turbine which converts the heat energy of steam tto mechanical energy.

13. ALTERNATOR:- The alternator converts the mechanical energy of steam turbine to electrical energy.

14. CONDENSER :- In order to improve the efficiency of the plant the steam exhausted from the turbine is condensed by means of a condenser. The condensate from the condenser is used as feed water to the boiler.

15. COOLING TOWER : The cooling tower provides a cooling arrangement for the feed
water to be reused in boiler

ADVANTAGES

i) The Fuel (i.e. Coal) used is quite cheap.
ii) Less initial cost as compared to other generating stations.
iii) It can be installed at any place & the coal can be transported by Rail / Road.
iv) It requires less space as compared to hydro-electric Power Station.

DISADVANTAGES

i) It pollutes air / atmosphere due to smoke / fumes
ii) Running cost is higher than hydro power plant.

site selection.

1. Near to the load center :-
It locates near the load center resulting low transmissions cost & loss.
2. Supply of water :-
Large quantity of water is required
1. To raise steam in boilers.

2. For cooling

3. For carrying disposal of Ash.

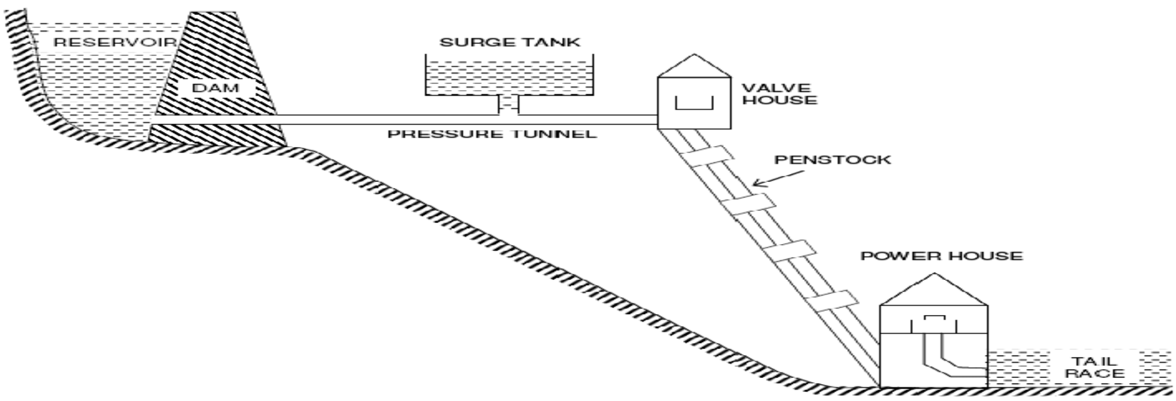
4. For drinking

3. Availability of coal :-
It required huge amount of coal so plants are located near the coal mines to avoide the transport of coal & ash.
4. Load requirement :-
Land is requires not only for setting of plant but also other purposes for staff colony, coal storage ash disposal etc.
TRANSPORTATION FACILITIES:-
These facilities most be available for trans potation of heavy equipment & fuels i.e. near railway station

HYDRO POWER STATION:

ELEMENTS OF HYDRO ELECTRIC POWER PLANT:

- Storage reservoir It stores water during excess flow periods (Rainy Seasons) & supplied the same during least flow of periods i.e. (dry seasons) It can be either natural i.e. lake or artificial made by construction dam across the river.



Dam :– It is the most expensive & important part which is built up concrete or stone masonry earth or rock fill. It is not only raise the water surface by creating artificial head but provide pondage or storage.

- **Fore bay :- It serves as regulating reservoir storing water temporary during light load period & providing same during increased load period i.e. it is either a pond behind the diversion dam or an enlarge section of canal spread out to accommodate required with of intake.**
- **Spillway :- These are constructed to discharge the over flow water to the downstream. When the reservoir is full. Generally it acts as safety valve during flood situation.**
- **Intake :- Generally intake includes head works i.e. structure at the intake the conduits & tunnel or flumes which are res possible for diverting & preventing entry of debris & ice into the turbines. These structures includes booms, screams, rocks or sluices.**
- **SURGE TANK: Surge tank regulates & maintains required pressure in the penstock. Because during light load pressure in the penstock becomes more even if which can burst the penstock but surge tank reduces the pressure by raising water level inside it.**
- **Similarly during the low pressure additional water flows provided by it. So search tank stabilize the velocity & pressure in the penstock.**
- **VALVE & GATES: Generally these are fitted at Entrance to the turbine during in section & repairing these are shut off.**
- **TAIL RACE : The water from turbine is discharged to the tail race generally tail race may be same stream or another one but design & size of tail race should be search that water are free exist.**
- **PRIME MOVERS / WATER TURBINES: In hydro power plant water turbines are used as prime movers which convert kinetic Energy of water into mechanical energy which is further utilized to drive the alternators generating electric at energy**

Advantage

- **1. No fuel is required by such plant because water is the source of energy.**

- 2. It is highly reliable & cheapest & operation & ma46intenance
- 3. No. Stand by loss & variable load demand can meet easily
- 4. Good longer life & robust.
- 5. Efficiency does not fall with age & it has neat & clean environment due to absence of smoke & ask.
- 6. In addition to generation of provides irrigation flood control on navigation.

Disadvantage

- 1. It covers large area.
- 2. Constructional cost is very high along with it requires long transmission line as it far away from load centre.
- 3. Its O/P is uncertain

SELECTION OF SIDE FOR HYDRO ELECTRIC POWER PLANT :

These are some factors which are taken in to consideration for the selection of site for hydro electric power plant i.e.

1. Availability of water :

Hydro electric power plant should be built where there adequate water available at goof head or huge quantity of water is flowing across a given point

WATER STORAGE:

For continuous supply of water. The water storage in suitable reservoir at height or building of dam across the river is essential so convient accommodation for the erection of a dam per Reservoir must be available.

WATER HEAD:

It has a considerable effect on the cost & economy of power generation i.e. an increasing effective head reduces the quantity of storage water & handle by pen stock screens & turbine resulting reduction in cost.

DISTANCE FROM LOAD CENTRE:

Generally these plant locate far away from load center so roots & distances affects on economical transmission.

ACCESSIBILITY OF SIZE:

It requires adequate transportation facilities for easy transportation required equipment & machine

AVAILABILITY OF LAND:

- The land available most be cheap & rocky to with stand large building & machinery.

NUCLEAR POWER STATION:

The power plant which generates electricity by utilizing the vast energy released from nuclear fission reaction is known as nuclear power.

