

# **SRI POLYTECHNIC**



## **LECTURE NOTE**

### **BASIC ELECTRICAL ENGINEERING**

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**SEMESTER-1<sup>ST</sup>**

# FUNDAMENTALS

## CHAPTER - ONE

### 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  $6.24 \times 10^{18}$  electrons.

The movement of electrons in a conductor remains unchannelised until it is acted upon by an electric field. The flow of electrons through a conductor constitutes an electric current & the path of electric current is known as electric circuit which is always a closed path. The direction of flow of positive current is opposite to the direction of flow of electrons. So current can be defined as:

The time rate of flow of electric charge is current  $I = \frac{dq}{dt}$

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.

1. Electric potential at a point is the work done in bringing a unit positive charge from infinity to that point.
2. If two points have different electric potentials, there is said to be a potential difference (p.d.) or voltage existing between the points.

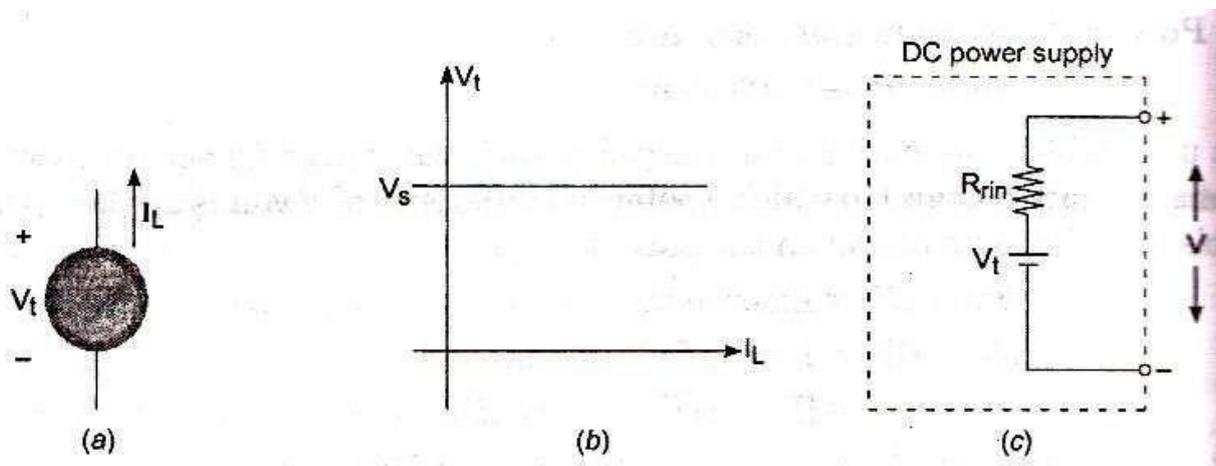
# Concept of Source & Load

## Voltage source

A Source may be a voltage or current source.

An ideal voltage source is a source that maintains the same voltage across its terminals irrespective of amount of current drawn from the source or whatever current flows into the source through its terminals (as shown in Fig.(a) below). Hence, the internal resistance of an ideal voltage source is zero. The voltage across the terminals is denoted as  $V_s$ . The current drawn from the source is denoted by  $I_L$  and the plot of terminal voltage against load current is shown in Fig.(b) below.

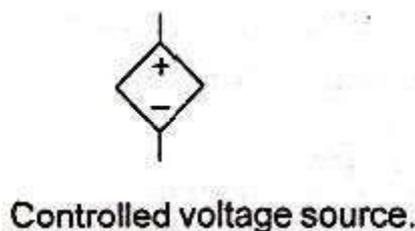
A Real/practical voltage source is represented by an ideal voltage source with a series resistance ( $r_{in}$ ) with it as shown in Fig.(c) below.



(Figure (a) shows symbol of Ideal voltage source), (Figure (b) shows plot of  $V_t$  vs  $I_L$  of an Ideal voltage source), Figure (c) shows a practical voltage source)

## Dependent and Independent voltage Source

If the voltage across an ideal voltage source can be specified independently of any other variable in a circuit, it is called an INDEPENDENT voltage source. However, If the voltage across an ideal voltage source is determined by some other voltage or current in a circuit, it is called a DEPENDENT or CONTROLLED voltage source and it is represented in a circuit diagram as shown in Fig.(d) below.

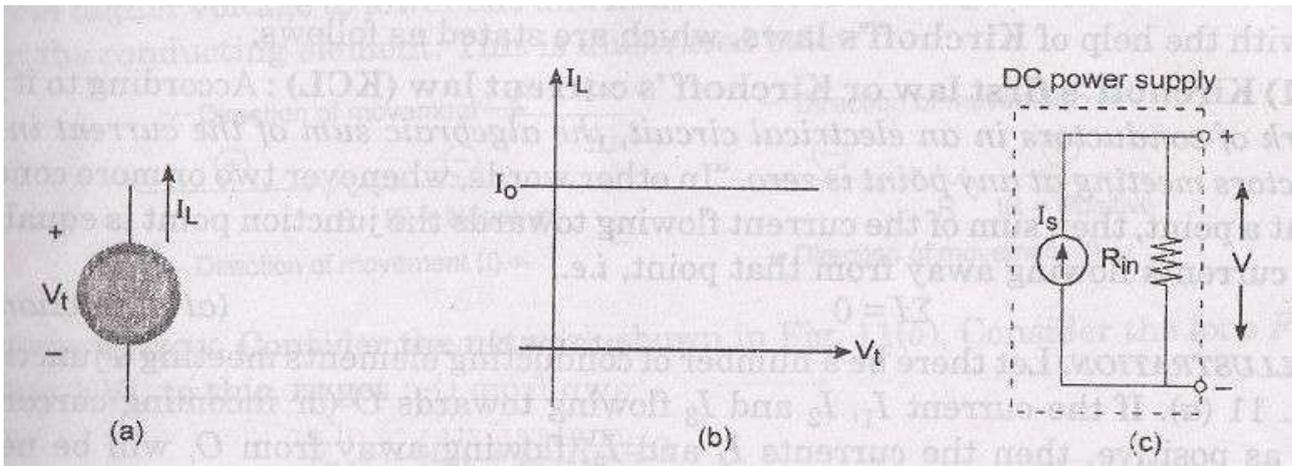


(Figure d)

## Current source

An ideal current source is one in which there is no change in current irrespective of the voltage at which current is drawn of which the circuit symbol is shown in figure (a) below. The internal resistance of an ideal current source is infinity. A plot of current ( $I_L$ ) drawn against terminal voltage is shown in Fig.(b) below where  $I_0$  represents a constant current irrespective of change in terminal voltage.

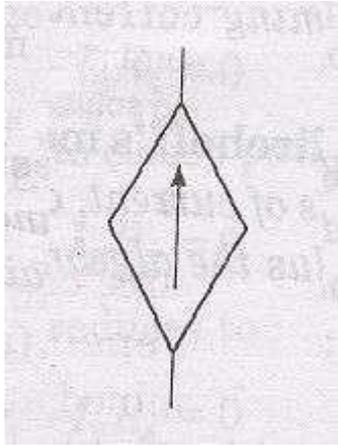
A Real/practical current source is represented by an ideal current source in parallel with a resistance ( $r_{in}$ ) as shown in Figure (c) below.



(Figure (a) shows symbol of Ideal current source), (Figure (b) shows plot of  $I_L$  Vs  $V_t$  of an Ideal current source), Figure (c) shows a practical current source)

## Dependent and Independent currentSource

If the current through an ideal current source can be specified independently of any other variable in a circuit, it is called an INDEPENDENT current source. However, If the current through an ideal current source is determined by some other voltage or current in a circuit, it is called a DEPENDENT or CONTROLLED current source and is shown in Fig.(d )below.

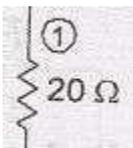


(Controlled or Dependent Current Source)

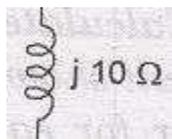
Figure(d)

## Load

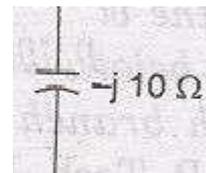
The electrical load is an application consuming electrical power and is represented by R(Resistance),L(Inductance),C(Capacitance),E( back EMF) etc. or combination of these circuit elements.



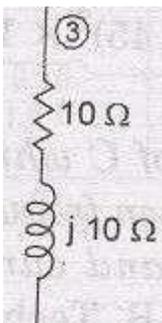
(Resistance)



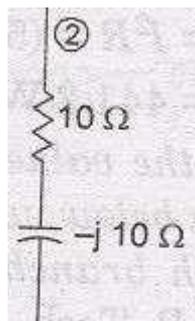
(Inductance)



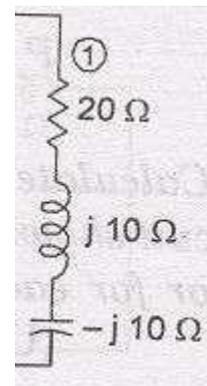
(Capacitance)



(R-LLoad)



(R-C Load)



(R-L-Cload)

## Ohm's law and concept of resistance

At a constant temperature, the current passing between the two points of a conductor is directly proportional to the potential difference existing between the two points.

Mathematically,  $I \propto V$  or  $V = IR$  ( $R$  is a constant of proportionality)

Electrical current in a conductor consists of movement of electrons. When electrons flow through a material they collide with other atomic particles and energy is lost in the form of heat due to these collisions and this is represented by resistance.

Resistance is the property of a material by virtue of which it opposes the flow of electrons (or current) through it. The opposition to flow of current is due to above collisions of electrons.

Resistance of a conductor (Figure (a) below) depends on its Length ( $L$ ), Area of cross-section ( $A$ ) and specific resistance or resistivity ( $\rho$ ) of the material and is given by:  $R = \rho L/A$

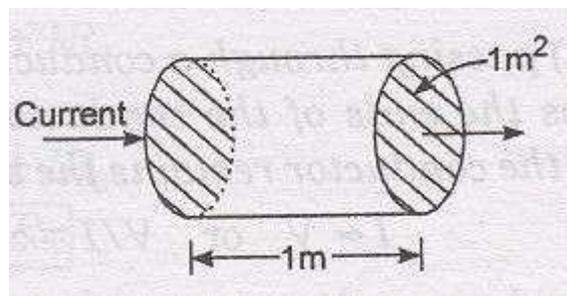
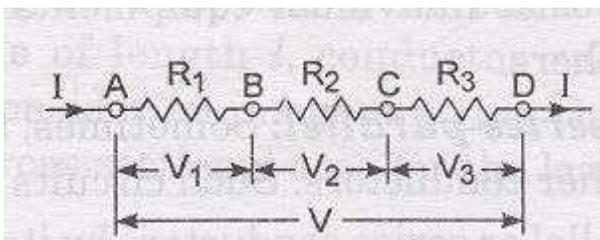


Figure (a)

[In the figure (a) above a conductor is shown with its length ( $L$ ) = 1 metre & Area of cross-section ( $A$ ) =  $1\text{m}^2$ ]

### 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  $R_1, R_2$  &  $R_3$  be the respective resistances.



[Figure S.1]

Let,  $R$  = Resistance of the combination

$V =$  Total potential difference across resistances.

$I =$  Strength of Current

Then  $V=IR$ .....1s

But  $V=$  sum of individual p.d. across  $R_1, R_2 \& R_3$  So,

$V = V_1+ V_2+ V_3=IR_1+IR_2+ IR_3$ .....2s

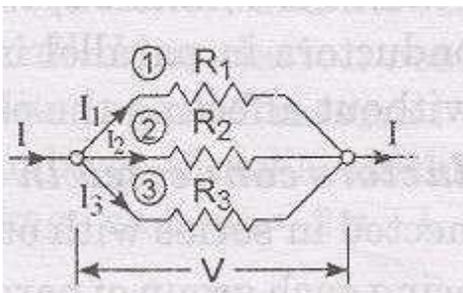
From equation 1s & 2s we get  $IR= I R_1+ IR_2+$

$IR_3$  Hence,  $R=IR_1+ R_2+ R_3$

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  $R_1, R_2 \& R_3$  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.



[Figure P.1]

Suppose the main current  $I$  is divided into  $I_1, I_2 \& I_3$  through the resistors  $R_1, R_2 \& R_3$  respectively.

Let,  $R =$  Resistance of the combination between A & B

$V =$  potential difference

$I =$  Strength of Current

Then,  $I = \frac{V}{R}$ .....1P

By KCL, the main current entering this combination must come out as such &

Hence,

$$I = I_1 + I_2 + I_3$$

$$\text{Then } I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \dots\dots\dots 2P$$

From equations 1p & 2p we get

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

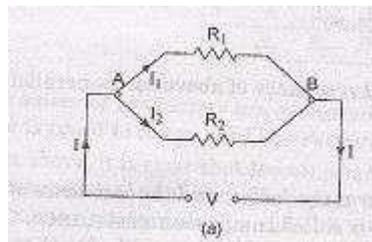
$$\text{Hence, } \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

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.

**Division of Current in parallel circuit**

Let us consider two resistors connected in parallel as shown in Figure P.2 below across a voltage V. Then, by ohm 's Law current in branches is

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



Two resistors in parallel,

[ Figure P.2]

Also considering the total current I & the total equivalent resistance of combination

$$\text{i.e. } R = \frac{R_1 R_2}{R_1 + R_2} \quad \text{and } V = IR = I \frac{R_1 R_2}{R_1 + R_2}$$

$$\text{from the above we get } V = IR = I \frac{R_1 R_2}{R_1 + R_2} = IR_1 = IR_2 \dots\dots\dots \text{DCP1}$$

from equation DCP1 above we get  $I_1 R_1 = I \frac{R_1 R_2}{R_1 + R_2}$  also  $I_2 R_2 = I \frac{R_1 R_2}{R_1 + R_2}$

Thus,  $I_1 = I \frac{R_2}{R_1 + R_2}$  &  $I_2 = I \frac{R_1}{R_1 + R_2}$

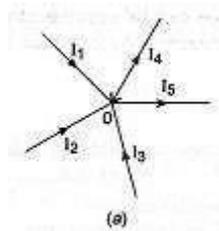
Hence, It is observed that in a parallel connected circuit of two resistances the current through a branch is the product of total current entering the combination & the Ratio of resistance of opposite side of the side through which the current is determined & the sum of individual resistances .

### Kirchoff's current Law

According to Kirchoff's current Law "In any network of conductors in an electrical circuit, the algebraic sum of the current in all the conductors meeting at any point is zero".

i.e.  $\sum I = 0$

Let there be a number of conducting elements meeting at a junction 'o' as shown in figure(a) below.



If the currents  $I_1, I_2 & I_3$  are flowing towards 'o' (incoming currents) be taken positive then the currents  $I_4, & I_5$  flowing away from o (outgoing currents) be negative then

According to KCL,

$$I_1 + I_2 + I_3 - I_4 - I_5 = 0 \text{ or } I_1 + I_2 + I_3 = I_4 + I_5$$

This follows from the above that there can be no accumulation of charge at any point.

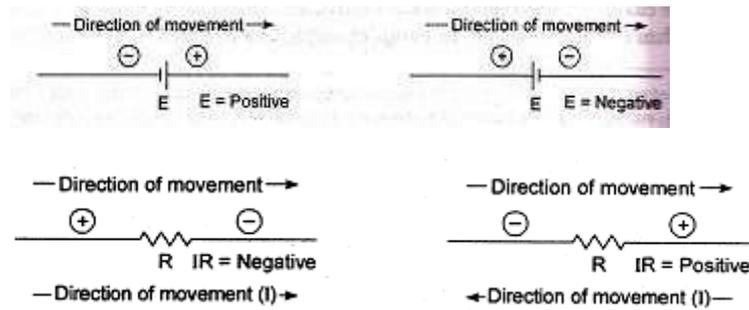
Sign Rules of KCL : If all the in-coming currents be taken to be positive then the outgoing currents must be taken Negative and vice versa.

### Kirchoff's voltage Law

According to Kirchoff's voltage Law 'algebraic sum of the product of current & resistance of each conductor in any closed path (or mesh) in a network plus the algebraic sum of the emf's in that path is zero.'

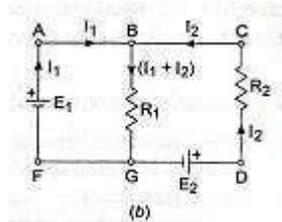
In other words  $\sum IR + E = 0$

Sign Rules of KVL : If we give positive sign to all rise in potential then we must give Negative sign for all fall in potential and vice versa as shown in Figure(a).



[ Figure(a) ]

Let us apply KVL to the circuit diagram in Figure(b) below and write down the Loop equations.



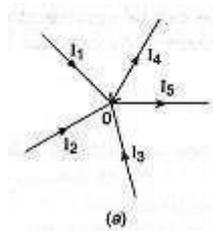
Considering the loop FABGF & applying KVL to this, we get

$$E_1 + (-)(I_1 + I_2)R_1 = 0 \dots\dots\dots A$$

Similarly applying KVL to loop BCDGB, we get

$$-E_2 + (I_1 + I_2)R_1 + I_2 R_2 = 0 \dots\dots\dots B$$

1. Find the values of  $I_3$  assuming that  $I_1 = 5A, I_2 = 2A, I_4 = 1A$  &  $I_5 = 4A$ .



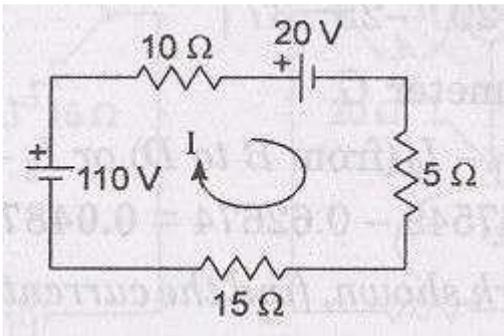
Solution : Application of KCL to node A in figure with proper sign convention results in the following equation:

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

Or Replacing the current values, we find

$$I_3 = I_4 + I_5 - I_1 - I_2 = 1 + 4 - 5 - 2 = -2A \text{ (Ans)}$$

2. Calculate the current flowing in the circuit and the potential difference(p.d) across the three resistances by applying KVL to the Network shownbelow.