NUCLEAR FISSION :-
The nuclear reaction in which a heavy nucleus is splited in to small nucleus is splited in to small nuclei with liberation of vast energy by bombardment of neutron is known as Nuclear Fission Reaction.
Eg- chemical reaction
92U 235 + 0n1 56Ba139 +36Kr94+30n1 + Energy
92U 235 + 0n1 92MO106+50Sn128 + 20n1 + Energy.

Components of the nuclear power plant :-
a. **Nuclear Reactor** :-

It is the main part of nuclear power plant which is very similar to boiler of thermal power plant it has following component.
1. **Reactor core** :-

It contains a number of fuel rods made of U235, U 234, U233 etc. as uranium gets oxidised rapidly so fuel rods clad with aluminum stainless steel or zirconium.
2. **Moderator** :
The moderator moderate or reduces the neurons speed to a value that increase the probability or fission reactor. The elements which are used as moderator in nuclear reactor are hydrogen deuterium He , Li, oxygen ,carbon heavy water etc.
3. **Control Rods:**
The control rods which are made of Boron-10 cadium or Hafnium are inserted in to nuclear reactor from the top of reactor vessels.
The control rods control rate of the nuclear fission reaction by absorbing neutrons.
It can be inserted or taken out as according to requirement i.e. if we need increased rate of reaction we have to taken out & vice verse.

4. **Coolant** :-

It is the medium through which heat generated in the reactor is transferred to the heat exchanger & it also keeps the reactor at desired temp.
a. The material like air He, H & CO_2 amongst the gases light or heavy water amongst the liquid or molten sodium or lithium amongst the metal used as coolant.

b. **Heat Exchanger** :-In heat Exchanger the gas is heated or steam is generated by utilizing heat from nuclear reactor, here heat is connected by heat exchanger tube by circulation.

c. **Steam turbine** :- The Steam produce in heat exchanger is transferred to steam turbines through steam valve where heat energy is converted in to mechanical energy.

d. **Condenser** : The exhausted steam from steam turbine is condensed by condenser & again feed to heat exchanger by feed water pump.

e. **Alternator** :- It is coupled to steam turbine & it generate electricity by converting mechanical energy to convert in to electrical energy .

ADVANTAGES

i) There is saving in fuel transportation as amount of fuel required is less.
ii) A Nuclear Power Plant requires less space as compared to other plants.
iii) This type of plant is economical for producing bulk Electrical Energy.

DISADVANTAGES

i) Fuel is expensive and difficult to recover.
ii) Capital lost is higher than other plants.
iii) Experienced workman ship is required for plant erection & commissioning.
iv) The Fission by-products are radio active & can cause dangerous radio-active pollution.
The disposal of by-product is big problem

SELECTION OF SITE FOR NUCLEAR POWER PLANT :

The factor to be considered while selecting a site for nuclear power plant for economical deficient generation.
Availability of water supply :-
1. It requires more water i.e. two times of thermal power plant of same rating. So it located near the river, sea side or lake.

2. Distance from populated area:-

Generally these are located for away from populated area due to danger of radio activity.
3. Nearness to load center :-

Those plants can be located near the load center because of absence of transportation.
4. Availability of space for disposal of water :-

Their should have adequate space & arrangement for the disposal of radio activity waste.
5. Types of land :
The land should be strong enough to support the heavy reactor i.e. 10,000 tones weight with imposed boarding pressure around 50 tones /m2

CHAPTER-4

CONVERSION OF ELECTRICAL ENERGY

INTRODUCTION TO DC MACHINE

Introduction

A d.c. machine is a device which converts mechanical energy into electrical energy. When the device acts as a generator mechanical energy is converted into electrical energy.

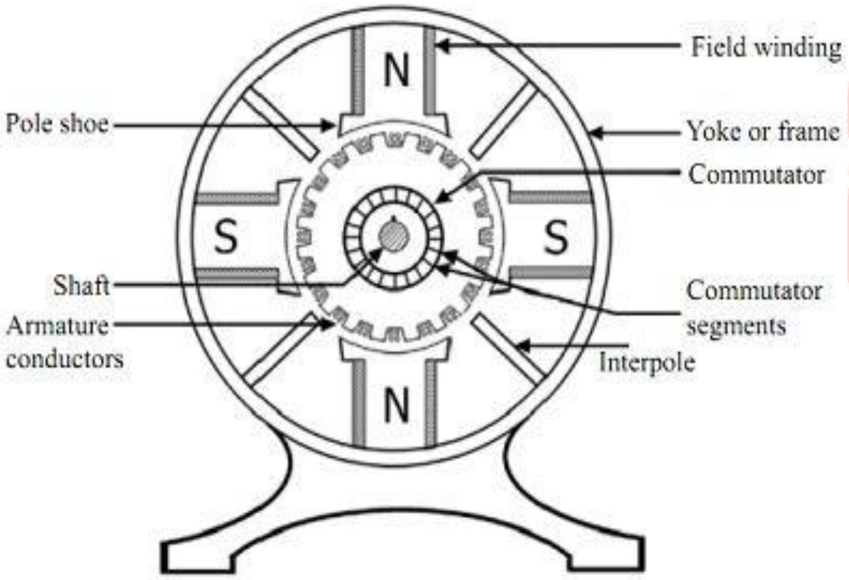
On the other hand when the device acts as a motor, the electrical energy is converted into mechanical energy.

However, during the conversion process a part of the energy is converted into heat, which is lost and is not reversible. Thus an electrical machine can be made to work either as a generator or a motor.

MAIN PARTS OF DC MACHINE

2 Main Parts of D.C. Machine

(1)Yoke or Magnetic frame (2) Pole Shoes and Pole Core (3) Armature Core (4)Field Coils (5) Armature windings (6)Commutator (7) Brushes and Bearings (8) Shaft (9) End Covers, (10)Feet.



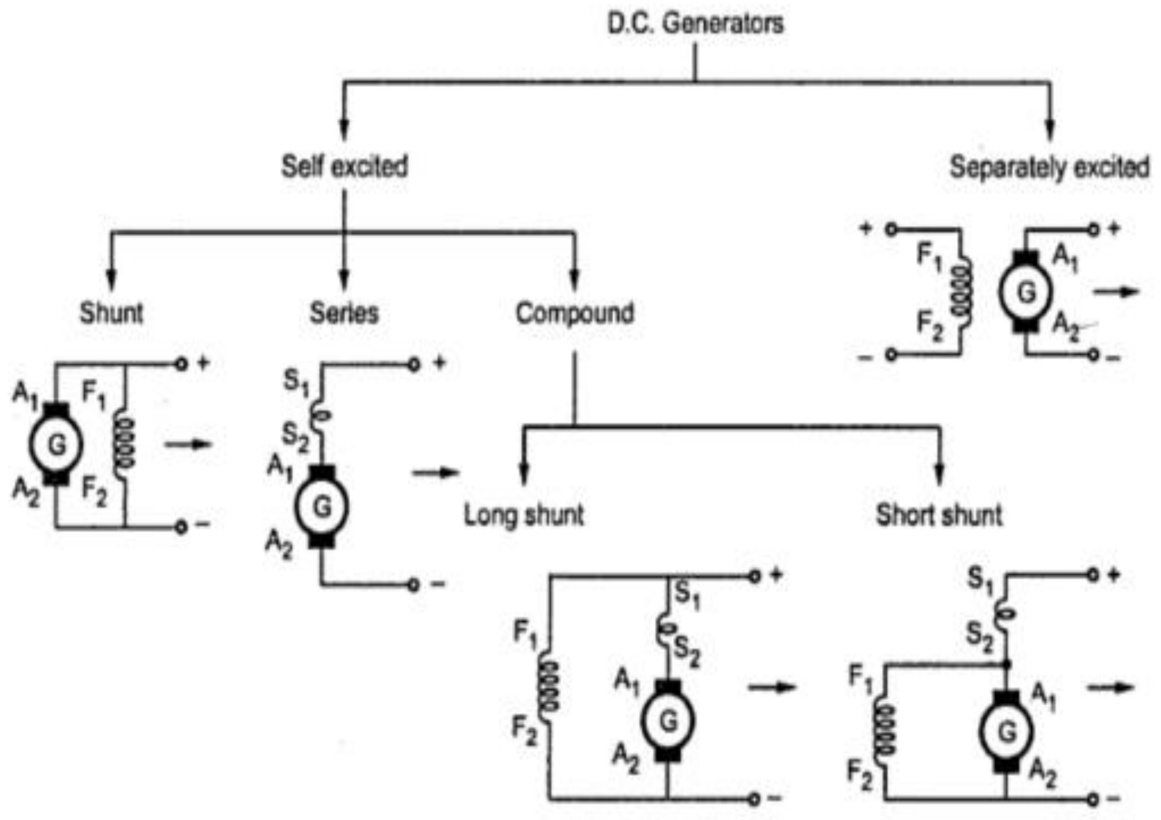
CLASSIFICATION OF DC GENERATOR:

DC generators are classified based on how their fields are excited (i.e. produced). There are three methods of excitation, and thus three main types of DC generators:

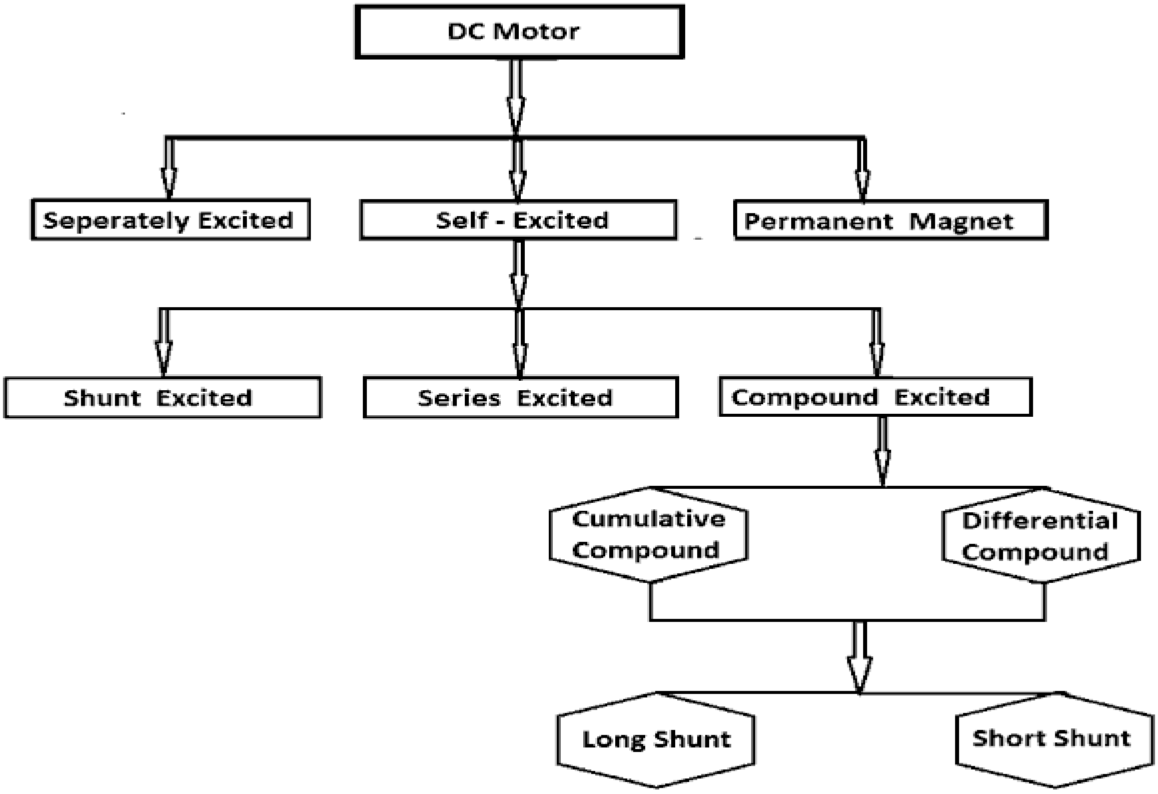
1. **Permanent Magnet DC Generators – Field coils excited by permanent magnets**
2. **Separately Excited DC Generators – Field coils excited by some external source**
3. **Self Excited DC Generators – Field coils excited by the generator itself**

Self-excited DC generators can further be classified depending on the position of their field coils. The three types of self-excited DC generators are:

1. **Series Wound Generators**
2. **Shunt Wound Generators**
3. **Compound Wound Generators**
    a. **Long shunt compound generator**
    b. **Short shunt compound generator**



CLASSIFICATION OF DC MOTOR



Uses OF DIFFERENT TYPES OF DC GENERATOR & MOTORS

Applications of DC Motors

The main applications of the three types of direct current motors are given below.

Series Motors

- The series DC motors are used where high starting torque is required, and variations in speed are possible.
- For example – the series motors are used in Traction system, Cranes, air compressors, Vaccum Cleaner, Sewing machine, etc.

Shunt Motors

- The shunt motors are used where constant speed is required and starting conditions are not severe.
- The various applications of DC shunt motor are in Lathe Machines, Centrifugal Pumps, Fans, Blowers, Conveyors, Lifts, Weaving Machine, Spinning machines, etc.