Solution : Applying Kirchoff's voltage Law to the circuit shown above and assuming the current direction to be as shown let us move in the direction of current and write down the equations.

$$+110-10I-20-5I-15I=0 \dots\dots\dots(1)$$

$$90-30I=0; \Rightarrow I = 3\text{Amp. (Ans)}$$

$$\text{Potential difference across } 10\Omega \text{ resistance} = 10I=10 \times 3 = 30 \text{ volts (Ans)}$$

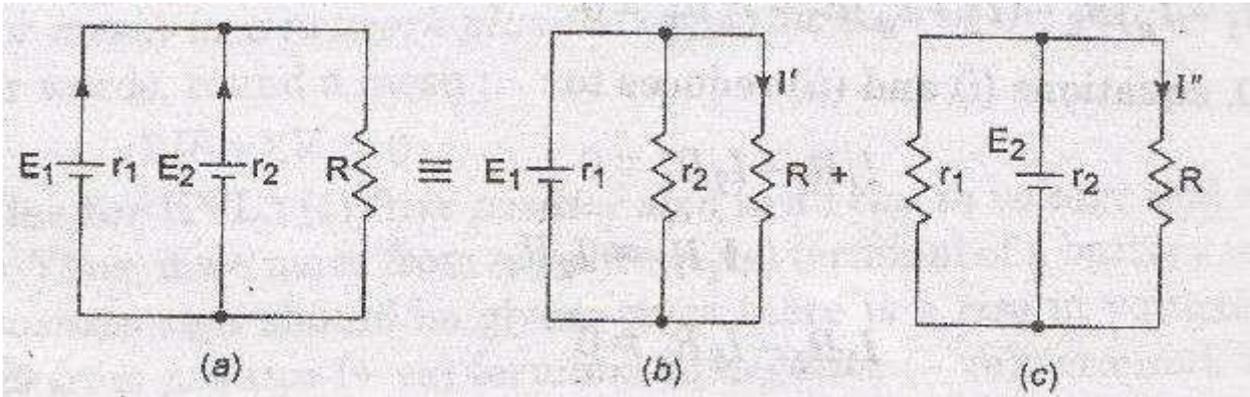
$$\text{Potential difference across } 5\Omega \text{ resistance} = 5I=5 \times 3 = 15 \text{ volts (Ans)}$$

$$\text{Potential difference across } 15\Omega \text{ resistance} = 15I=15 \times 3 = 45 \text{ volts (Ans)}$$

There are two voltage sources i.e. 110 volt & 20 volt of which the first one(110 volt) is taken positive because , there is a rise in voltage from -ve terminal of battery to +ve terminal of battery as we move in clock-wise direction. Similarly for the second voltage source i.e.20 volt ,there is a fall in voltage from +ve terminal of battery to -ve terminal of battery in the direction of movement. The voltage drops across 10Ω, 5Ω & 15Ω are -ve as they are all cases of fall in voltage in the direction of current flow.

**SUPERPOSITION THEOREM**

In a network of linear resistors containing more than one source(voltage or current source), the resultant current flowing in an element may be found by considering one source at a time & all other voltage sources replaced by their internal resistance if any and current sources replaced by a open circuit, followed by summing the currents due to individual sources, OR in other words if a number of sources are acting simultaneously in any linear network then each source acts independent of the others. Thus the resultant value of current in a conductor element of a network can be obtained by superposing the current due to each source in the network.



[ Figure(a) with the circuit with two Sources( $E_1$ & $E_2$ )]

[Figure(b) with the circuit with Sources( $E_1$ ) only]

[Figure(c) with the circuit with Sources( $E_2$ ) only]

**Current through Resistance  $R = I = I' + I''$  ( by superposition theorem)**

From circuit(b) :

$$I_{s1} = \text{current from source} = \frac{E_1}{r_1 + \frac{r_2 \times R}{r_2 + R}}$$

$$I' = I_{s1} \times \frac{r_2}{r_2 + R} = \frac{E_1}{r_1 + \frac{r_2 \times R}{r_2 + R}} \times \frac{r_2}{r_2 + R} = \frac{E_1 r_2}{r_1 r_2 + R(r_1 + r_2)}$$

Similarly, from circuit(c) :

$$I_{s2} = \text{current from source} = \frac{E_2}{r_2 + \frac{r_1 \times R}{r_1 + R}}$$

$$I'' = I_{s2} \times \frac{r_1}{r_1 + R} = \frac{E_2}{r_2 + \frac{r_1 \times R}{r_1 + R}} \times \frac{r_1}{r_1 + R} = \frac{E_2 r_1}{r_1 r_2 + R(r_1 + r_2)}$$

$$\text{Hence, } I = I' + I'' = \frac{E_1 r_2}{[r_1 r_2 + R(r_1 + r_2)]} + \frac{E_2 r_1}{[r_1 r_2 + R(r_1 + r_2)]} = \frac{(E_1 r_2 + E_2 r_1)}{[r_1 r_2 + R(r_1 + r_2)]}$$

When both the sources acting i.e. in Figure(a) according to superposition theorem the current through

$$\text{the resistance } R \text{ is } I = \frac{(E_1 r_2 + E_2 r_1)}{[r_1 r_2 + R(r_1 + r_2)]}$$

## Thevenin's Theorem

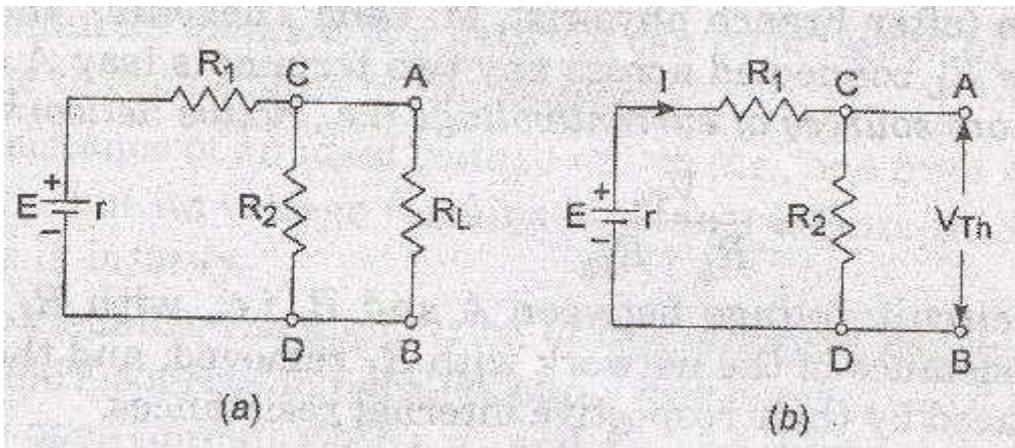
The current( $I$ ) flowing through a resistance  $R_L$  connected across any two terminals(say A & B) of a network containing one or more sources of current/voltage is given by :

$$I = \frac{V_{TH}}{(R_{TH} + R_L)}$$

$V_{TH}$  = open circuit voltage between A & B where  $R_L$  disconnected,

$R_{TH}$  = Equivalent resistance of the network from open circuit terminals A & B, with all voltage sources replaced by internal resistance and current sources replaced by a open circuit.

For visualization of the application of Thevenin's theorem let us consider the Network shown in Figure (a) below.

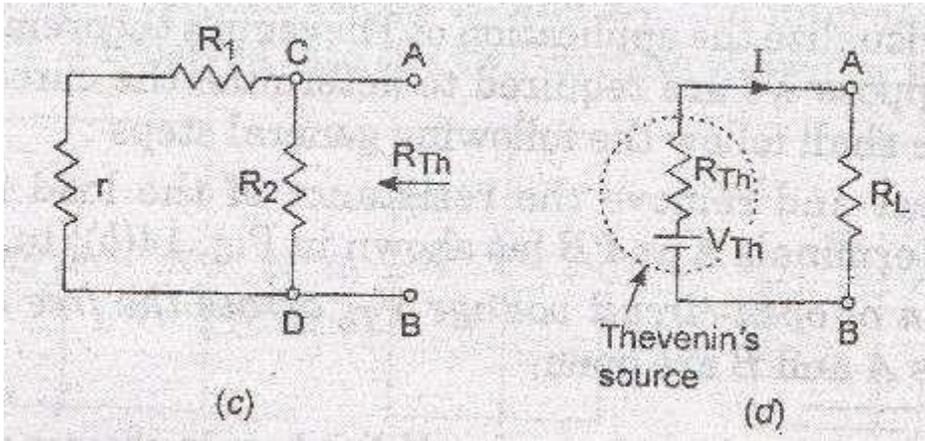


Step I : Disconnect & remove the resistance of the load resistance( $R_L$ ) under consideration from the terminals A & B to get open circuit.

Step II : Calculate the open circuit voltage  $V_{TH}$  across the open terminals A & B

$$\text{Current } = I = \frac{E}{(r + R_1 + R_2)} \quad \text{and}$$

$$\text{the Open circuit voltage } = v_{TH} = \text{potential drop across } R_2 = IR_2 = \frac{E R_2}{(r + R_1 + R_2)}$$



Step III : Remove the voltage source from the circuit, leaving behind only its internal resistance ( $r$ ) as shown in Figure (c) above. Now, view the circuit inwards. It is found that the circuit now consists of two parallel paths i.e. one containing resistance  $R_2$  only and the other containing resistances  $R_1$  &  $r$  in series. Consequently the equivalent circuit resistance ( $R_{TH}$ ) as viewed from open circuit terminals A and B is given by:

$$R_{TH} = \frac{R_2(R_1 + r)}{R_2 + (R_1 + r)}$$

The entire open circuit network as viewed from A & B is reduced to a single source, called Thevenin's source, whose voltage and internal resistances respectively are given by  $V_{TH}$  and  $R_{TH}$  as depicted in figure (d).

Step IV : Connect back load resistance under consideration ( $R_L$ ) across the terminals A and B, from where it was removed earlier.

Then the current flowing through the load resistance  $R_L$  is given by  $I = \frac{V_{TH}}{(R_{TH} + R_L)}$

### MAXIMUM POWER TRANSFER THEOREM (M.P.T.)

This theorem states that "Maximum power output from a network is obtained when the load resistance ( $R_L$ ) is equal to the Thevenin's equivalent resistance of the network as seen from the load terminals. This Theorem is used to find  $R_L$  such that the power dissipated in  $R_L$  is maximum.

OR

Maximum power is delivered by a source to the Load resistance ( $R_L$ ) when the load resistance is equal to the internal resistance of the source

$$\text{i.e. } R_i = R_L$$

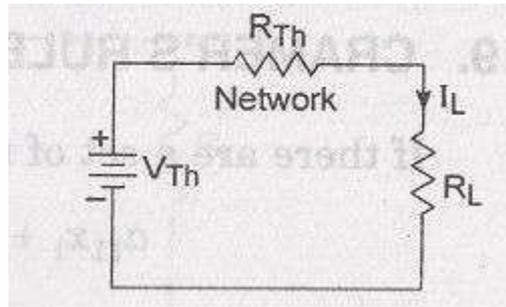


Figure (MP-1)

Proof: In the Figure(MP-1) shown above

$$\text{Load current, } I_L = \frac{V_{Th}}{R_{Th} + R_L}$$

$$\text{Power delivered to Load } P_L = I_L^2 R_L$$

$$= \left( \frac{V_{Th}}{R_{Th} + R_L} \right)^2 R_L = \frac{V_{Th}^2 R_L}{R_{Th}^2 + 2R_{Th}R_L + R_L^2}$$

If  $R_L = 0$  (i.e., short circuit), then  $P_L = 0$  and when  $R_L$  is infinite (i.e., an open circuit), then  $I_L = 0$  and hence  $P_L = 0$ . Between these two extreme conditions,  $P_L$  always possesses finite and positive values. Hence, for a particular value of  $R_L$ , power dissipated ( $P_L$ ) must be maximum. This occurs when RHS of above equation is maximum or when denominator of RHS of above equation is minimum, since  $V_{Th}$  is constant.

$$\text{Let } \left( \frac{R_{Th}^2}{R_L} \right) + 2R_{Th} + R_L = r$$

$$\text{For minimum value of } r, \quad \frac{dr}{dR_L} = 0 \quad \text{and} \quad \frac{d^2r}{dR_L^2} \text{ is positive i. e.,}$$

$$\frac{d}{dR_L} \left( \frac{R_{Th}^2}{R_L} + 2R_{Th} + R_L \right) = - \frac{R_{Th}^2}{R_L^2} + 0 + 1 = 0$$

$$\text{Or } R_{Th}^2 R_L^2 R_{Th} R_L \text{ or } =$$

$$\text{Also } \frac{d^2r}{dR_L^2} = \frac{d}{dt} \left( - \frac{R_{Th}^2}{R_L^2} + 1 \right) = 2 \frac{R_{Th}^2}{R_L^3} = 2 \frac{R_{Th}^2}{R_{Th}^3} = \frac{2}{R_{Th}} \quad (\text{as } R_{Th} = R_L)$$

Hence second derivative is positive, thereby showing that  $R_L = R_{Th}$  is a condition for minimum value of  $r$  or maximum value of  $P_L$ .

$$\text{Also } P_L(\text{Max}) = I_L^2 R_L = \frac{V_{Th}^2}{4R_{Th}}$$

### DELTA-STAR TRANSFORMATION

This is a method of obtaining equivalent star of a delta connected circuit.

Consider a delta connected circuit with three resistances  $R_{12}$ ,  $R_{23}$  &  $R_{31}$  as shown in figure S-D1 below.

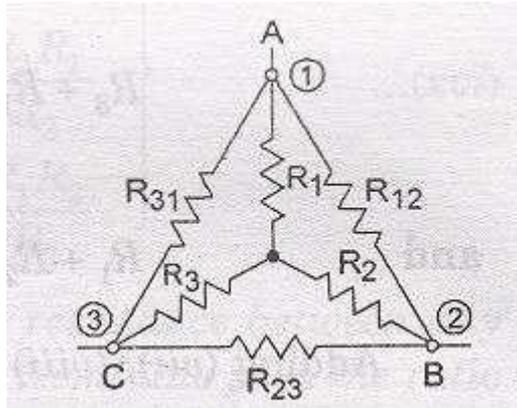


Fig.S-D1

Suppose its equivalent star circuit be represented by  $R_1$ ,  $R_2$  &  $R_3$ .

The resistance between terminals A & B in delta connection

$$= R_{12} \times (R_{23} + R_{31}) / (R_{12} + R_{23} + R_{31}) \dots \dots \dots (i)$$

The resistance between terminals A & B in star connection

$$= R_1 + R_2 \dots \dots \dots (ii)$$

Since the terminals are same

$$R_1 + R_2 = [R_{12} \times (R_{23} + R_{31})] / (R_{12} + R_{23} + R_{31}) \dots \dots \dots (iii)$$

Similarly, by solving for terminals B & C, C & A we get

$$R_2 + R_3 = [R_{23} \times (R_{31} + R_{12})] / (R_{12} + R_{23} + R_{31}) \dots \dots \dots (iv)$$

&  $R_3 + R_1 = [R_{31} \times (R_{12} + R_{23})] / (R_{12} + R_{23} + R_{31}) \dots \dots \dots (v)$

On solving above equations we get the Delta – Star Transformation as :

$$R_1 = (R_{12} R_{31}) / (R_{12} + R_{23} + R_{31})$$

$$R_2 = (R_{23} R_{12}) / (R_{12} + R_{23} + R_{31}) \dots \dots \dots (vi)$$

$$R_3 = (R_{31} R_{23}) / (R_{12} + R_{23} + R_{31})$$

## STAR- DELTATRANSFORMATION

This is a method of obtaining equivalent delta of a given star connected circuit.

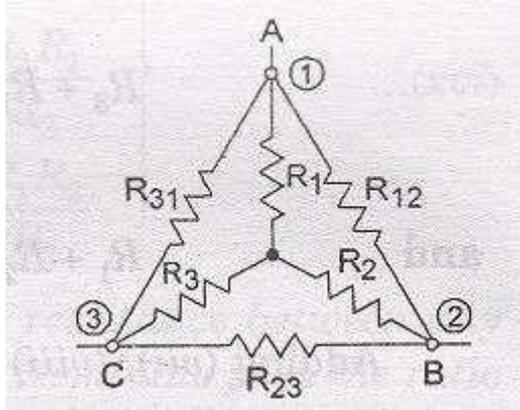


Figure. S-D2

Referring to the circuit with resistances connected in star i.e.  $R_1$ ,  $R_2$  &  $R_3$  as shown in figure S-D2 above and the equivalent DELTA values  $R_{12}$ ,  $R_{23}$  &  $R_{31}$  can also be determined as follows :

Total resistance between B & C must be same for both star & delta connections.

So, Between terminals B & C:

$$R_2 + R_3 = R_{23} \parallel (R_{31} + R_{12}) = \frac{(R_{23} \cdot R_{31} + R_{23} \cdot R_{12})}{(R_{12} + R_{23} + R_{31})} \dots \dots \dots (vii)$$

Similarly, For terminals C & A, A & B we get,

$$R_3 + R_1 = R_{31} \parallel (R_{12} + R_{23}) = \frac{(R_{31} \cdot R_{12} + R_{31} \cdot R_{23})}{(R_{12} + R_{23} + R_{31})} \dots \dots \dots (viii)$$

$$\text{and } R_1 + R_2 = R_{12} \parallel (R_{31} + R_{23}) = \frac{(R_{12} \cdot R_{31} + R_{12} \cdot R_{23})}{(R_{12} + R_{23} + R_{31})} \dots \dots \dots (ix)$$

Adding the above three equations we get :

$$2(R_1 + R_2 + R_3) = 2(R_{12} \cdot R_{23} + R_{23} \cdot R_{31} + R_{31} \cdot R_{12}) / (R_{12} + R_{23} + R_{31})$$

$$\text{and } (R_1 + R_2 + R_3) = (R_{12} \cdot R_{23} + R_{23} \cdot R_{31} + R_{31} \cdot R_{12}) / (R_{12} + R_{23} + R_{31}) \dots \dots \dots (x)$$

Solving the above equations for  $R_1$ ,  $R_2$  &  $R_3$  we get :

$$R_1 = \frac{R_{31} \cdot R_{12}}{(R_{12} + R_{23} + R_{31})} \dots \dots \dots (xi)$$

$$R_2 = \frac{R_{12} \cdot R_{23}}{(R_{12} + R_{23} + R_{31})} \dots \dots \dots (xii)$$

$$R_3 = \frac{R_{23} \cdot R_{31}}{(R_{12} + R_{23} + R_{31})} \dots \dots \dots (xiii)$$

Dividing (xi) by (xii) we get,

$$R_1 / R_2 = R_{31} / R_{23} \quad \text{OR} \quad R_{31} = R_1 \cdot R_{23} / R_2 \dots \dots \dots (xiv)$$

Similarly we get

$$R_3/R_1=R_{23}/R_{12} \quad \text{OR} \quad R_{12}=R_1.R_{23}/R_3 \dots\dots\dots(xv)$$

Substituting the value of  $R_{31}$  &  $R_{12}$  from eqn.(xiv) & ( xv) respectively in (vii) we get

$$R_2+R_3=\{ R_{23}(R_1.R_{23}/R_2) + R_{23}(R_1.R_{23}/R_3)\}/\{ R_{23}+(R_1.R_{23}/R_2)+ (R_1.R_{23}/R_3)\}$$

$$R_2+R_3=\{ (R_1.R_{23}/R_2) + (R_1.R_{23}/R_3)\}/\{ 1+(R_1/R_2)+ (R_1/R_3)\}$$

$$R_2+R_3=(R_1.R_3.R_{23}+R_1.R_2.R_{23})/( R_2R_3+ R_1R_3+ R_1R_2)=R_1R_{23}(R_3+R_2)/( R_2R_3+ R_1R_3+ R_1R_2)$$

$$R_1R_{23}= R_2R_3+ R_1R_3+ R_1R_2$$

$$\text{OR } R_{23}= R_2+ R_3+ R_2R_3/R_1$$

Similarly we get

$$R_{31}= R_3+ R_1+R_3R_1/R_2 \quad \text{and} \quad R_{12}= R_1+ R_2+ R_1R_2/R_3$$

Hence, the Delta equivalent values are obtained given the star values of the network.