Compound Motors

- The compound motors are used where higher starting torque and fairly constant speed is required.
- The examples of usage of compound motors are in Presses, Shears, Conveyors, Elevators, Rolling Mills, Heavy Planners, etc.

- The small DC machines whose ratings are in fractional kilowatt are mainly used as control device such in Techno generators for speed sensing and in Servo motors for positioning and tracking.

Application of DC Generator:

Separately Excited DC Generators

- Separately excited DC Generators are used in laboratories for testing as they have a wide range of voltage output.
- Used as a supply source of DC motors.
-
- **Shunt wound Generators**

- DC shunt wound generators are used for lighting purposes.
- Used to charge the battery.
- Providing excitation to the alternators.

Series Wound Generators

- DC series wound generators are used in DC locomotives for regenerative braking for providing field excitation current.
- Used as a booster in distribution networks.
- Over compounded cumulative generators are used in lighting and heavy power supply.
- Flat compounded generators are used in offices, hotels, homes, schools, etc.
- Differentially compounded generators are mainly used for arc welding purpose.

TYPES AND USES OF 1-PHASE OF INDUCTION MOTOR

Types of Single Phase Induction Motor
(1) Split phase motor
(2) Capacitor start motor
(3) Capacitor start – Capacitor run single phase Induction Motor.
(4) Shaded Pole Motor -
(5) Repulsion Motor

Uses :
(1) **Split phase motor** :
(i) Small Pumps
(ii) Grinders

(2) Capacitor start motor
(i) Compressor
(ii) Pumps

(3) Capacitor start capacitor Run Motor

(i) Compressor of Air-conditioner
(ii) Water Cooler

(4) Shaded Pole Motor
(i) Small fans

(5) Repulsion Motor
(i) Mixing Machine
(ii) Blowers

Lumen:

The **lumen** (symbol: **lm**) is the SI derived unit of luminous flux, a measure of the total quantity of visible light emitted by a source per unit of time.

The lumen is defined in relation to the candela as

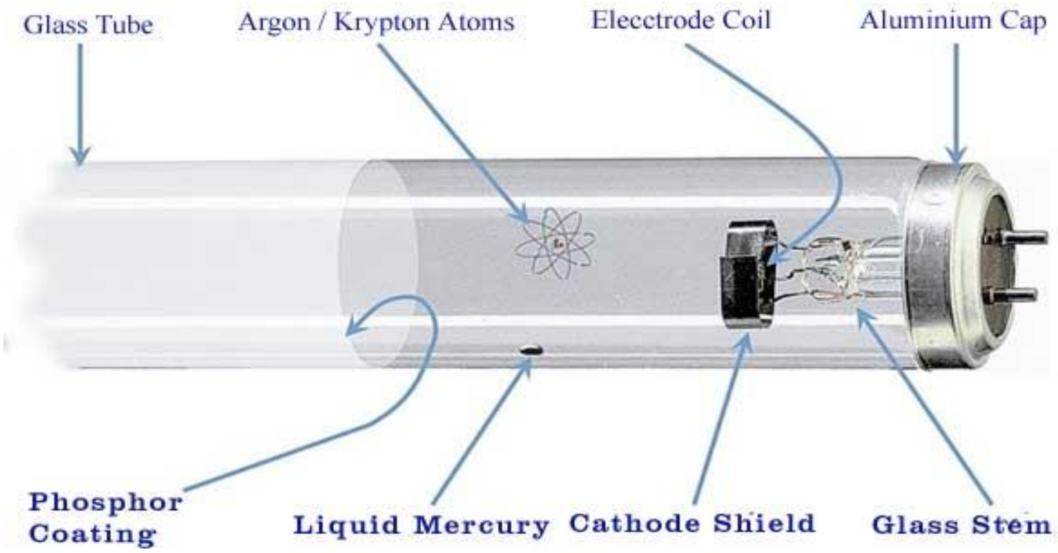
1 lm = 1 cd · sr

Fluorescent Tube:

A fluorescent tube light consists of

1. a lime glass tube
2. drop of mercury
3. argon gas
4. phosphor coating
5. electrode coils
6. mounting assemblies
7. aluminum cap

Total set up of a lamp requires two bases and electromagnetic ballast or choke coil with a starter.



- The electrode mount assemblies are at both the ends of lamp tube.
- This electrode mounting assembly is almost similar to the stem press unit in the incandescent lamps.
- The electrode is similar to the incandescent lamp filament.
- The filaments of electrodes play both roles as anode and cathode.
- Small plates are attached to the filament to protect the electron bombardment and reduce the wattage loss at both ends.
- The filament is dipped in a mixture of barium, strontium and calcium carbonate. It is baked during manufacturing to become oxides and thus it becomes capable of providing abundance of free electrons easily.
- Liquid mercury is provided inside the lamp bulb.
- Phosphor coating is used on inner wall of the bulb tube.
- At a certain pressure argon gas is filled up inside the tube.
- Two pins at each end are taken out of the lamp body through the cap.

Working:

As electricity is supplied to the tube through the electrodes, the current passes through the gas conductor, in form of free electrons and ions and vaporizes the mercury.

As the electrons collide with the gaseous atoms of mercury, they give away free electrons which jump to higher levels and when they fall back to their original level, photons of light are emitted.

This emitted light energy is in the form of ultraviolet light, which is not visible to humans.

When this light strikes the phosphor coated on the tube, it excites the electrons of phosphor to higher level and as these electrons fall back to their original level, photons are emitted and this light energy is now in form of visible light.

Led Bulb:

LED light bulbs are a more environmentally-friendly alternative to incandescent bulbs.

LED bulbs use a semiconductor device that emits visible light when an electric current passes through it. That property is known as elecroluminescence.

Compact fluorescents, the most common alternative to incandescent bulbs, use electricity to excite mercury gas until it emits ultraviolet (UV) light. That light is then passed through a phosphor, which causes it to emit more visible light.

LEDs themselves have been around for some time, but only recently have improvements in efficiency, cost and output made them viable for the larger-scale lighting used in households, businesses and other environments.

Due to the rapid progress in LED technologies, products exist with wide ranges of efficiencies and life spans.

The bulbs can work for 50000 hours, if not run outside of the specified temperature range. They use about 8-11 watts of power to replace a 60-watt incandescent with at least 806 lumen and 9.5 watts for a 75-watt equivalent. This capacity provides an efficiency gain of up to 80% over incandescent bulbs.

Other benefits of LED light bulbs:

- Cooler than incandescent bulbs in operation.
- Instant on, unlike compact fluorescent bulbs.
- Broad range of color possibilities.
- Customizable lights can be controlled through a Bluetooth connection.
- Lowest cost over ownership of all lights.
- No mercury and minimal toxic materials required.
- A single lamp represents a reduction of hundreds of pounds of CO_2, compared to use of incandescents.

CHAPTER-5

WIRING AND POWER BILLING

TYPES OF WIRING FOR DOMESTIC INSTALLATION

Introduction

Electricity is used at home for different purposes such as light loads, fans, computer, refrigerator, cooler etc.

In industries most of the machines run with electricity. The electric supply is given by the distribution company supplies upto energy meter of the consumer.

The process by which the electric supply is made available to various load points through a network of conductors is called the wiring.

Types of Wiring

Different methods of wiring are used under different conditions. The selection of an
individual system of wiring depends upon on the following factors.

(i) Initial cost
(ii) Durability
(iii) Mechanical Protection
(iv) Fire safety
(v) Appearance
(vi) Accessibility

Taking the above factors into account, any of the following types of wining are used :-

(i) Cleat wiring
(ii) Wooden casing and capping wiring
(iii) CTS or TRS wiring
(iv) Lead sheathed wiring
(v) Conduit Pipe Wiring

(1) Cleat Wiring

Single core VIR (Vulcarized India Rubber) or PVC (Poly Vinyl Chloride) cables are used in this wiring. The cables are run in grooves of glazed porcelain cleats which are fastened in wooden plugs (gutties) mounted on walls.

Merits

(i) It is cheapest system of wiring.
(ii) A little skill is required to lay the wining.
(iii) The wiring can be dismantled easily and used again with very little waste of
material.

Demerits

` (i) There is no protection from mechanical injury, fire, gas or water.
(ii) It is rarely employed for permanent jobs.
(iii) It is not good looking.

2. Wooden casing and capping wiring

The casing is base which consists of wooden block of seasoned teak wood and has usually tow grooves to accommodate wires. The casing is fixed on the wall with the help of screws and gutties.

After placing the wires in the grooves casing at the top is covered by means of rectangular strips of seasoned wood of same width known as capping with the help of screws.

Merits :

(i) It gives better appearance then cleat wiring.
(ii) There is sufficient mechanical and environmental protection to the wires/ cables
used.
(iii) Easy to inspect only by opening the capping.
(iv) Easy to install and rewire.

Demerits

(i) Costlier in compare to cleat wiring.
(ii) There is risk of fire.
(iii) It is not suitable for damp situation.

3. C.T.S. or T.R.S. wiring

In this system of wiring generally C.T.S. (cable Tyre Sheath) or T.R.S. (Tough Rubber
Sheathed) conductors are employed. The conductors are run on well seasoned perfectly
straight and well varnished teak wood batten of different width. The width of the batten is
chosen depending upon the number of wires to be run on it.

Merits

(i) It is easy to install and repair.
(ii) It gives nice appearance.
(iii) This type of wiring gives sufficient mechanical protection to the cable.

Demerits

(i) The conductors are upon and liable to mechanical injury, can not be used in
workshop.
(ii) It takes more time for installation.
(iii) The fire risk is high.
(iv) Its performance is affected under damp condition.

4. Lead Sheathed Wiring

This system of wiring is similar to CTS or TRS wiring. Only difference is that in this case
VIR conductors covered with lead alloy sheath (metal sheathed cable) are used. The lead
sheathed cables are run on the Wooden battens.

Merits

(i) The conductors are protected against mechanical injury.
(ii) It is free from fire hazards.
(iii) It can be installed in open space.
(iv) It has longer life.

Demerits

(i) It is relatively expensive due to the cost of lead sheath.
(ii) In case of leakage, there is every risk of shock.
(iii) Skilled labour and proper supervision is required. Other wise, the durability of
insulation may be affected.

5. Conduit wiring

There are two types of conduit wiring
(i) Surface conduit wiring
(ii) Concealed conduit wiring
In surface conduit wiring the conduit run over the wall supported by means of saddles where as in concealed conduit wiring the conduit is embedded in the walls and ceilings
by placing in the premade cavity in them.

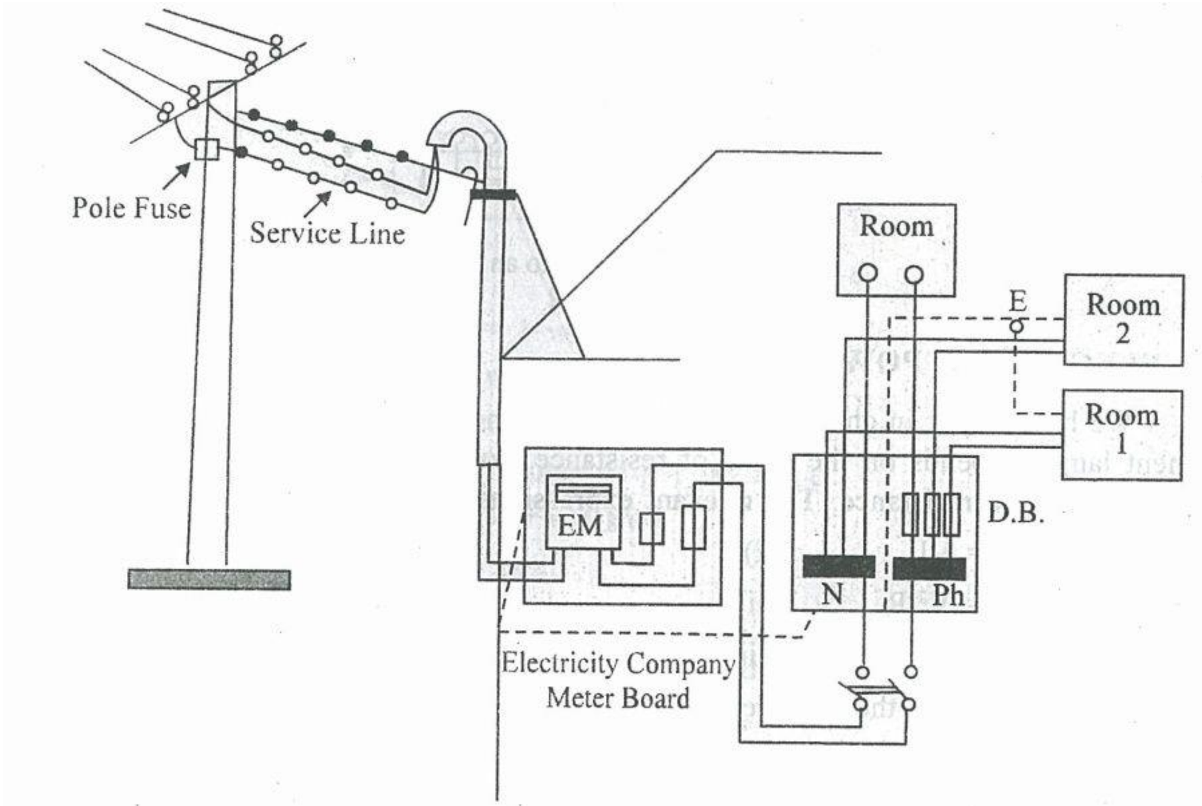
Merits

i. The wiring presents a neat and attractive appearance.
ii. It gives good protection against fire, mechanical damage & moisture.
iii. Its durability is very high.