## ELECTRO-MAGNETIC INDUCTION

In 1931, M. Faraday discovered that a current is generated whenever the magnetic flux linked with a circuit changes.

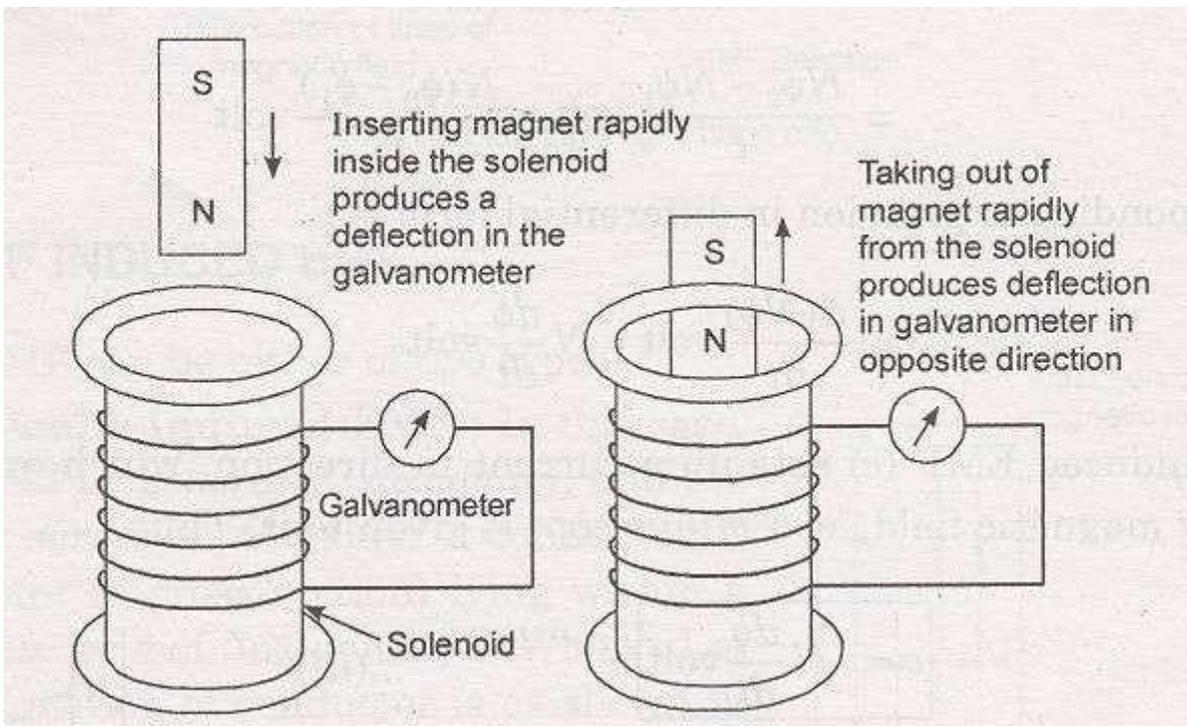
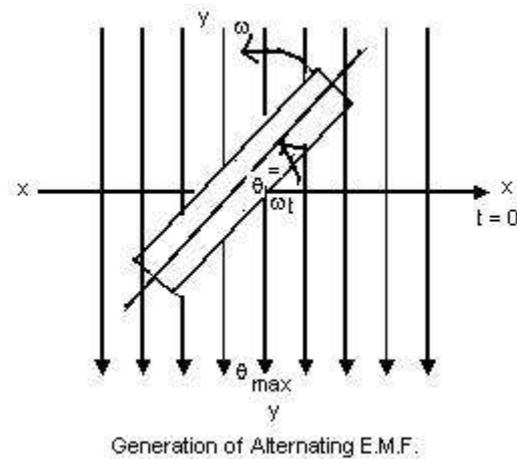


Illustration of electromagnetic induction.

For example, If we take a solenoid (i.e. a coil of a conducting material wound on a hollow cylinder of card board) and place it vertically on a table & connect the two ends of the coil to a sensitive galvanometer. Now, If we insert a magnet rapidly into the solenoid, a deflection in galvanometer needle is produced. Now, if we withdraw the magnet rapidly from the solenoid, a momentary deflection, but in opposite direction is produced. This demonstrates the fact that an electric current is induced in a circuit when the strength of magnetic field or the number of lines of force through it changes. The current so produced is called induced current & the emf causing this current to flow is called induced emf & this phenomena of production of induced emf as described above is called electro-magnetic induction.

### Faraday's Laws of Electro-Magnetic Induction

1. Faraday's first law states that 'when the number of magnetic lines of force (or magnetic flux) passing through a circuit changes, an induced emf is set up in the circuit.
2. Faraday's second law states that the magnitude of emf induced is proportional to the rate of change of magnetic lines of force.



Suppose the flux of a coil having  $N$  turns, changes from initial value  $\phi_1$  weber to the final value of  $\phi_2$  weber in  $t$  seconds. Then, the initial flux linkage = [No. of Turns]  $\times$  [initial flux linked with coil] =  $N \phi_1$

Similarly, the final flux linkage = [No. of Turns]  $\times$  [final flux linked with coil] =  $N \phi_2$

Hence, the Induced EMF ( $e$ ) = (Change in flux linkages/Time in seconds)

The corresponding expression in different form is  $e = d(N\phi/dt) = N d\phi/dt$  volts

Since the emf set up a current in direction which opposes the very cause producing magnetic field So a minus sign is given to it.

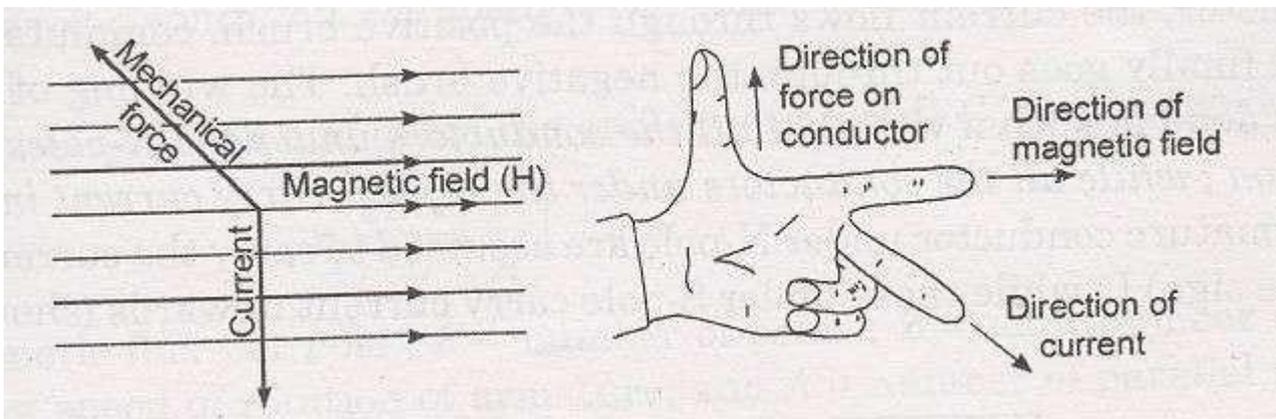
Thus  $e = -N d\phi/dt$  volt

## 2. LENZ'slaw

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

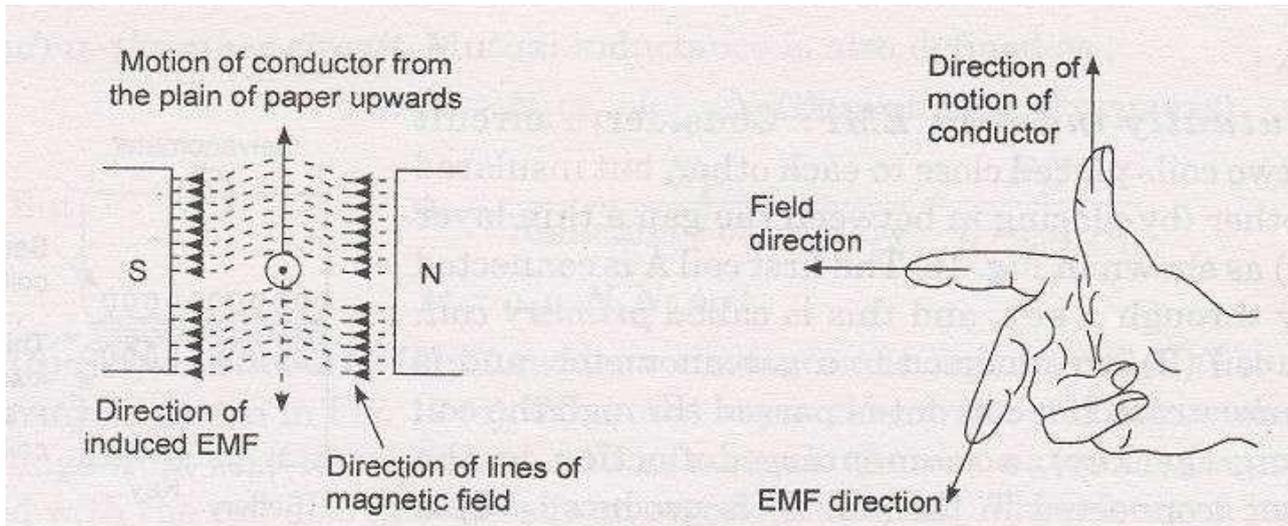
Flemming's left hand rule states that If we stretch out the thumb, the fore-finger & the middle finger of the left hand so that they are at right angles to each other then if the fore-finger points in the direction of magnetic field, the middle finger in the direction of current then the thumb points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

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.



Fleming's right-hand rule.

.....XXXXXXXX.....

# MAGNETIC CIRCUITS

## CHAPTER- TWO

### 2.1 *Electric Field versus Magnetic Field.*

#### Similarities

##### **Electric Field**

- 1) Flow of Current ( $I$ )
- 2) Emf is the cause of flow of current
- 3) Resistance offered to the flow of Current, is called resistance ( $R$ )

4) Conductance ( $\sigma$ ) =  $\frac{1}{R}$

4)

- 5) Current density is amperes per square meter.

6) Current ( $I$ ) =  $\frac{EMF}{R}$

5)

##### **Magnetic Field**

- 1) Flow of flux ( $\Phi$ )
- 2) MMF is the cause of flow of flux
- 3) Resistance offered to the flow of flux, is called reluctance ( $S$ )

$$\frac{1}{S}$$

Permittivity ( $\mu$ ) =

Flux density is number of lines per square meter.

6) Flux ( $\Phi$ ) =  $\frac{MMF}{S}$

#### Dissimilarities

- 1) Current actually flows in an electric circuit.
- 2) Energy is needed as long as current flows

- 3) Conductance is constant and independent of current strength at a particular temperature.

1)

*Flux does not actually flow in a magnetic circuit.*

- 2) *Energy is initially needed to create the magnetic flux, but not to maintain it.*
- 3) *Permeability (or magnetic conductance) depends on the total flux for a particular temperature.*

## 2.2 Introduction

An object which attracts iron, nickel, cobalt etc and when suspended freely, points towards the poles of earth, is called magnet. The power of a magnet by which it attracts certain substances, is called magnetism, while materials which are attracted by a magnet, are called magnetic materials.

### Types of Magnetic Materials:

Magnetic materials can be broadly classified into two groups.

- (i) Soft Magnetic Materials
- (ii) Hard Magnetic Materials

#### (i) Soft magnetic materials

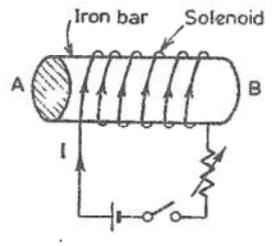
Like silicon iron (3 to 4% silicon content) are used in electric machines & transformers. Their hysteresis loops are, generally, characterised by a tall, but narrow hysteresis loop of small area.

#### (ii) Hard magnetic materials :-

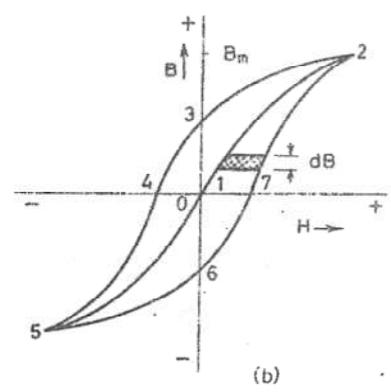
Like alnico (iron alloyed with aluminum, nickel and cobalt) are used for permanent magnets and magnetic tapes. Their hysteresis loops are generally characterised by a broad hysteresis loop of large area.

### B-H. Curve :

Place a piece of an unmagnetised iron bar AB within the field of a solenoid to magnetise it. The field  $H$  produced by the solenoid, is called magnetising field, whose value can be altered (increased or decreased) by changing (increasing or decreasing) the current through the solenoid. If we increase slowly the value of magnetic field ( $H$ ) from zero to maximum value, the value of flux density ( $B$ ) varies along 1 to 2 as shown in the figure and the magnetic materials (i.e iron bar) finally attains the maximum value of flux density ( $B_m$ ) at point 2 and thus becomes magnetically saturated.



(a)



(b)

Now if value of  $H$  is decreased slowly (by decreasing the current in the solenoid) the corresponding value of flux density ( $B$ ) does not decrease along 2-1 but decreases somewhat less rapidly along 2 to 3. Consequently during the reversal of magnetization, the value of  $B$  is not zero, but is '13' at  $H=0$ . In other words, during the period of removal of magnetization force ( $H$ ), the iron bar is not completely demagnetized.

In order to demagnetise the iron bar completely, we have to supply the demagnetisation force ( $H$ ) in the opposite direction (i.e. by reversing the direction of current in the solenoid). The value of  $B$  is reduced to zero at point 4, when  $H='14'$ . This value of  $H$  required to clear off the residual magnetisation, is known as coercive force i.e. the tenacity with which the material holds to its magnetism.

If after obtaining zero value of magnetism, the value of  $H$  is made more negative, the iron bar again reaches, finally a state of magnetic saturation at the point 5, which represents negative saturation. Now if the value of  $H$  is increased from negative saturation (= '45') to positive saturation (= '12') a curve '5,6,7,2' is obtained. The closed loop "2,3,4,5,6,7,2" thus represents one complete cycle of magnetisation and is known as hysteresis loop.

### 2.3 Permeability:-

Every substance possesses a certain power of conducting magnetic lines of force. For example, iron is better conductor for magnetic lines of force than air (vacuum). Permeability of a material ( $\mu$ ) is its conducting power for magnetic lines of force. It is the ratio of the flux density.

(B) Produced in a material to the magnetic field strength ( $H$ ) i.e.  $\mu = \frac{B}{H}$

### Reluctance :

Reluctance ( $S$ ) is akin to resistance (which limits the electric Current). Flux in a magnetic circuit is limited by reluctance. Thus reluctance( $S$ ) is a measure of the opposition offered by a magnetic circuit to the setting up of the flux.

Reluctance is the ratio of magnetomotive force to the flux. Thus

$$S = \frac{Mmf}{\phi}$$

Its unit is ampere turns per webber (or AT/wb)

*Ex:- A coil of 300 turns and of resistance  $10\Omega$  is wound uniformly over a steel ring of mean circumference 30cm and cross sectional area  $9\text{cm}^2$ . It is connected to a 20v d.c. If the relative*

permeability of the ring is 1500, Find (i) the magnetizing force (ii) the reluctance (iii) mmf (iv) the flux.