Demerits

i. It is costly system of wiring.
ii. Highly skilled technician is necessary.
iii. It requires more time for erection.

LAYOUT OF HOUSEHOLD ELECTRICAL WIRING



BASIC PROTECTIVE DEVICES USED IN HOUSE HOLD WIRING

1. Fuse 2. MCB (Miniature Circuit Breaker)

3. Lightening arrester 4. Earthing Wire

Electrical Power

As we have learnt that power consumed by load depends on the value of resistance, current

through the resistance and voltage across the resistance.

P = VI

ÞP = V_2/R Þ P=I_2R

Thus, I watt is the power consumed by resistive load when current is 1A and Voltage

Across is 1V

1 Killowatt (KW) = 1000 W

1 HP (Horse Power) = 746 W

Ex. A heater takes 8A current at 250V supply. Calculate how much power does it consume ?

Solution : Given I = 8A, V = 250V

P = V, I = 250 X 8 = 2000W = 2KW

Power in small Electrical Installation

Ex. A building has the following electrical appliances (i) 1 KW Motor. (ii) 2 bulbs 100w rating each (iii) Two fans having 60w each (iv) one heater 1.5 KW. Calculate the total

Power Consumed by the building if all loads are switched on.

Solution : Total Power (P) = Sum of individual Power of all appliances.

$P = P_1 + P_2 + P_3 + P_4$

P = 1000 + (2 X 100) + (2 X 60) + 1500

P = 1000 + 200 + 120 + 1500

P = 2820 W = 2.82 KW

Electrical Energy

Energy = Power X Time

E = P X t

The unit of energy will depend upon the unit of Power and unit of time.

When P = 1 watt, t = 1 Second

Energy (E) = 1 W X 1S = 1 Watt Second = 1 Joule

When P = 1 Watt, t = 1 hour

Energy = 1 Watt X 1 hour = 1 Watt. hour

1 watt. hour = 1 watt X (60 X 60) Second

1 watt hour = 3600 Watt Second = 3600 J = 3.6×10^3 Joules

Similarly for bigger unit 1 Kwhr = 1000 whr.

65

So 1 Kwhr = 1000 X 3600 = 3.6×10^6 Joules

1 Kwh is called 1 Unit

CALCULATE ENERGY CONSUMED IN SMALL ELECTRICAL INSTALLATION

**EX.A building has the following electrical appliances (i) A 1 HP motor running for 5 hrs.
in a day. (ii) Three fans each of 80W running for 10 hrs. in a day. (iii) Four tube lights
of 40W running for 15 hrs. per day. Find the monthly bill for the month of November if
unit cost of bill is Rs.2.50.**

Ans:

Solution

(i) Electrical Energy Consumed per day for motor = 746 X 5 = 3730 whr = 3.730 kwhr.
(ii) Electrical Energy Consumed per day by three fans = 3 X 80 X 10 = 2400 whr = 2.4 Kwhr.
(iii) Electrical Energy Consumed per day by four tube lights = 4 X 40 X 15 = 2400 whr= 2.4whr.
Total Energy Consumed = 3.73 + 2.4 + 2.4 = 8.53 Kwhr = 8.53 units.

In the month of November total Electrical Energy Consumed = 8.53 X 30 = 255.9 units.
Monthly bill = 255.9 X Rs.2.5 = Rs. 639.75P

CHAPTER-6

MEASURING INSTRUMENTS

INTRODUCTION TO MEASURING INSTRUMENTS

The **instruments**, which are used to **measure** any quantity are known as **measuring instruments**. This tutorial covers mainly the electronic **instruments**, which are useful for **measuring** either electrical quantities or parameters

Measuring instruments are classified according to both the quantity measured by the instrument and
the principle of operation. Three general principles of operation are available:
(i) Electromagnetic, which utilizes the magnetic effects of electric current;
(ii)Electrostatic; which utilizes the forces between electrically –charged conductors;
(iii)Electro-thermic ,which utilizes the heating effect.

Electrical measuring instruments used to measure electrical quantities such as current, voltage,

power ,energy& frequency etc.

There are different types of measuring instruments such as

Ammeter measure current, voltmeter measure voltage, Wattmeter measure power, Energy meter

measure energy and Ballistic Galvanometer measure charge.

Instruments are divided into two types such as

(i) Primary instruments/Absolute instruments

(ii) Secondary instruments

(i) Primary instruments/Absolute instruments:

These instruments give the magnitude of the quantity under measurement in terms of physical constants of the instrument. Example Tangent alvanometer andRayleigh's current balance. These instruments are not generally used. These instruments are used in International Laboratory for testing or calibrating.

(ii) Secondary Instruments:

These instruments are calibrated by comparisons with an absolute instrument or secondary instrument which has already been calibrated against an absolute instrument. Example:voltmeter , ammeter etc.

These types of instrument are used in various laboratories for experimental purposes.

Secondary instruments are divided into following types such as

(a)Indicating Instruments

(b)Recording Instruments

(c)Integrating Instruments

(a)Indicating Instruments:

TORQUE IN INSTRUMENTS

- For operation of an indicating instrument three kinds of torques are required.
  These are namely
- Deflecting torque
- Control torque

- Damping torque

Deflecting Torque or (Operating torque)(Td):

- Deflecting torque is an important torque in an indicating instrument which makes the pointer to deflect .Without deflecting torque the pointer will always free at zero.

Control torque or Restoring torque (Tc):

- This torque control the movement of the pointer and stop the pointer at required place.
- Without control torque the pointer will always reach at final position.
- Controlling torque opposes the deflecting torque.

Damping torque ( ):

- Without damping torque the pointer makes oscillation about the steady state position.
- This oscillations are damped out by means of damping torque.
- Damping torque present only when the pointer moves and becomes zero when the pointer is at steady state position.

There are two types of controlling torque

- (i) Gravity control method
- (ii) Spring control method

DIFFERENT USES OF PMMC TYPE OF INSTRUMENTS

PMMC:

It is an instrument that allows you to measure the current through a coil by observing the coil's angular deflection in a uniform magnetic field.

Advantage

(i) Scale is uniform.
(ii) Lower power consumption.
(iii) It has high torque/weight ratio.
(iv) Accuracy is very high.
(v) Damping is effective.
(vi) It can be used for multiple range of current and voltage.
(vii) It has no hysteresis error.
(viii) It does not have stray magnetic field error.
(ix) It can be used in any position.

Disadvantage

(i) It can measure only DC.
(ii) It is a delicate instrument.
(iii) It is costly.

(iv) Aging problem due to permanent magnet.

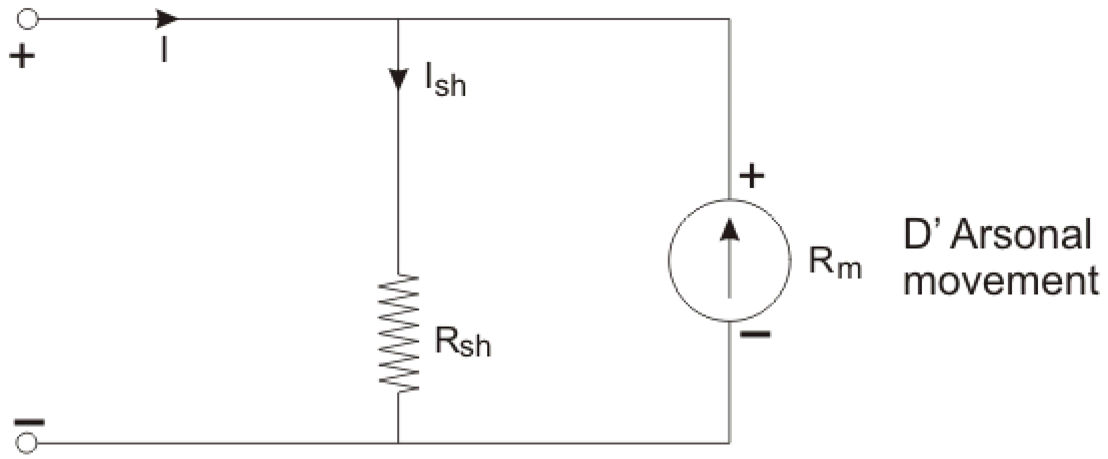
Application:-

(i) To measure voltage.
(ii) To measure current.
(iii) It is used in DC Galvanometer.
(iv) It is used in Ballistic Galvanometer to measure charge

- **Principle PMMC as Ammeter:**
  When current carrying conductor placed in a magnetic field, a mechanical force acts on the conductor, if it is attached to a moving system, with the coil movement, the pointer moves over the scale.
- Explanation: As the name suggests it has permanent magnets which are employed in this kind of measuring instruments.
- It is particularly suited for DC measurement because here deflection is proportional to the current and hence if current direction is reversed, deflection of the pointer will also be reversed so it is used only for DC measurement.
- This type of instrument is called D Arnsonval type instrument.
- It has major advantage of having linear scale, low power consumption, high accuracy. Major disadvantage of being measured only DC quantity, higher cost etc.
  Deflecting torque,
  $T = BiNlbNm$
  Where,
  B = Flux density in Wb/m^2.
  i = Current flowing through the coil in Amp.
  l = Length of the coil in m.
  b = Breadth of the coil in m.
  N = No of turns in the coil.

Extension of Range in a PMMC Ammeter:
Now it looks quite extraordinary that we can extend the range of measurement in this type of instrument.

we can measure higher currents, but there is nothing like that, we just have to connect a shunt resistance in parallel and the range of that instrument can be extended, this is a simple solution provided by the instrument.



In the figure I = total current flowing in the circuit in Amp.
I_{sh} is the current through the shunt resistor in Amp.
R_m is the ammeter resistance in Ohm.

$$Then,\ R_{sh} = \frac{R_m}{\frac{I}{I-I_{sh}} - 1}$$

PMMC Voltmeter

- **When current carrying conductor placed in a magnetic field, a mechanical force acts on the conductor, if it is attached to a moving system, with the coil movement, the pointer moves over the scale.**
- **PMMC instruments have parmanent magnets. It is suited for DC measurement because here deflection is proportional to the voltage because resistance is constant for a material of the meter.**
- **hence if voltage polarity is reversed, deflection of the pointer will also be reversed so it is used only for DC measurement.**
- **This type of instrument is called D'Arnsonval type instrument.**
- **It has advantages of having linear scale, power consumption is low, high accuracy.**
  Major disadvantages are –
  It only measures DC quantity, higher cost etc.

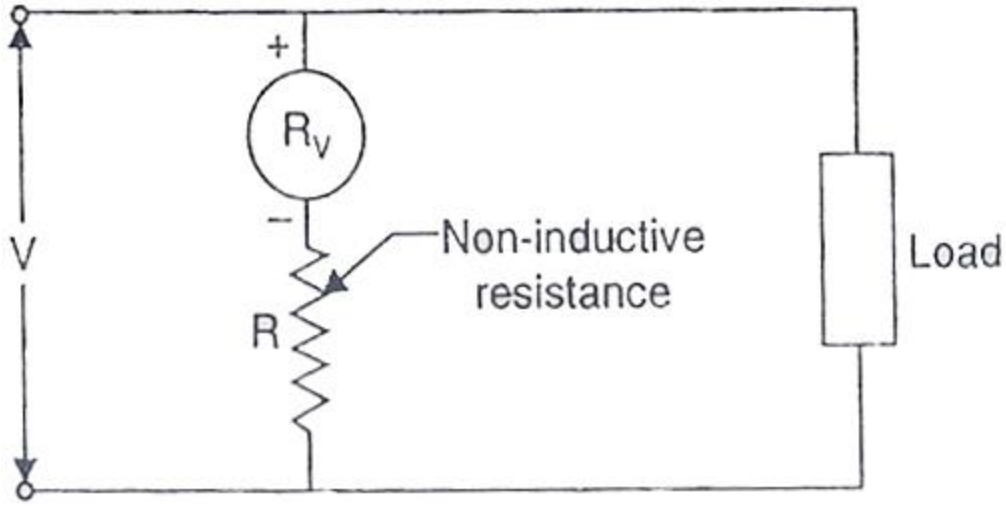
$$Deflecting\ torque,\ T = BiNlb\ \ Nm$$

Where,
B = Flux density in Wb/m^2.
i = V/R where V is the voltage to be measured and R is the resistance of the load.
l = Length of the coil in m.

b = Breadth of the coil in m.
N = No of turns in the coil.

Extension of Range in a PMMC Voltmeter

In the PMMC voltmeters we have the facility of extending the range of measurement of voltage also. Just connecting a resistance in series with the meter we can extend the range of measurement.