Sol<sup>n</sup>:- Hence  $N = 300$ ,  $R_{coil} = 10\Omega$ ,  $l = 30 \text{ cm} = 0.3 \text{ m}$ ,

$$A = 9 \text{ cm}^2 = 9 \times 10^{-4} \text{ m}^2, \mu_r = 1500, \mu_r = 4\pi \times 10^{-7}$$

$$I = \frac{V}{R_{coil}} = \frac{20}{10} = 2 \text{ A}$$

(i) Magnetizing force  $H = \frac{NI}{l} = \frac{300 \times 2}{0.3} = 2,000 \text{ AT / m}$

---

(ii) Reluctance  $S = \frac{l}{\mu_0 \mu_r A} = \frac{0.3}{4\pi \times 10^{-7} \times 1500 \times 9 \times 10^{-4}} = 1,7684 \times 10^9 \text{ AT/wb}$

(iii) Mmf -  $NI = 300 \times 2 = 600 \text{ AT}$

(iv) Flux  $\phi = \frac{\text{Mmf}}{\text{Reluctance}} = \frac{NI}{S} = \frac{300 \times 2}{1.7684 \times 10^9}$

$$= 3.39 \times 10^{-3} \text{ wb} = 3.39 \text{ wb}$$

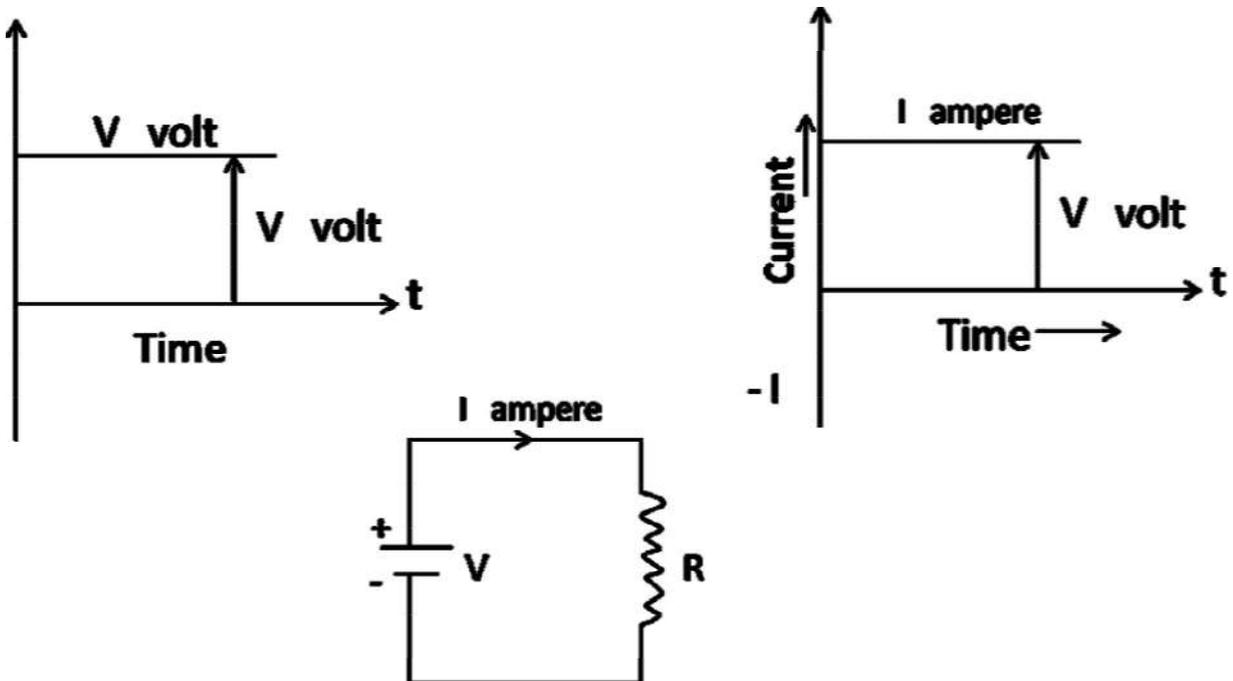
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# ALTERNATING CURRENT THEORY

## CHAPTER-THREE

### what is D.C.

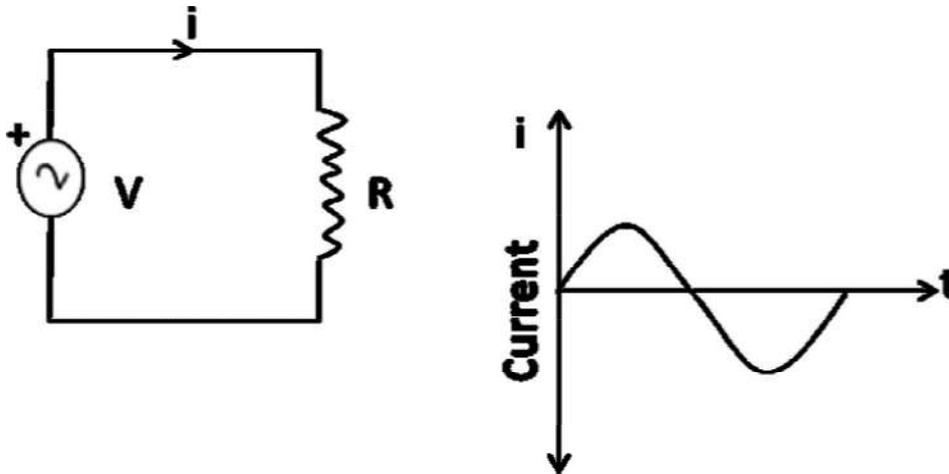
1. The Direct current or D.C. always flows in one direction & its magnitude remains unchanged
2. Here you see the voltage value is  $V$  volts & Current value is  $I$  amperes for all time to come i.e. as the time progresses.



[ Figure (a) ]

**what is A.C**

1. The Alternating current or A.C. is one which changes both in its direction & its magnitude .



[Figure(b)]

The AC current shown in the above circuit reverses its direction after some time as you see in the wave form diagram.

AC waveforms can also be other than like a sine wave that will be discussed

later on. HOW A.C. IS DIFFERENT FROM D.C

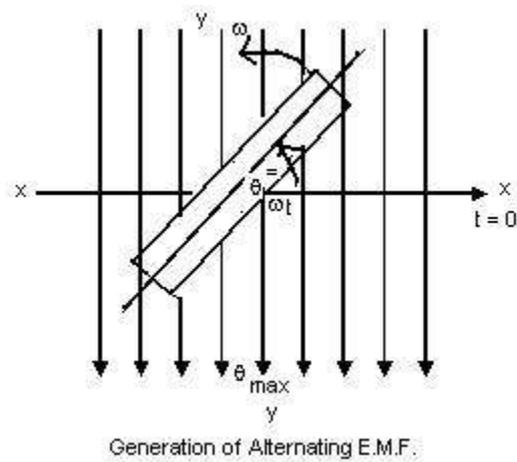
<b>Alternating Current</b>	<b>Direct Current</b>
<p>1. The magnitude and direction both changes .</p> <p>2. By using transformers, A.C. voltages can be increased or decreased as desired.</p> <p>3. A.C. circuit current can be decreased by using choke or capacitor without any appreciable power loss.</p> <p>4. A.C. can be converted into D.C. by using a device, called convertor (rectification circuit)</p> <p>5. A.C. cannot be used directly for electroplating, electrotyping, etc.</p>	<p>1. Both magnitude &amp; Direction remain constant.</p> <p>2. No such provision can be made.</p> <p>3. For decreasing D.C. circuit current, a resistance has to be used, whose power dissipation factor (<math>I^2R</math>) is large.</p> <p>4. D.C. can be converted to A.C. by using choppers (inverters).</p> <p>5. D.C. can be used directly for carrying out such operations.</p>

**Faradays laws of Electromagnetic Induction.**

First Law- Whenever a coil cuts the magnetic lines of flux ( $\phi$ ) Electro-Magnetic Force(e.m.f) is induced in the coil i.e.

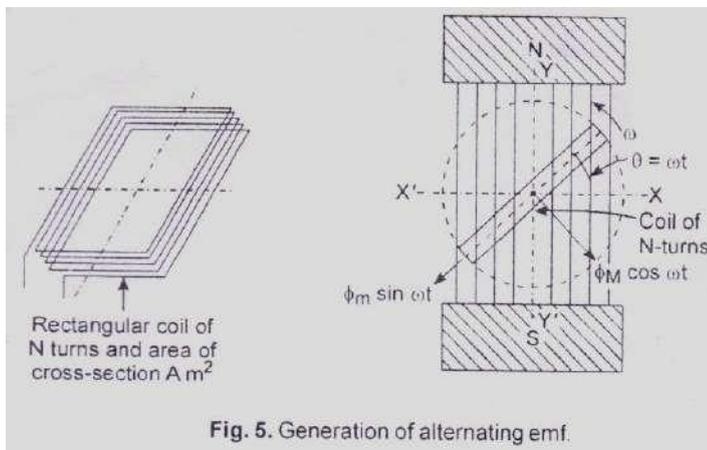
EMF Induced in a coil of N turns =  $e = - N d\phi/dt$

Second Law-The magnitude of e.m.f induced is directly proportional to the rate of change of Magnetic Flux cut by the coil i.e.  $e = -N \frac{d\phi}{dt}$



### GENERATION OF ALTERNATING EMF

Let there be a rectangular coil of  $N$  turns and is made free to rotate in a counter clockwise direction and is positioned inside the magnetic field produced by a north-south pole magnet as shown in the figure below.



If the coil rotates at an angular velocity of  $\omega$  radians per second then after a time of  $t$  seconds the coil will make an angle of  $\theta = \omega t$  degrees with the horizontal i.e. starting position.

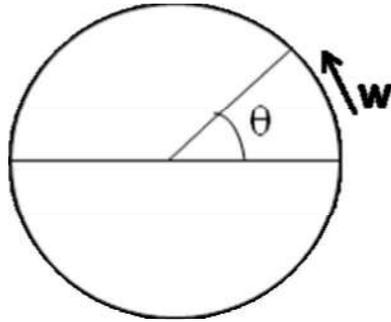
Component of flux perpendicular to the plane of the coil is :-

$$\Phi = \Phi_M \cos \omega t$$

Angle subtended by the coil in time  $t$  is

$$\theta = \omega t$$

So 
$$\omega = \frac{\theta}{t}$$



Magnetic Flux =  $\Phi = \Phi_m \cos \omega t$

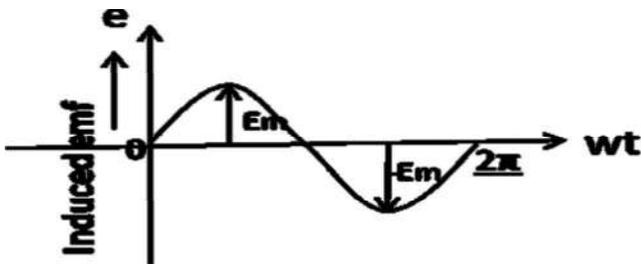
For  $N$  turns  $N\Phi = N\Phi_m \cos \omega t$

Induced emf in the coil according to Faradays

Law =  $e = -d(N\Phi)/dt$  volt =  $-d\{(N\Phi_m \cos \omega t)\}/dt$   
volts

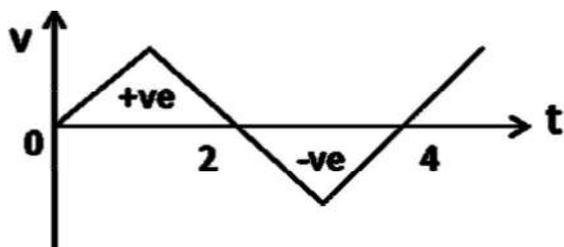
$$= -N\Phi_m d(\cos \omega t)/dt \text{ volts} = \omega N\Phi_m \sin \omega t$$

$$\text{volt } e = E_m \sin \omega t \quad (E_m = \omega N\Phi_m)$$

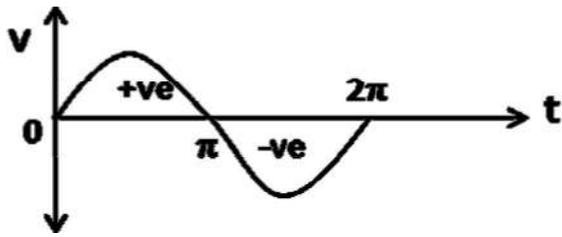


Questions/Answers

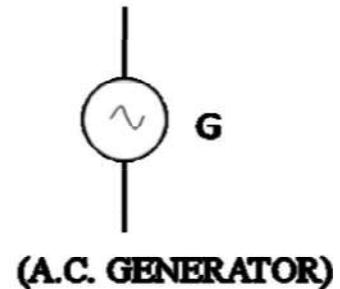
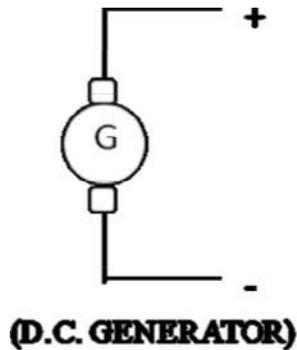
1. Is this wave forms AC?



2. What is the period of sinusoidal A.C. wave form shown below?



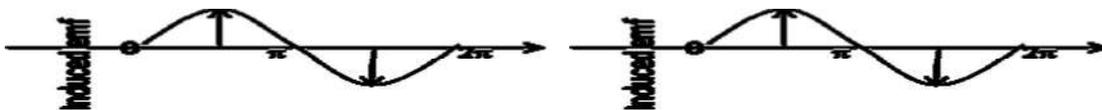
3. What is happening in a Generator or a Cell.



### VARIOUS A.C. TERMS

**AMPLITUDE:** The maximum value (positive or negative) attained by an alternating quantity is called its

Amplitude or Peak value.



**CYCLE:** One complete set of positive and negative values of an alternating quantity is known as cycle.

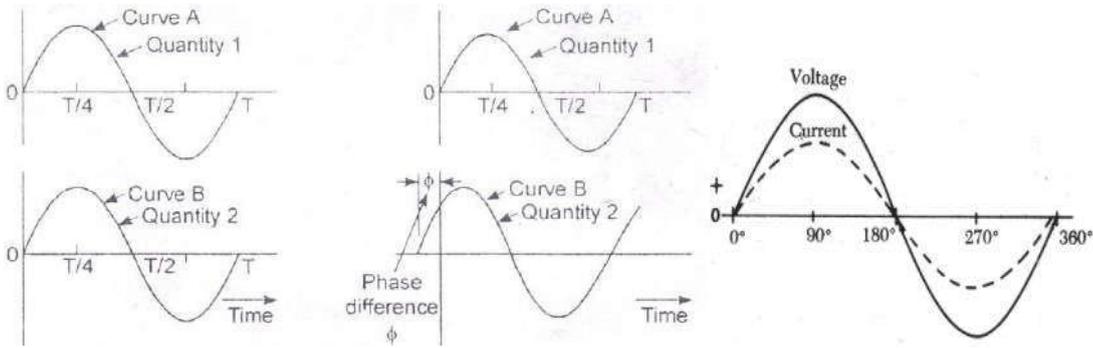
**TIME PERIOD (T):** The time period taken in seconds to complete one cycle of an alternating quantity is called its time period.

**FREQUENCY (f):** The number of cycles that occur in one second is called the frequency (f) of the alternating quantity.

**ALTERNATION:** Alternation is one-half of the cycle of an alternating quantity.

**PHASE:** Phase of an alternating quantity is the fraction of the time period or cycle that has elapsed since it last passed from the chosen zero position on origin.

**PHASE DIFFERENCE:** Phase difference between two alternating quantities is the fractional part of a period through which time of one alternating quantity has advanced over another alternating quantity.



**INSTANTANEOUS VALUE:** The value of an alternating quantity at any instant is called its instantaneous value.

### AVERAGE VALUE

Average value of a.c. is that value of steady current (d.c.) which when flowing through a circuit transfers same amount of charge as is done by a.c. through the same circuit in same time.

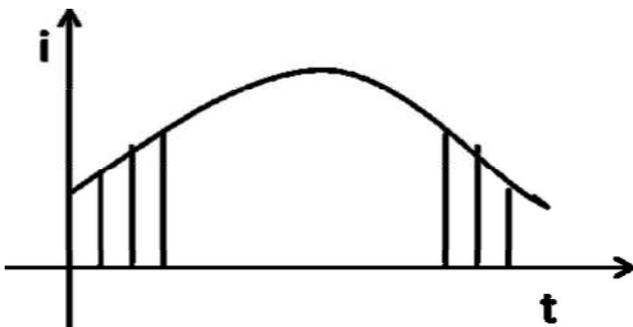
$$I_{av} = \frac{1}{T} \int_0^T i(t) dt \text{ or } I_{av} = \frac{1}{2\pi} \int_0^{2\pi} i d\theta$$

### RMS / EFFECTIVE VALUE

The effective or r.m.s. value of an alternating current is that steady current (d.c.) which when flowing through a given resistance for a given time produces the same amount of heat as produced by the alternating current when flowing through the same resistance for the same time.

$$I_{rms} = \sqrt{\frac{1}{T} \int_0^T i^2 dt} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i^2 d\theta}$$

Graphical Method



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

### **Amplitude factor (peak factor)**

The ratio of peak value or maximum value to r.m.s. value of an a.c. quantity is called Amplitude factor.

$$\text{Amplitude factor (peak factor)} = \frac{\text{Maximum value}}{\text{R.M.S. value}}$$

### **Form factor:**

The ratio of R.M.S. value to average value of an a.c. quantity is called form factor.

$$\text{Form factor} = \frac{\text{R.M.S. value}}{\text{Average value}}$$

### **Assignments / Discussion:-**

1. Determine the following for the a.c. waveform given by  $V = 141.4 \sin(628t)$ 
  - a. Maximum value
  - b. R.M.S. value
  - c. Average value
  - d. Amplitude factor
  - e. Form factor
  - f. Frequency
  - g. Time period
  - h. Determine the time taken to attain 100 volt after reaching maximum value and decreasing thereafter.

### **Solution**

Do YOU KNOW

$$2\pi f = 628$$

$$100 = 141.4 \sin 628 t$$

$$\sin 628t = (100/141.4) = (1/\sqrt{2}) = \sin 45, 135 = \sin (\pi/4), (3\pi/4)$$

$$\text{Hence } 628t = (3\pi/4) \text{ (Think why not } \pi/4)$$

$$t = [3\pi/(4 \times 628)] = ?$$

## PHASOR REPRESENTATION OF ALTERNATING QUANTITY

A phasor is a vector rotating at a constant angular velocity in Counter-clockwise Direction.

$$\text{At } t_1, e_1 = E_m \sin \omega t_1 = OA \sin \omega t_1$$

$$\text{At } t_2, e_2 = E_m \sin \omega t_2 = OA \sin \omega t_2$$

$$\text{At } t_3, e_3 = E_m \sin \omega t_3 = OA \sin \omega t_3$$

$$\text{At } t_4, e_4 = E_m \sin \omega t_4 = OA \sin \omega t_4$$

$$\text{At } t_5, e_5 = E_m \sin \omega t_5 = OA \sin \omega t_5$$

and so on.

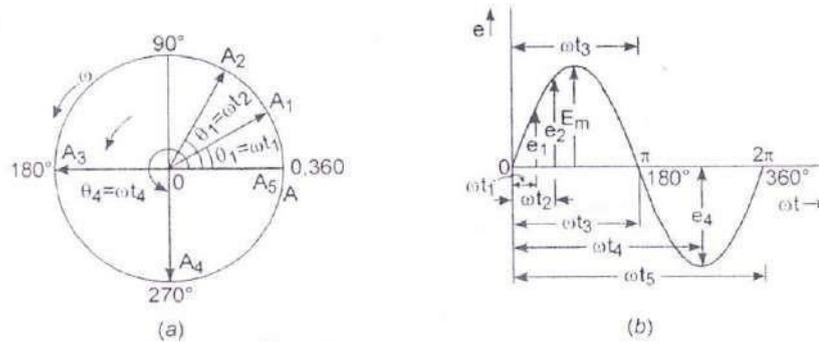


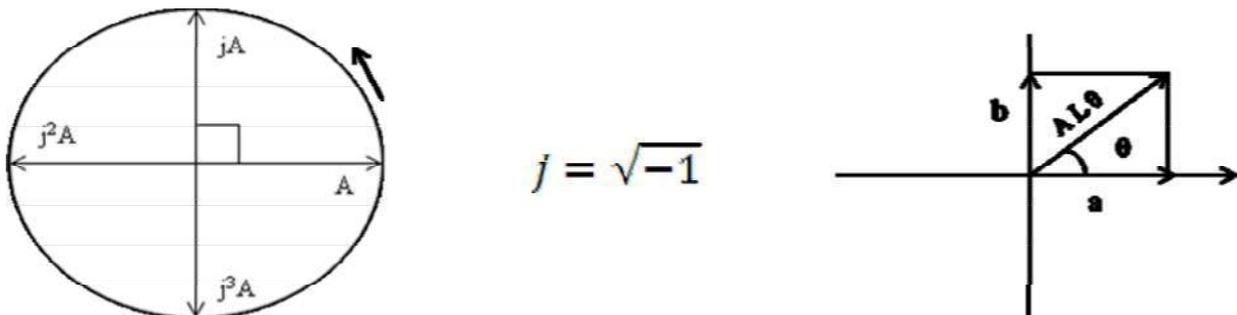
Fig. 7. Phasor (or vector) representation of alternating emf

**Note:** Instantaneous value of A.C. quantity is given by *projection of rotating vector at that instant on vertical axis.*

Phasor diagram is one in which different alternating quantities (sinusoidal) of the same frequency are represented by phasors with their correct phase relationship.

### SIGNIFICANCE OF $j$ - OPERATOR

Multiplication of a phasor with  $j$  rotates the phasor by an angle of  $\pi/2$  or  $90^\circ$  in counter clock-wise direction.



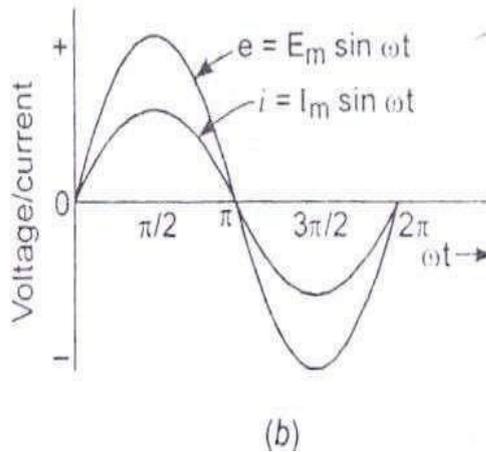
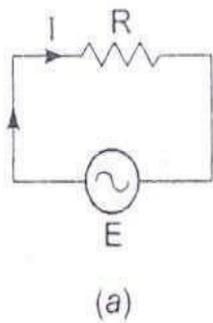
### REPRESENTATION OF PHASOR IN COMPLEX PLANE

- I) Rectangular or Cartesian Form:  $A = a + jb$ ,  $\theta = \tan^{-1}(b/a)$
- II) Trigonometric Form (Euler's Identity):  $A = Ae^{j\theta} = A (\cos \theta + j \sin \theta)$
- III) Polar Form:  $A = A \angle$

**Discussion :**

- a. Convert  $7+j24$  to Polar coordinate? Modulus =  $\sqrt{7^2 + 24^2} = 25$ , But Argument/Angle = ?
- b. Convert  $5 \angle 53.13^\circ$  to Rectangular coordinate . $[5(\cos 53.13^\circ + j\sin 53.13^\circ)]$

**A.C. THROUGH PURELY RESISTIVE CIRCUIT**



Ohm's law

states  $E = iR$

$E =$  Applied voltage

$i =$  Instantaneous value of

current  $R =$  Ohmic resistance

**Let us Find Current flowing in this circuit :**

$$E = E_m \sin \theta = E_m \sin wt$$

Also  $e = iR$  (Ohm's law)

$$iR = E_m \sin wt$$

$$i = \left(\frac{E_m}{R}\right) \sin wt = I_m \sin wt \text{ (Where } I_m = \frac{E_m}{R} \text{)}$$

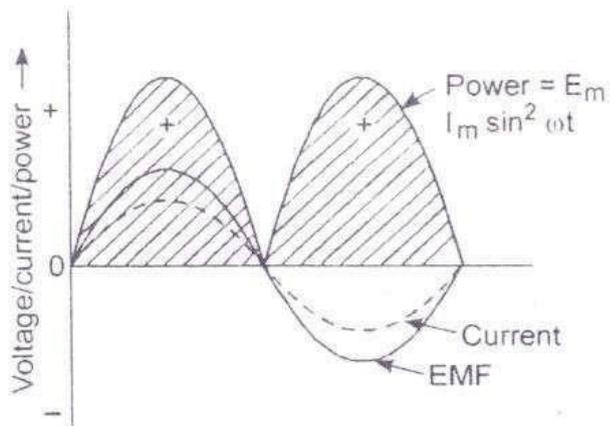
**CONCLUSION: IN A PURELY RESISTIVE CIRCUIT THE APPLIED A.C. VOLTAGE & CIRCUIT CURRENT ARE IN-PHASE.**

**POWER IN A PURELY RESISTIVE CIRCUIT**

$$P = ei = E_m \cdot I_m \sin^2 wt = \left(\frac{E_m I_m}{2}\right) (1 - \cos 2wt)$$

**CONCLUSION: AVERAGE POWER DISSIPATION OVER COMPLETE CYCLE =**

$$P = \frac{E_m I_m}{2} = \frac{E_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} = E_{rms} I_{rms}$$



Comparison of power wave with that of voltage, and current in a purely resistive circuit

Let us Solve

A voltage  $v = 141 \sin(314t + \pi/3)$  is applied to a resistance of  $10 \Omega$ . Find the R.M.S and maximum value of current

$$i = V/R = (141/10) \sin(314t + \pi/3) \\ = 14.1 \sin(314t + \pi/3)$$

Maximum value = ?

$$\text{R.M.S value} = \text{Maximum value} / \sqrt{2} = ?$$

### A.C. THROUGH PURELY INDUCTIVE CIRCUIT

$$\text{Induced emf} = e_{in} = -L \frac{di}{dt}$$

$e = \text{Applied voltage} = -$

$$e_{in} = L \frac{di}{dt} = E_m \sin$$

$wt$

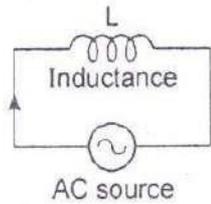
$$di = (E_m/L) \sin wt \cdot dt$$

On integration

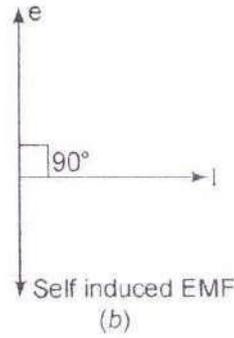
$$i = E_m/L \int \sin wt \cdot dt = E_m/wL (-\cos wt) = (E_m/wL) \sin(wt - \pi/2)$$

$$(\text{where } I_m = E_m/wL)$$

$$wL = 2\pi fL = X_L = \text{INDUCTIVE REACTANCE}$$



(a)



(b)

A.C. circuit with inductance only.

**CONCLUSION:**

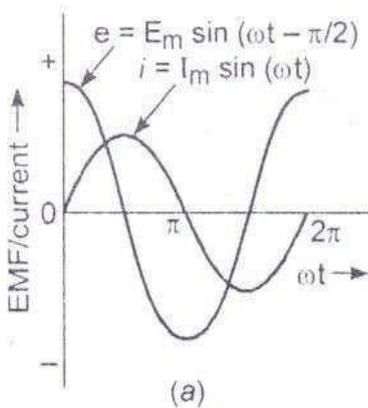
*IN A PURELY INDUCTIVE CIRCUIT THE CIRCUIT CURRENT (I) LAGS BEHIND THE APPLIED A.C. VOLTAGE (e) BY AN ANGLE OF  $\pi / 2$  OR  $90^\circ$ .*

**POWER IN A PURELY INDUCTIVE CIRCUIT**

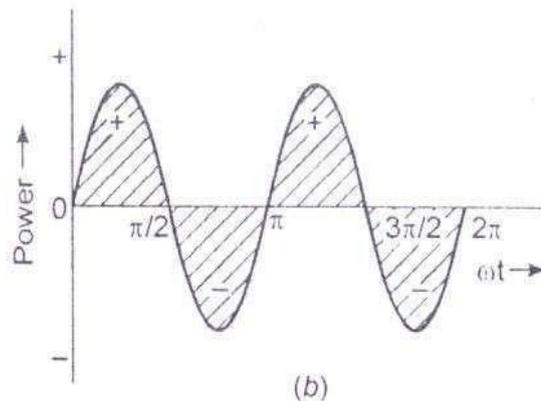
$$p = ei = E_m \cdot I_m \sin wt \cdot \sin (wt - \pi / 2)$$

$$= - E_m I_m \sin wt \cdot \cos wt = - (E_m I_m / 2) \sin 2wt$$

Power in complete cycle ,  $P = - (E_m I_m / 2) \int \sin 2wt = 0$



(a)



(b)

Graphs for A.C. circuit containing inductance only for : (a) voltage, and current ; (b) power

**CONCLUSION:**

*AVERAGE POWER DISSIPATION BY A PURELY INDUCTIVE A.C. CIRCUIT IS ZERO.*

### Discussion/Assignment

A voltage  $V = 141 \sin(314t + \pi/3)$  is applied to an inductance of 0.1 H. Find  $X_L$ ,  $i$ ,

$I_{MAX}$  Solution :

$$\omega L = 2\pi fL$$

i.e.,  $X_L = \text{INDUCTIVE REACTANCE} = 314 \times 0.1 = \text{WHAT}$

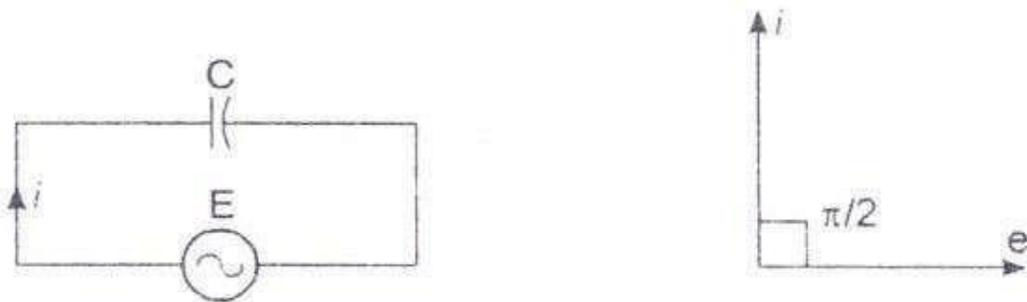
$$i = V_m / X_L = \sin(314t + (\pi/3) - (\pi/2))$$

$$= 141 / 31.4 \sin(314t - \pi/6)$$

$$= 4.49 \sin(314t - \pi/6)$$

Maximum value of current  $I_{MAX} = \text{FIND}$

### A.C. THROUGH PURELY CAPACITIVE CIRCUIT



A.C. through purely capacitive circuit

For a capacitor :  $C = q / v = q$

$$/ e \quad q = C.e = C. E_m \sin \omega t$$

(putting  $e = E_m \sin \omega t$ )

$$i = dq / dt = \frac{d(C E_m \sin \omega t)}{dt}$$

$$= \omega.C. E_m \cos \omega t$$

$$= \frac{E_m}{\omega C} \sin(\omega t + \pi/2) = \frac{E_m}{X_C} \sin(\omega t + \pi/2)$$

$$= I_m \sin(\omega t + \pi/2) \quad (\text{where } I_m = \frac{E_m}{X_C})$$

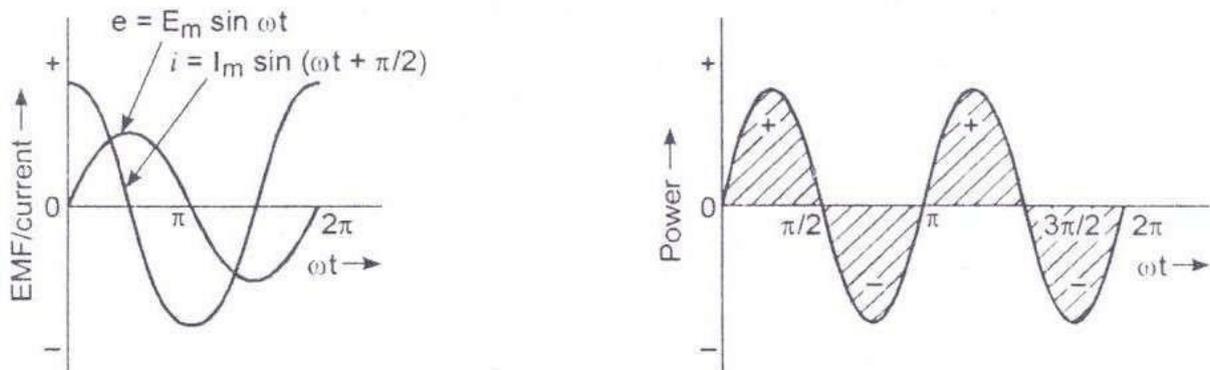
Where,  $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \text{Capacitive Reactance}$

**CONCLUSION: IN A PURELY CAPACITIVE CIRCUIT THE CIRCUIT CURRENT (I) LEADS THE APPLIED VOLTAGE (e) BY AN ANGLE OF  $\pi/2$  OR  $90^\circ$ .**

**POWER IN A PURELY CAPACITIVE CIRCUIT**

$$P = ei = E_m \cdot I_m \sin \omega t \cdot \sin (\omega t + \pi / 2)$$

$$= E_m \cdot I_m \sin \omega t \cdot \cos \omega t = \frac{1}{2} \cdot E_m I_m \sin 2\omega t$$



Graphs of purely capacitive A.C. circuit for EMF, and current

**CONCLUSION:**

**THE POWER DISSIPATION OVER A COMPLETE A.C. CYCLE IN A PURELY CAPACITIVE CIRCUIT IS ZERO.**

**Solve Yourself**

A voltage  $V = 141 \sin (314t + \pi / 3)$  is applied to a  $10 \mu\text{f}$  capacity. Find  $X_c, i,$

$I_{rms}, I_{MAX}$  **SOLUTION:**

$$X_c = 1/\omega c = 1/314 \times 10 \times 10^{-6} = 318.47 \Omega$$

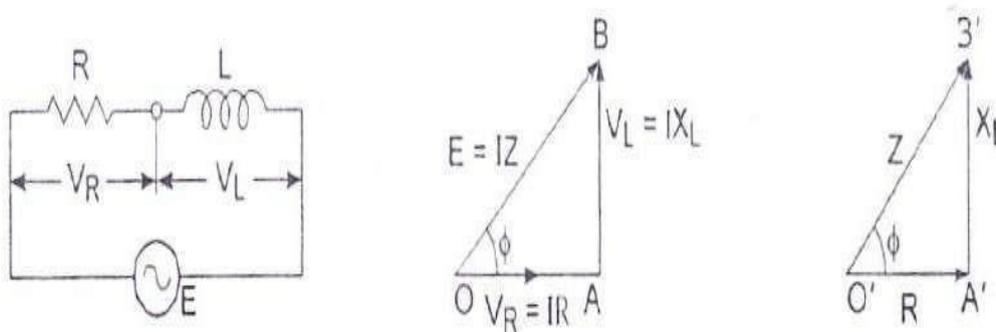
$$i = (141 / 318.47) \sin (314t + (\pi / 3) + (\pi / 2))$$

$$= 0.443 \sin (314t + 5\pi / 6)$$

Maximum value of current  $I_{MAX} = 0.443 \text{ Amp}$

$$I_{rms} = 0.443 / 2 = 0.313 \text{ Amp}$$

**A.C. THROUGH SERIES R-L CIRCUIT**



(a) R - L series A.C. circuit ; (b) voltage triangle ; (c) impedance triangle.

Voltage across resistance =  $V_R =$

$IR$  Voltage across

Inductance =  $V_L = IX_L$

$R \quad L$

$$= \sqrt{[(IR)^2 + (IX_L)^2]}$$

$$= I \sqrt{[R^2 + X^2]}_L$$

$$I = E / \sqrt{[R^2 + X^2]}_L$$

$$= E / Z$$

Where,  $Z = \text{IMPEDANCE} = \sqrt{[R^2 + X^2]}_L$

$$\angle Z = \tan^{-1}(X_L / R)$$

### CONCLUSION:

**IN A SERIES R-L CIRCUIT CONNECTED TO A.C. SUPPLY, THE APPLIED VOLTAGE (E) LEADS THE CIRCUIT CURRENT (I) BY AN ANGLE  $\phi$  CALLED THE POWER FACTOR ANGLE.**

POWER FACTOR IS COSINE OF THE ANGLE OF LEAD / LAG BETWEEN APPLIED VOLTAGE & CURRENT IN AN A.C. CIRCUIT.

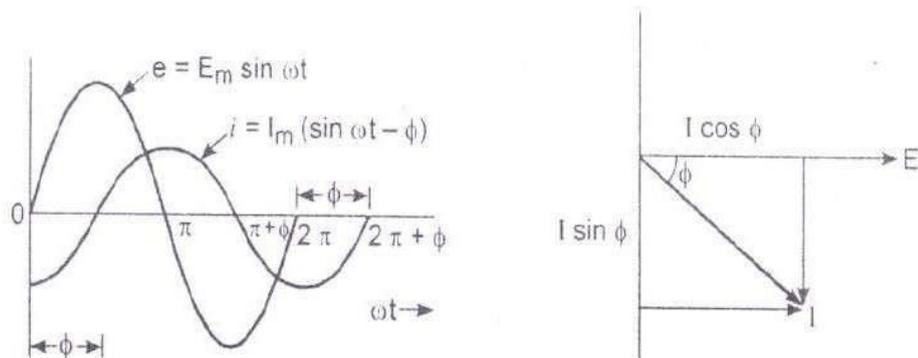
$$P.F. = \cos \phi = (R / Z)$$

$$P = V.I. \cos \phi = IZ.I.(R / Z) = I^2 R \text{ (ACTIVE POWER)}$$

$$Q = V.I. \sin \phi = IZ.I.(X_L / Z) = I^2 X_L \text{ (REACTIVE POWER) S}$$

$$= V.I = IZ.I = I^2 Z \text{ (APPARENT POWER)}$$

$$S = \sqrt{(P^2 + Q^2)} \text{ \& } \angle S = \tan^{-1}(Q / P)$$



Voltage, and current waves in R-L series A.C. circuit.

### PROBLEM-

An inductive coil takes 10 Amp when connected to 250v, 50hz mains. The power consumed is 1000 watt. Find (a) Z, R,  $X_L$  (b) Power factor, (c) App power and reactive power (d) Phase angle between V & I.