Let,
V is the supply voltage in volts.
R_v is the voltmeter resistance in Ohm.
R is the external resistance connected in series in ohm.
V_1 is the voltage across the voltmeter.
Then the external resistance to be connected in series is given by

$$R = \frac{V - V_1}{V_1} \times R_V$$

It is a moving iron instrument, used for both AC and DC, It can be used for both because the deflection **θ** proportional square of the current so whatever is the direction of current, it shows directional deflection, further they are classified in two more ways-

1. **Attraction type**.
2. **Repulsion type**.

Its torque equation is: $T = \frac{1}{2} I^2 \frac{dL}{d\theta}$

Where,
I is the total current flowing in the circuit in Amp.
L is the self inductance of the coil in Henry.
θ is the deflection in Radian.

1. **Attraction Type MI Instrument Principle**:
   When an unmagnetised soft iron is placed in the magnetic field, it is

attracted towards the coil, if a moving system attached and current is passed through a coil, it creates a magnetic field which attracts iron piece and creates deflecting torque as a result of which pointer moves over the scale.

2. **Repulsion Type MI Instrument Principle:**
   When two iron pieces are magnetized with same polarity by passing a current than repulsion between them occurs and that repulsion produces a deflecting torque due to which the pointer moves.
   The advantages of MI instruments are they can measure both AC and DC, cheap, low friction errors, robustness etc. It is mainly used in AC measurement because in DC measurement error will be more due to hysteresis.

MI type instrument as voltmeter

MI instruments mean moving iron instrument. It is used for both AC and DC measurements, because the deflection θ proportional square of the voltage assuming impedance of the meter to be constant, so what ever is polarity of the voltage, it shows directional deflection, further they are classified in two more ways,

1. Attraction type.
2. Repulsion type.

$$Its\ Torque\ equation\ is:\ T = \frac{1}{2} \times I^2 \frac{dL}{d\theta}$$

Where, I is the total current flowing in the circuit in Amp. I = V/Z
Where, V is the voltage to be measured and Z is the impedance of the load.
L is the self inductance of the coil in Henry.
θ is the deflection in Radian.

Attraction type MI Instrument Principle

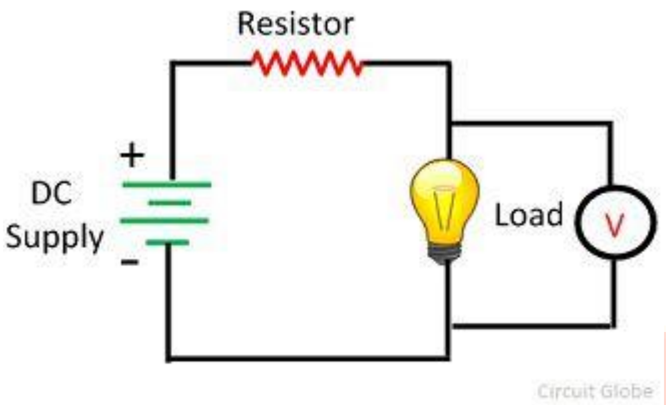
If an unmagnetised soft iron is placed in the magnetic field, it is attracted towards the coil, if a pointer is attached to the systems and current is passed through a coil as a result of the applied voltage, it creates a magnetic field which attracts iron piece and creates deflecting torque as a result of which pointer moves over the scale.

Repulsion type MI Instrument Principle

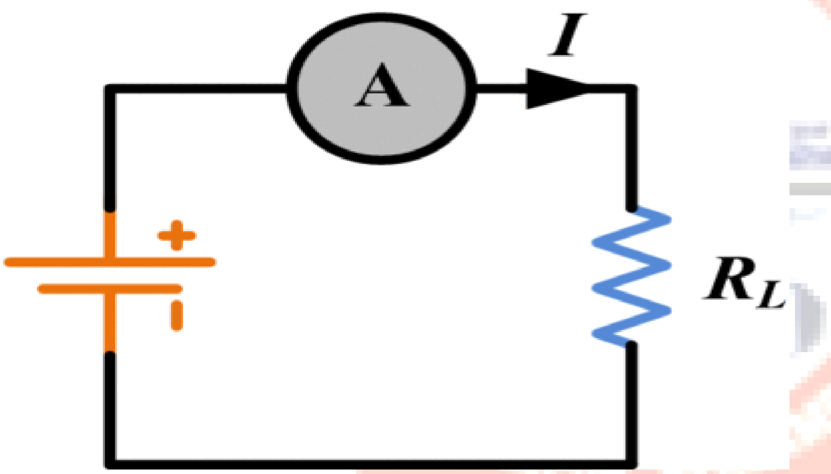
When two iron pieces are magnetized with the same polarity by passing a current which done by applying a voltage across the voltmeter than repulsion between them occurs and that repulsion produces a deflecting torque due to which the pointer moves.

CONNECTION DIAGRAM OF AC/DC AMMETER, VOLTMETER,ENERGY METER & WATTMETER

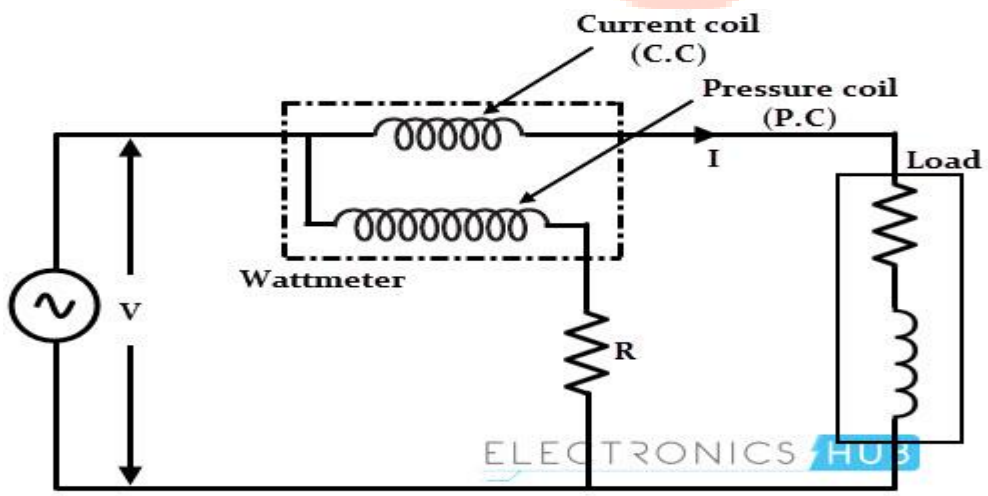
Connection diagram of voltmeter:



Connection Diagram of ammeter:



connection diagram of wattmeter



connection diagram of 1 phase energy meter