### SOLUTION:

$$(a) Z = (V / I) = 250 / 10 = 25 \Omega$$

$$P = VI \cos \theta$$

$$\cos \theta = (P / VI) = (1000 / (250 \times 10)) = 0.4$$

$$\sin \theta = 0.917$$

$$R = Z \cos \theta = 25 \times 0.4 = 10 \Omega$$

$$X_L = Z \sin \theta = 25 \times 0.917 = 22.93 \Omega$$

$$L = (X_L / \omega) = (22.93 / (2 \pi \times 50)) = 0.073 H$$

(b) Power factor =  $\cos \theta = 0.4$  lagging

(c) App Power =  $S = VI = 2500 VA$

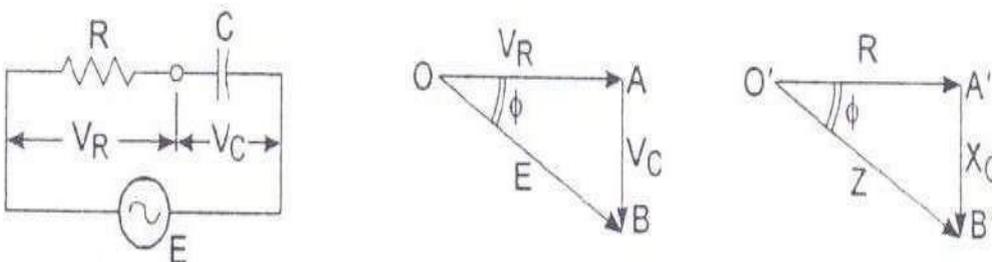
$$\text{Reactive power} = \theta = VI \sin \theta = 2500 \times 0.917 = 2292.5 \text{ Vars}$$

(d)  $\cos \theta = 0.4$

$$\theta = 66.42^\circ$$

Current phasor lags voltage phasor by  $66.42^\circ$

### A.C. THROUGH SERIES R-C CIRCUIT



(a) Series R-C A.C. circuit ; (b) voltage triangle ; (c) impedance triangle.

$$\text{Voltage across resistance} = V_R = IR$$

$$\text{Voltage across capacitance} = V_C =$$

$$IX_C \text{ Supply voltage } := E = \sqrt{[V_R^2 + V_C^2]}$$

$$V_R = IR$$

$$V_C = IX_C$$

$$\begin{aligned} E &= \sqrt{V_R^2 + V_C^2} \\ &= \sqrt{(IR)^2 + (IX_C)^2} \\ &= I\sqrt{R^2 + X_C^2} \end{aligned}$$

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

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

$$\angle Z = \tan^{-1}(X_C / R)$$

### CONCLUSION:

IN A SERIES R-C CIRCUIT CONNECTED TO A.C. SUPPLY, THE APPLIED VOLTAGE (E) LAGS THE CIRCUIT CURRENT (I) BY AN ANGLE  $\phi$  CALLED THE POWER FACTOR ANGLE.

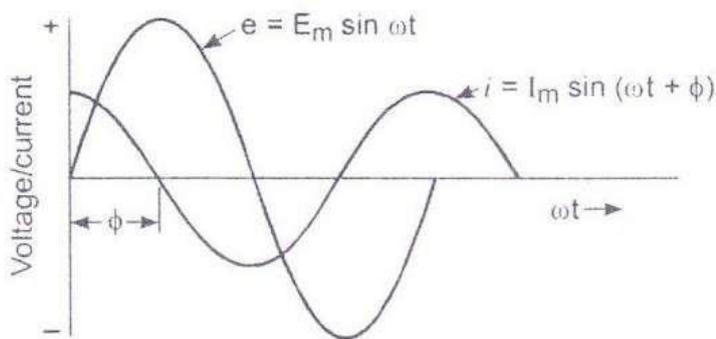
$$P.F. = \cos \phi = (R / Z)$$

$$P = V.I. \cos \phi = IZ.I.(R / Z) = I^2 R \text{ (ACTIVE POWER)}$$

$$Q = V.I. \sin \phi = IZ.I.(X_C / Z) = I^2 X_C \text{ (REACTIVE POWER) S}$$

$$S = V.I = IZ.I = I^2 Z \text{ (APPARENT POWER)}$$

$$S = \sqrt{P^2 + Q^2} \text{ \& } \angle S = \tan^{-1}(Q / P)$$



Voltage, and current waves in series R-C A.C. circuit.

### PROBLEM-

A voltage  $V = \sqrt{2} (230) \sin \omega t$  is applied to a series RC Circuit having  $R = 20 \Omega$  and  $C = 100 \mu F$ .

Find (a)  $X_C$ ,  $Z$ , (b)  $Y$ ,  $B$ ,  $G$ , (c) Current and power factor (d)  $S$ ,  $P$ ,  $Q$  (e) Write expression for instantaneous current.

SOLUTION:  $V = 230 \angle 0^\circ$

$$(a) X_C = (1 / \omega C) = (1 / 2 \pi \times 50 \times 100 \times 100 \times 10^{-6}) = 31.83 \Omega$$

$$Z = R - jX_C = 20 - j31.83 \Omega = 37.59 \angle -57.86^\circ$$

$$(b) Y = (1 / Z) = \text{Admittance} = (1 / 37.59 \angle -57.86^\circ) = 0.0266 \angle 57.86^\circ$$

$$= 0.01415 + j 0.0225$$

$$\text{Siemens } Y = G + jB$$

$$\text{So } G = 0.01415 \text{ Siemens \& } B = 0.0225 \text{ Siemens}$$

$$(c) I = (V / Z) = (230 \angle 0^\circ / 37.59 \angle -57.86^\circ) = 6.12 \angle 57.86^\circ \text{ Amp}$$

$$\text{Power factor} = \cos (57.86^\circ) = 0.522 \text{ leading}$$

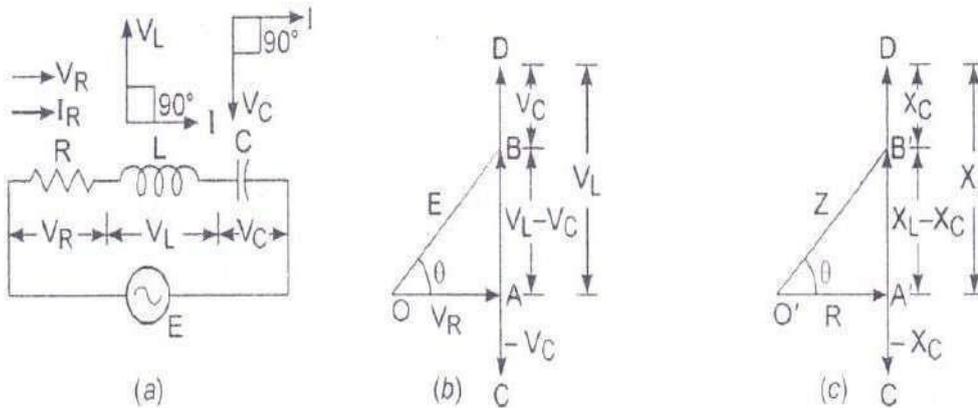
$$(d) \text{ App Power} = S = VI = 230 \times 6.12 = 1407.6 \text{ VA}$$

$$\text{Active power} = P = VI \cos \theta = (1407.6 \times 0.532) = 748.84 \text{ watt}$$

$$\text{Reactive power} = Q = -VI \sin \theta = (-1407.6 \times \sin 57.86^\circ) = -1191.9 \text{ Vars}$$

$$(e) \text{ Instantaneous value} = 2 \times 6.12 \sin (\omega t + 57.86^\circ) = 8.65 \sin (\omega t +$$

57.86^\circ) A.C. THROUGH SERIES R-L-C CIRCUIT



(a) Series R-L-C A C circuit ; (b) voltage triangle ; (c) impedance triangle.

Voltage across resistance =  $V_R =$

$IR$  Voltage across

Inductance =  $V_L = IX_L$  Voltage

across capacitance =  $V_C = IX_C$

$$\text{Supply Voltage} = E = \sqrt{V_R^2 + (V_L - V_C)^2} = \sqrt{[IR]^2 + [IX_L - IX_C]^2}$$

$$= I \sqrt{R^2 + (X_L - X_C)^2}$$

$$I = E / \sqrt{R^2 + (X_L - X_C)^2} = E / \sqrt{R^2 + X^2} = E / Z$$

$$= \text{IMPEDANCE} = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\angle Z = \tan^{-1}(X_L - X_C) / R$$

**CONCLUSION:**

**IN A SERIES R-L-C CIRCUIT CONNETED TO A.C. SUPPLY, THE APPLIED VOLTAGE (E) LEADS THE CIRCUIT CURRENT (I) IF  $X_L > X_C$  & LAGS BEHIND CIRCUIT CURRENT IF  $X_L < X_C$  & REMAIN IN-PHASE IF  $X_L = X_C$ .**

$$P.F. = \cos \phi = (R/Z) = R / \sqrt{R^2 + (X_L - X_C)^2}$$

$$P = V.I. \cos \phi = IZ.I.(R/Z) = I^2 R \text{ (ACTIVE POWER)}$$

$$Q = V.I. \sin \phi = IZ.I. ((X_L - X_C) / Z) = I^2 [X_L - X_C] \text{ (REACTIVE POWER) } S =$$

$$V.I = IZ.I = I^2 Z \text{ (APPARENT POWER)}$$

$$S = \sqrt{P^2 + Q^2} \text{ \& } \angle S = \tan^{-1}((X_L - X_C) / R)$$

**PROBLEM-**

*A resistance of 10 Ω, inductance of 0.1 H & capacitance 50 micro farad are connected in series across a 230v, 50Hz supply. Find (a)  $X_L$ ,  $X_C$  &  $Z$ , (b)  $I$  & Power factor (C) Active, reactive and apparent power (d)  $Y$ ,  $G$ ,  $B$*

**SOLUTION:**  $V = 230 \angle 0^\circ$

(a)  $\omega L = 2 \pi fL = X_L = \text{INDUCTIVE REACTANCE}$

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

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

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

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

$$\text{Power factor} = \cos (72.77^\circ) = 0.296 \text{ leading}$$

(c)  $\text{App Power} = S = VI = 230 \times 6.8 = 1564 \text{ VA}$

$$\text{Active power} = P = VI \cos \theta = (1564 \times 0.296) = 462.9 \text{ watt}$$

$$\text{Reactive power} = Q = VI \sin \theta = (1564 \times \sin -72.77^\circ) = -1496.80$$

Vars (d)  $Y = (1 / Z) = \text{Admittance} = (1 / 33.76 \angle -72.77^\circ) = 0.0296$

$$\angle 72.77^\circ$$

$$= 0.00877 + j 0.0283$$

$$\text{Siemens } Y = G + jB$$

$$\text{So } G = 0.00877 \text{ Siemens \& } B = 0.0283 \text{ Siemens}$$

.....XXX.....

GENERATION OF

ELECTRICAL POWER

CHAPTER-FOUR

BULK ELECTRIC POWER IS PRODUCED BY SPECIAL PLANTS KNOWN AS GENERATING STATIONS OR POWER PLANTS.

1. STEAM POWER STATION (THERMAL STATION)
2. HYDRO-ELECTRIC POWER STATION
3. NUCLEAR POWER STATION

#### STEAM POWER STATION (THERMAL STATION)

#### CHOICE OF SITE

1. **SUPPLY OF FUEL** :- The steam power station should be located near coal mines so that transportation cost of fuel is minimum.
2. **AVAILABILITY OF WATER** :- A huge amount of water is required for the condenser for which it is essential that the plant should be located at the bank of a river or near a canal to ensure continuous supply of water.
3. **TRANSPORTATION FACILITIES** :- A modern steam power station often requires the transportation of material and machinery. Therefore adequate transportation facilities by rail or Road should exist.

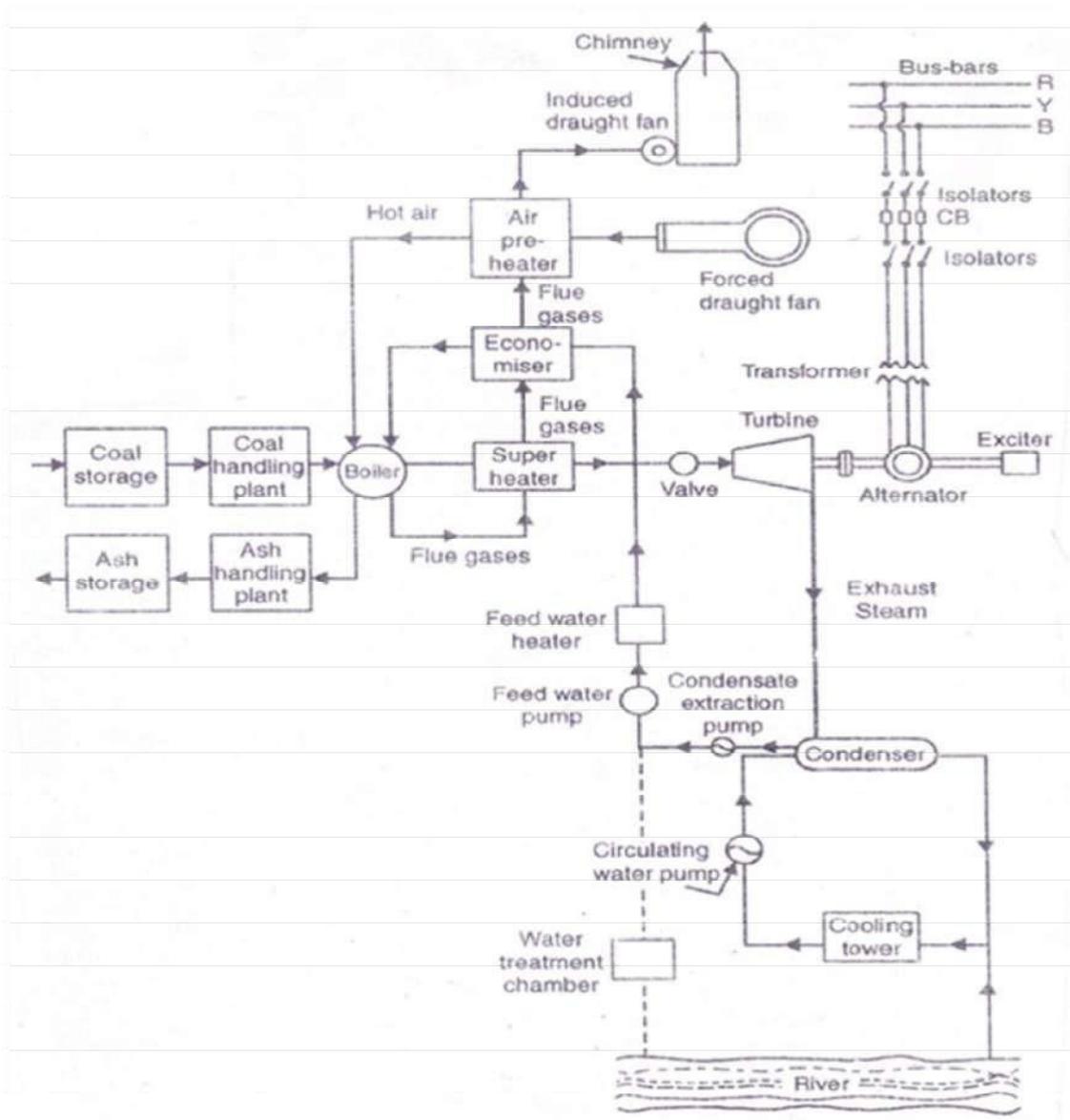
4. **COST AND TYPE OF LAND**:- The steam power station should be located at a place where land is cheap and further extension if necessary is possible.
5. **NEARNESS TO LOAD CENTRES**:- In order to reduce transmission cost the plant should be located near the center of load.
6. **DISTANCE FROM POPULATED AREA** :- As huge amount of coal is burnt in a steam power Plant due to which smoke and fumes pollutes the surrounding area. This necessitates that plant should be located at a considerable distance from the populated areas.

### **MAIN UNITS OF 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 without 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 make 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 superheated.
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 atmosphere 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 through 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 to 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.

## **SCHEMATIC ARRANGEMENT OF STEAM POWER STATION**



**Working of Thermal power Plant** :When the water from condenser is fed to the Boiler through Economiser it remains a little hot .The Boiler is a extremely heated chamber because of a continuous burning of Coal in presence of air injected by F.D fan through pre-heater.

So, the water gets converted to steam with very high temperature and pressure and reaches the Steam Turbine through Super-Heater. The Internal Energy of Steam gets converted to Mechanical Energy by Turbine and the Alternator converts the mechanical Energy of Turbine output to Electrical Energy. The Electrical Energy thus produced is supplied to the Bus-Bar for Power use.

### Assignments / Discussion:-

➤ What are the Advantages / Disadvantages of a Steam Power Station?

### 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.

### HYDRO-ELECTRIC POWER

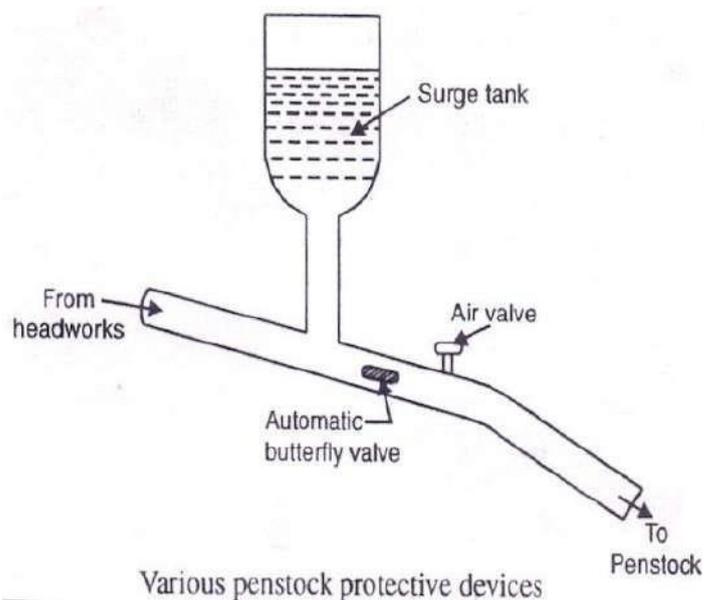
### STATION CHOICE OF SITE

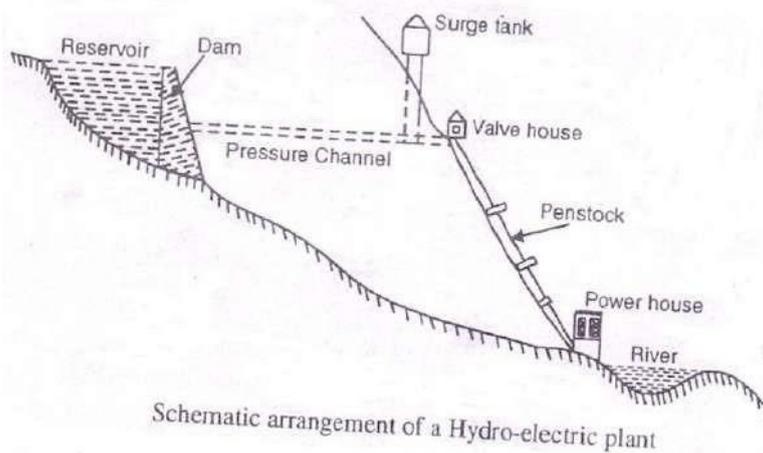
1. **AVAILABILITY OF WATER**:- Since the primary requirement of a hydro-electric power station is the availability of huge quantity of water at a good head this requirement is very essential.
2. **STORAGE OF WATER**:- There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a Dam in order to ensure the generation of power throughout the year.
3. **COST & TYPE OF LAND** :- The land for the construction of Plant should be available at a reasonable price. Further the bearing capacity of the ground should be adequate to withstand the weight of heavy equipment to be installed.
4. **TRANSPORTATION FACILITY** : The site selected should be accessible by Rail and Road so that necessary equipment and machineries be easily transported.

### MAIN CONSTITUENTS OF PLANT

1. **DAM** :- A Dam is a barrier which stores water & creates water head. Dams are built of concrete or stone masonry, earth or rockfill.

2. **SPILWAYS** :- There are times when the river flow exceeds the storage capacity of the reservoir. In order to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam, spill ways are used.
3. **HEAD WORKS** :-The head works consists of the diversion structures at the head of an intake.They generally include booms and racks for diverting floating debris,sluices for by-passing debris,sediments and valves for controlling the flow of water to the turbine.
4. **SURGE TANK** :-For close conduits abnormal pressure may cause damage to the conduit leading from head works to penstock.Surge tank acts as a protection for such situation.
5. **PENSTOCKS** :-Penstocks are open or close conduits which carry water to the turbines.They are generally made of reinforced concrete or steel.
6. **WATER TURBINES** :- Water turbines are used to convert the energy of falling water into mechanical energy.
7. **ALTERNATOR** :- The alternator converts the mechanical energy of turbine to electrical energy.





**Working of Hydro-Electric Power Plant** :When the water from Reservoir is allowed to get released through pressure channel, it reaches the Valvehouse.

The surge tank is provided in order to safe guard the extra back-thrust of water causing heavy damage to Penstock. The valve house controls the amount of water that will flow to the power house turbines through the Large sized Pen-stocks.

Inside the power house the water Turbine convert the potential energy of water with sufficient head to Kinetic energy i.e. mechanical Energy which in turn acts as a prime-mover for the Alternator as before and generates ElectricalEnergy.

### **Assignments / Discussion:-**

- State the Advantages / Disadvantages of a Hydro-Power Station?

### **ADVANTAGES**

- i) It requires no fuel as water is used for the generation of ElectricalEnergy.
- ii) It is quite neat & clean as no smoke or ash is produced.
- iii) Running cost is very less as water is used.
- iv) It is simple in construction & requires less maintenance.
- v) It can be started quickly as compared to Thermal Power Station.
- vi) In addition to generation of Electrical Energy these plants are also helpful in irrigation & control of floods.

## **DISADVANTAGES**

- i) *It involves high capital lost due to construction of dams.*

- ii) Generation depends on average rainfall round the year.
- iii) High cost of transmission as these plants are located in hilly areas quite far off from localities.

## NUCLEAR POWER

### STATION CHOICE OF SITE

1. **AVAILABILITY OF WATER** :- A huge amount of water is required for the condenser for which it is essential that the plant should be located at the bank of a river or near a canal to ensure continuous supply of water.
2. **DISPOSAL OF WASTE** :- The waste produced by fission in a nuclear power station is generally radio-active which must be disposed off properly to avoid health hazards for which it must be buried in deep trench.
3. **DISTANCE FROM POPULATED AREA**:- The site for setting up a nuclear power station should be quite away from populated areas.
4. **TRANSPORTATION FACILITY**:- The site selected for a nuclear power station should have adequate facilities in order to transport the heavy equipment during erection.

### NUCLEAR FUEL

1. URANIUM( $U^{235}$ )
2. PLUTONIUM( $Pu^{239}$ )
3. THORIUM( $Th^{232}$ )

### FISSION & CHAIN REACTION

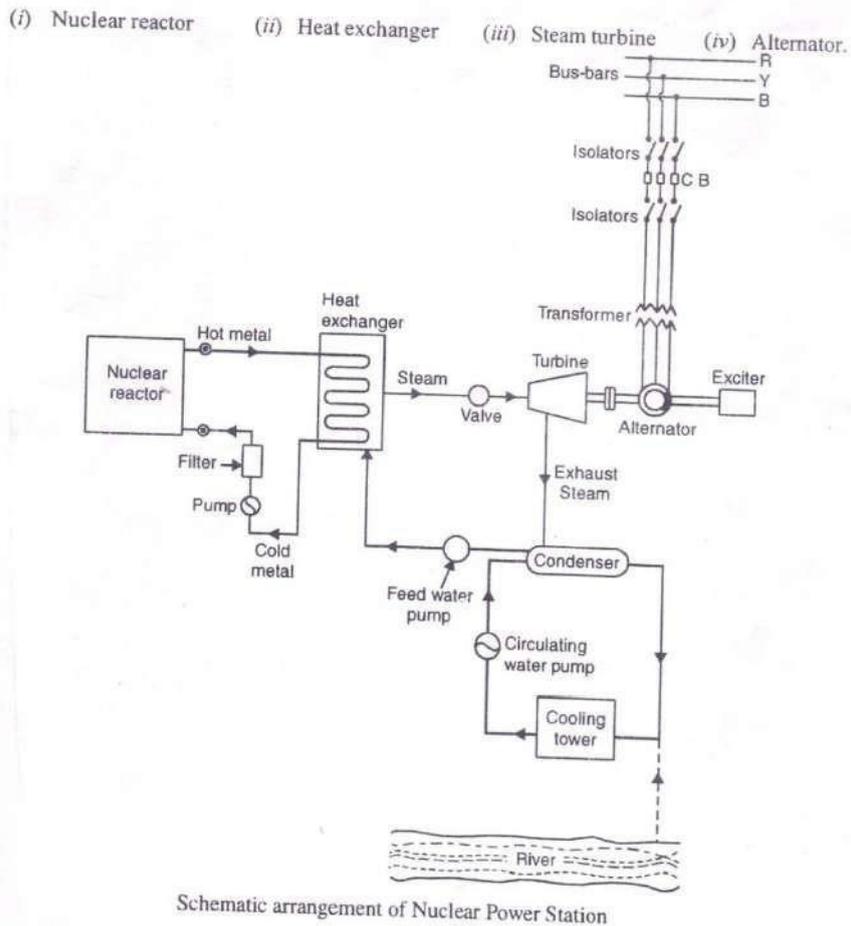
When a  $U-235$  atom is struck by a slow neutron, it will split into two or more fragments. This is called a nuclear fission. This splitting (fission) is accompanied by release of thermal energy in large quantity and two or three fast neutrons. These fast moving neutrons are slowed down by moderators so that they have high probability to hit other  $U-235$  atoms which in turn get fissioned and release heat and neutrons. This continuous self sustaining sequence of nuclear fissions is called CHAIN REACTION.

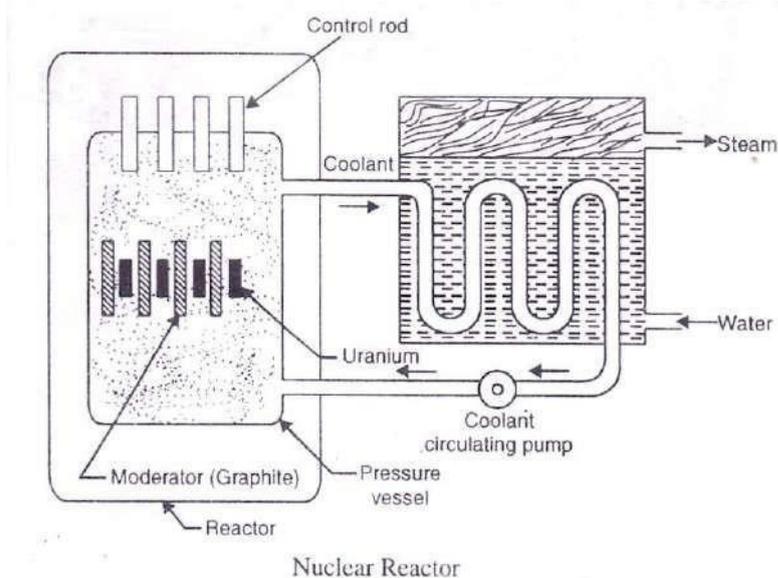
### MAIN UNITS OF PLANT

1. **NUCLEAR REACTOR** :- It is an apparatus in which the nuclear fuel ( $U^{235}$ ) is subjected to nuclear fission.
2. **HEAT EXCHANGER** :- The coolant gives up heat to the heat exchanger which is utilized in raising the steam & after giving up heat the coolant is again fed to

*thereactor.*

3. **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 to mechanical energy.
4. **ALTERNATOR:-** The alternator converts the mechanical energy of turbine to Electrical Energy.





**Working of Nuclear PowerPlant:** As discussed earlier, the chain reaction produces a huge amount of heat inside the Nuclear Reactor and requires a lot of care to control this reaction. The heat of the Reactor is carried to Heat-Exchanger by molten sodium which also heats the water injected into this Heat Exchanger chamber. After the water gets converted to steam with very high temperature and high pressure ,the Turbine converts the internal Energy of steam to Mechanical Energy and this is converted to Electrical Energy by Alternator asbefore.

**Assignments / Discussion:-**

➤ State the Advantages / Disadvantages of a Nuclear Power Station?

**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 cost 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 bigproblem.*

.....XXXX.....

# Conversion of Electrical Energy

## CHAPTER – FIVE

### 4.1 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.

### 4.2 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.

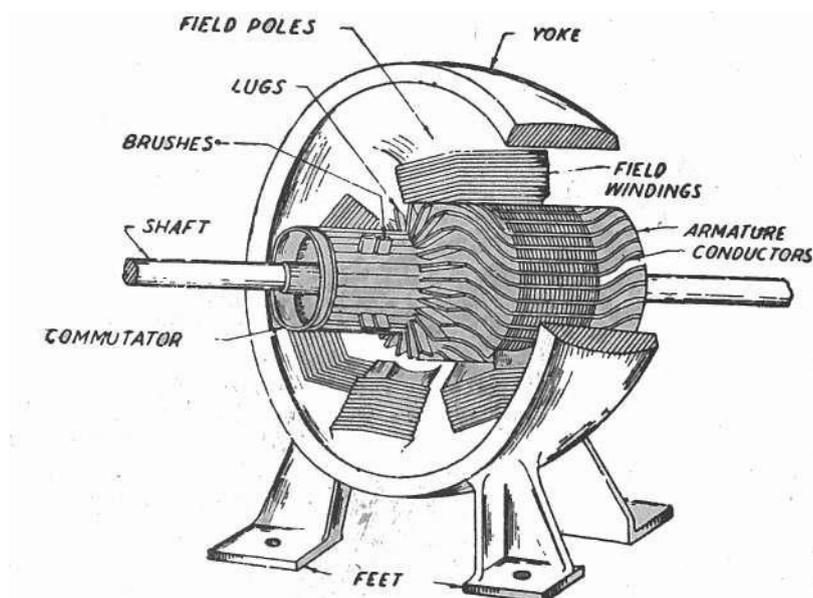


Fig. 4.1

### 4.3 Principle of operation of D.C. Generator

When a conductor or conductors rotate in a magnetic field, an emf. is induced in the conductor or conductors. The instantaneous value of the induced emf is given by

$$e = Blv \sin\theta$$

where  $B$  = Magnetic flux

density  $l$  = length of  
the conductor

$v$  = Velocity of the conductor

And  $\theta$  = Angle between the magnetic field and direction of motion of the conductor with respect to magnetic field.

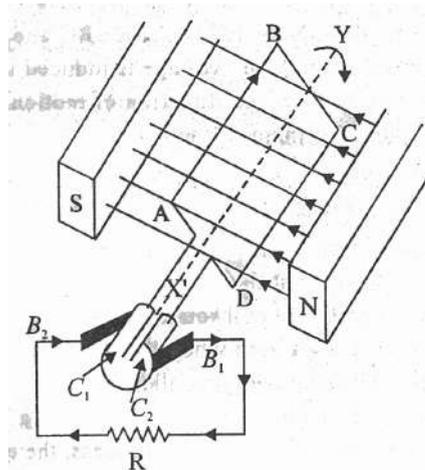


Fig. 4.2

When shaft is rotated (by some prime mover) the rotor turns and a.c. is induced in the armature coil. The instantaneous emf given earlier as

$$e = Blv \sin\theta$$

In the above figure the plane of the coil is in the direction of the magnetic field and the induced emf is maximum. But as the armature rotates through  $90^\circ$ , the induced emf reduces and becomes zero. During this period, the current direction is shown in the figure where current flows from the bottom segment and brush into the top segment and brush.

As the armature rotates further from this position, the polarity of induced emf is

reversed and the current direction is also reversed. As the armature rotates  $90^\circ$  another

the emf. induced in the armature is again at a maximum. The current during this period flows out of the top segment. As the polarity of induced emf. has been reversed during this period current in the external circuit flows in the same direction.

With continued rotation of the armature, the a.c. emf. induced in the armature conductors is made to enter and leave the brushes in the same direction into the external circuit at all times. The action of commutator and the coil results in a fluctuating d.c. output of a full waverectifier.

#### 4.4. EMF Equation of Generator:

Let  $\phi$  = flux / pole in weber.

$Z$  = Total Number of armature conductors.

= No of Slots X No of Conductors / Slot

$P$  = No of generator poles  
 $A$  = No of Parallel paths in armature  
 $N$  = Armature rotation in revolutions per minute (RPM)

Generated EMF ( $E_g$ ) = emf induced in any one Parallel path in armature.

$$\text{Average emf. Generated / Conductor} = \frac{d\phi}{dt} \text{ volts.}$$

Now flux cut/ conductor in one revolution.

$$d\phi = \phi P \text{ wb}$$

$$\text{No of revolution / second} = \frac{N}{60}$$

$$\text{Therefore time fore one revolution.} \quad \frac{60}{N} \text{ s}$$

$$dt =$$

$$\text{Henc } \frac{d\phi}{dt} = \frac{\phi P}{(60/N)} = \frac{\phi P}{N} \text{ volt}$$

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

For wave - wound

Generator No of parallel

path ( $A$ ) = 2

No. of conductors in one path =  $Z/2$

$$\text{EMF generated / path} = \frac{\phi P N \times Z}{60 \times 2} = \frac{\phi P N Z}{120} \text{ Volt}$$

For Lap wound

generator No of

Parallel Paths =  $P$

No of conductors in one path =  $Z/P$

$$\text{EMF generated / path} = \frac{\phi P N \times Z}{60 \times p} = \frac{\phi Z N}{60} \text{ Volt}$$

$$\text{In general, generated EMF } E_g = \frac{\phi Z N}{60} \times P$$

$$60 \text{ s} \text{ A}^\dagger$$

)

Where  $A = 2$  – for wave –winding.

$A = P$  for lap – winding.

- 4.5 Ex. A shunt generator delivers 450 A at 230V and the resistance of the shunt field and armature are  $50\Omega$  and  $0.03\Omega$  respectively. Calculate the generated EMF.

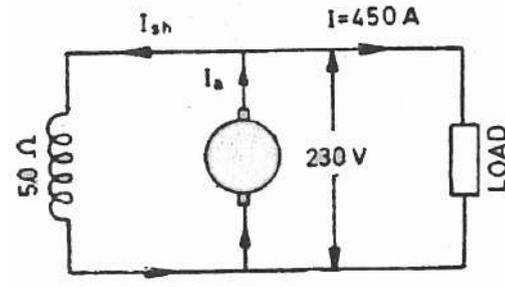


Fig.4.3

$$\frac{230}{50} = 4.6A$$

Current through the field

50

winding = Load current  $I = 450A$

Armature Current  $I_a = I +$

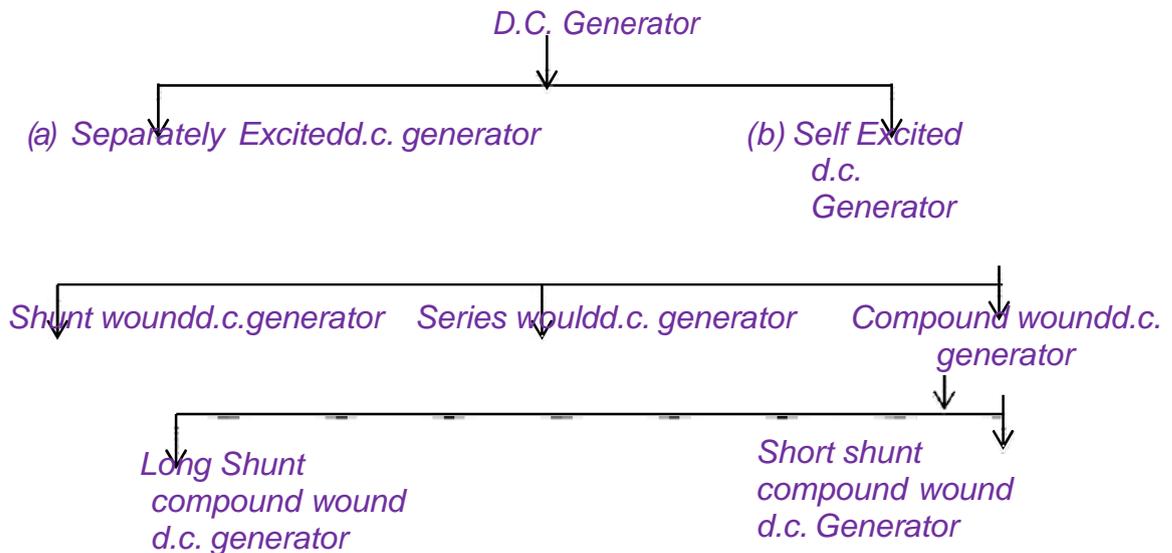
$I_f I_a = 450 + 4.6 = 453.6A$

Armature voltage drop  $(I_a R_a) = 453.6 \times 0.03 =$

$13.6V$ .  $E_g =$  terminal voltage + Armature drop

$E_g = V + I_a R_a = 230 + 13.6 = 243.6V$ .

46 **Classification of D.C. Generator**



47 **Motor Equation**

When the motor armature rotates, the conductors also rotate and hence cut the flux. In accordance with the laws of electromagnetic induction emf. is induced in them whose direction is found by Flemings' Right hand rule, is in opposition to the applied voltage. Because of its opposing direction, it is referred to as back emf.  $E_b$ .

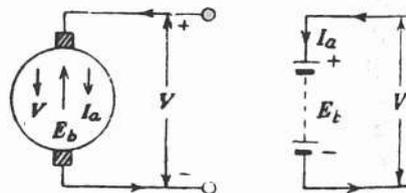


Fig. 4.4

$$\text{Current } I_a = \frac{\text{Net voltage}}{e}$$

So  $V = E_b + I_a R_a$ .

$I_a$

$$\Rightarrow V - E_b = I_a R_a$$

Resistance

$R_a$

$= V - E_b$

\_\_\_\_\_

*Ex. A 220 V D.C. machine has an armature resistance of  $0.5\Omega$ . If the full load armature current is 20A. Find the induced emf. When the machine acts as (i) Generator (ii) Motor*

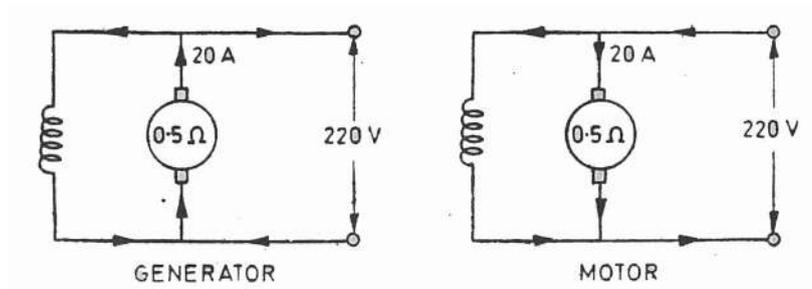
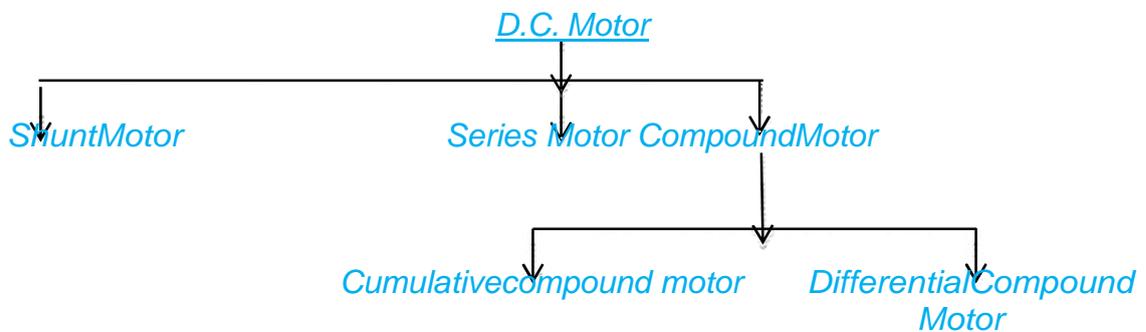


Fig.4.5

(a) As Generator  $E_g = V + IaRa$   
 $= 220 + (0.5 \times 20) = 220 + 10 = 230V$

(b) As motor  $E_b = V - IaRa = 220 - (0.5 \times 20)$   
 $E_b = 220 - 10 = 210V$

48 Classification of D.C. Motor



49 Uses of D.C. Generators:

- (1) Shunt Generator
  - (i) Lighting and Power Supply
  - (ii) Charging batteries.
- (2) Series Generator–
  - (i) Boosters.
- (3) Compound Generator–
  - (i) Large range load
  - (ii) Power Supply

Uses of D.C. Motors

- (1) Shunt Motor
  - (i) Constant speed drive
  - (ii) Drilling machine, lathes, elevators, water pump, cutting machine.
- (2) Series Motor
  - (i) Electric Cranes
  - (ii) Electric Trains
  - (iii) Hoists
- (3) Compound Motor
  - (i) Heavy tool machines
  - (ii) Printing machines

#### 4.10 Necessity of a starter

As current drawn by a d.c. motor armature is given by the relation.

$$I_a = \frac{(V - E_b)}{R_a}$$

when the motor is at rest, i.e.  $N=0$ , no back emf developed in the armature. If now full supply voltage is applied across the stationary armature, then it will draw a very large current as armature resistance is very small. This excessive current will blow out the fuses and may damage the commutator and brushes etc.

To avoid this happening, a resistance is introduced in series with the armature (for the duration of starting period only i.e. 5 to 10 seconds) which limits the starting current to a safe value. The starting resistance is gradually cut out as the motor gains speed and develops the back emf. This starting resistance with some protective devices is known as starter.

**There are three types of starter**

(1) 3- point starter (2) 4-Point starter (3) Drum –controller

#### 4.11 Principle of operation of single phase Induction Motor:

A single-Phase induction motor consists of a single phase winding mounted on the stator and a cage winding on the rotor. When a single - phase supply is connected to the stator winding a pulsating magnetic field is produced. By pulsating field the field builds up in one direction falls to zero, and then builds up in the opposite direction. Under these conditions, the rotor does not rotate due to inertia. Hence a single phase induction motor is initially not selfstarting.

To make the motor self starting another winding is provided on the stator which temporarily converted to a two phase induction motor. When supply is given a rotating magnetic field is produced and rotor starts rotating.

Two theories have been suggested to analyze the performance of a single phase induction motor.

- (1) Double Field Revolving Theory
- (2) Cross Field Theory

#### 4.12 Types of Single Phase Induction Motor

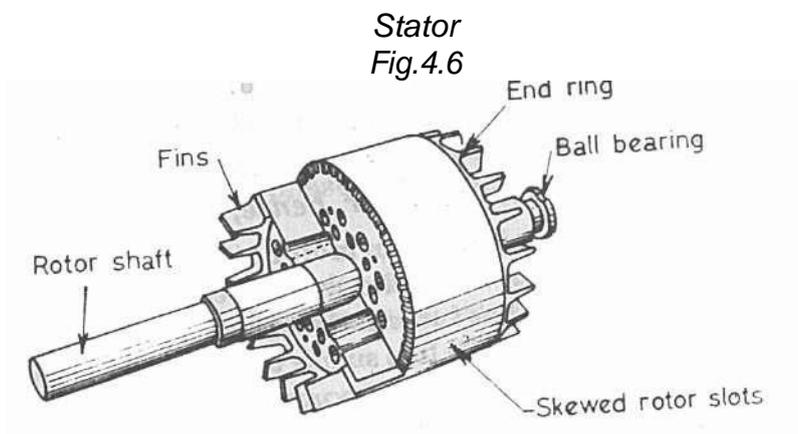
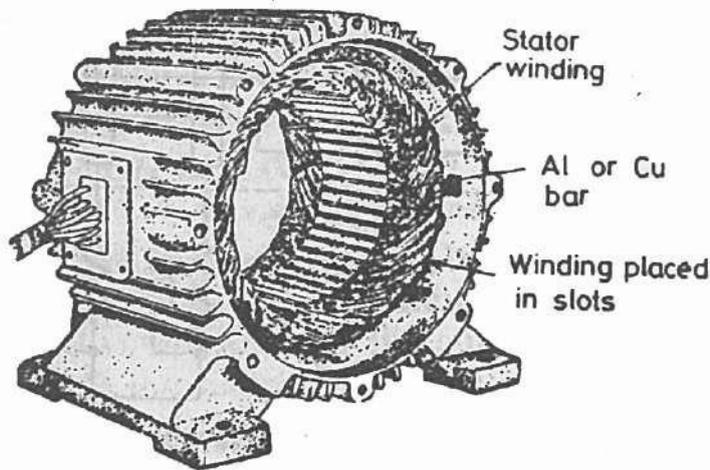
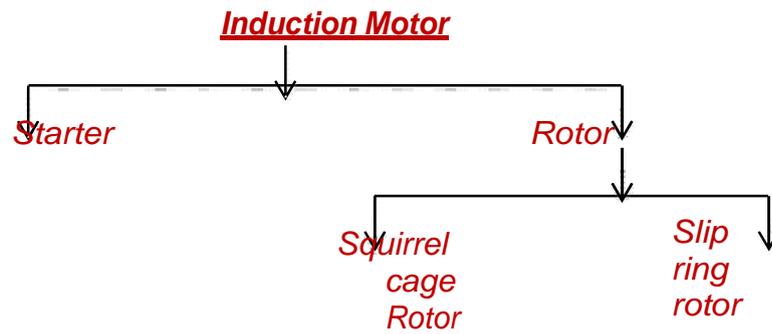
- (1) Split phase motor
- (2) Capacitor start motor
- (3) Capacitor start – Capacitor run single phase Induction Motor.
- (4) Shaded Pole Motor-
- (5) Repulsion Motor

**Uses:**

- (1) **Split phase motor:**
  - (i) Small Pumps
  - (ii) Grinders
- (2) **Capacitor start motor**

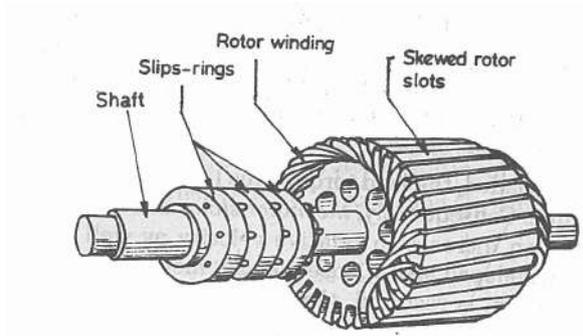
- (i) Compressor
- (ii) Pumps
- (3) **Capacitor start capacitor RunMotor**
  - (i) Compressor of Air-conditioner
  - (ii) Water Cooler
- (4) **Shaded Pole Motor**
  - (i) Small fans
- (5) **Repulsion Motor**
  - (i) Mixing Machine
  - (ii) Blowers

4.13 **Parts of Three – Phase Induction Motor**



Squirrel cage

*Rotor Fig.4.7*



Slip ring Rotor Fig. 4.8

**4.14 Principle of operation of three phase Induction Motor:**

**Induction Motor:**

When the three phase winding of the stator is connected to the three phase supply, then a rotating magnetic field is produced, which rotates round the stator at synchronous speed ( $N_s$ ). This rotating flux passes through the air gap and cuts the rotor conductors (which is stationary). Due to relative velocity between the rotating flux and stationary rotor, emf. induced in the rotor conductors. Since the rotor conductors circuit is closed, so induced emf. produces rotor current.

Due to the interaction of stator flux and rotor flux a torque is produced as the rotor is free, rotor starts rotating.

**4.15 Types of 3-Phase Induction Motor**

According to rotor construction 3-Phase Induction Motor divides into two types.

- (1) Squirrel cage Induction Motor.
- (2) Slip ring Induction Motor.

**Uses:**

**(1) Squirrel Cage Induction Motor**

- (i) Flour Mills
- (ii) Big Pump

**(2) Slip Ring Induction Motor**

- (i) Hoists (ii) Lifts (iii) Driving Shaft

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# WIRING AND POWER BILLING

## CHAPTER – SIX

### 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.

### 5.1 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) Initialcost
- (ii) Durability
- (iii) MechanicalProtection
- (iv) Firesafety
- (v) Appearance
- (vi) Accessibility

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

-

- (i) Cleatwiring
- (ii) Wooden casing and cappingwiring
- (iii) CTS or TRSwiring
- (iv) Lead sheathedwiring
- (v) Conduit PipeWiring

### (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 wiring.*
- (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 two 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 than 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 wire.*

### **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, cannot 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. Otherwise, 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 whereas in concealed conduit wiring the conduit is embedded in the walls and ceilings by placing in the pre-made 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.

## 5.2 Layout of House hold Electrical Wiring (Single Line Diagram)

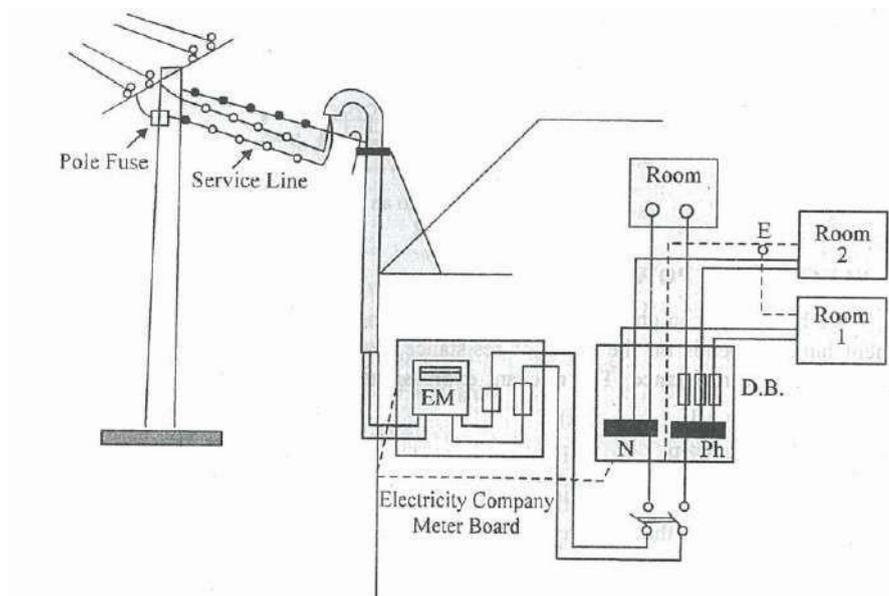


Fig. 5.1

### 5.3 Basic protective Devices used in House hold wiring:

1. Fuse
2. MCB (Miniature CircuitBreaker)
3. Lighteningarrester
4. EarthingWire

### 5.4 ElectricalPower

As we have learnt that power consumed by load depends on the value of resistance, current through the resistance and voltage across the resistance.

$$P = VI$$
$$\Rightarrow P = V^2/R \quad \Rightarrow \quad P = I^2R$$

Thus, 1 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  $I = 8A$ ,  $V = 250V$   
 $P = V, I = 250 \times 8 = 2000W = 2KW$

### 5.5 Power in small ElectricalInstallation

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.  $P = P_1 + P_2 + P_3 + P_4$

$$P = 1000 + (2 \times 100) + (2 \times 60) + 1500$$

$$P = 1000 + 200 + 120 +$$

$$1500 \quad P = 2820 \text{ W} = 2.82$$

KW

### 5.6 Electrical

Energy Energy = Power

$$\times \text{Time } E = P \times t$$

The unit of energy will depend upon the unit of Power and unit of time. When  $P = 1 \text{ watt}$ ,  $t = 1 \text{ Second}$

$$\text{Energy (E)} = 1 \text{ W} \times 1 \text{ S} = 1 \text{ Watt Second} = 1 \text{ Joule}$$

When  $P = 1 \text{ Watt}$ ,  $t = 1 \text{ hour}$

$$\text{Energy} = 1 \text{ Watt} \times 1 \text{ hour} = 1 \text{ Watt.}$$

$$\text{hour } 1 \text{ watt. hour} = 1 \text{ watt} \times (60 \times 60)$$

*Second*

*1 watt hour = 3600 Watt Second = 3600 J = 3.6 X*

*10<sup>3</sup>Joules Similarly for bigger unit 1 Kwhr = 1000 whr.*

So 1 Kwhr =  $1000 \times 3600 = 3.6 \times 10^6$  Joules

1 Kwh is called 1 Unit

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.

Solution (i) Electrical Energy Consumed per day for motor =  $746 \times 5 = 3730$  whr = 3.730 kwhr.

(ii) Electrical Energy Consumed per day by three fans =  $3 \times 80 \times 10 = 2400$  whr = 2.4 Kwhr.

(iii) Electrical Energy Consumed per day by four tube lights =  $4 \times 40 \times 15 = 2400$  whr = 2.4 Kwhr.

Total Energy Consumed =  $3.73 + 2.4 + 2.4 = 8.53$  Kwhr = 8.53 units.

In the month of November total Electrical Energy Consumed =  $8.53 \times 30 = 255.9$  units. Monthly bill =  $255.9 \times \text{Rs.}2.5 = \text{Rs.} 639.75$  P.

## 5.7 Earthing

The process of connecting metallic bodies of all the electrical apparatus and equipment to the huge mass of earth by a wire having negligible resistance is called earthing.

### Necessity of Earthing

- (i) To prevent electrical shock to the human being if the electrical appliance (body) are charged.
- (ii) To prevent risk of fire due to leakage current through un wanted path.
- (iii) To protect large building and machines from lightning by connecting lightning arrester to the general mass of the earth.

### Types of Earthing

There are two types of Earthing (i) Pipe Earthing (ii) Plate Earthing

#### (i) Pipe Earthing

In pipe earthing a galvanized iron (GI) pipe of 38mm diameter, 2m length with 12mm holes drilled at diametrical opposite points is buried vertically in the wet Earth to work as the earth electrode.

If the soil is dry, a larger pipe may be 3m in length is used. The lower part of the pipe is tapered to make the boring easy.

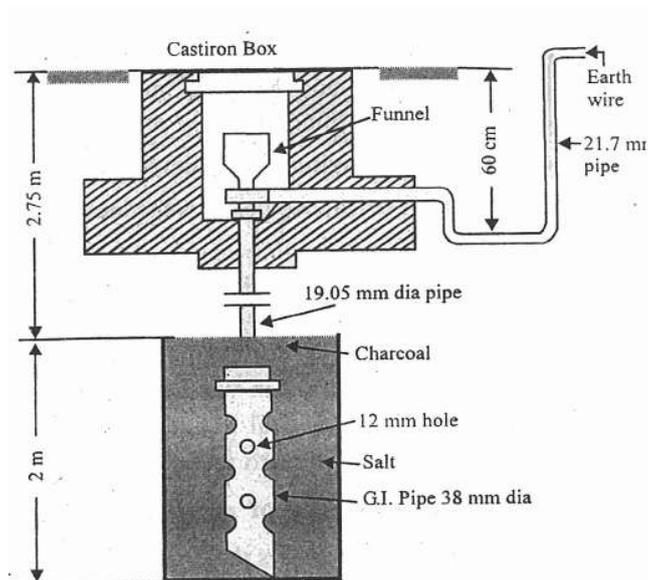


Fig. 5.2

A second narrower GI pipe of about 12mm diameter is fixed over the wider pipe through a reducing socket. A funnel with wire mesh is fixed at the top of the narrower pipe.

Alternate layers of salt and charcoal are filled in the hole around the earth electrode. During summer water may be poured in the funnel to keep the soil wet and to maintain the desired value of earthresistance.

(ii) **PlateEarthing**

In this system of earthing an earthing pit is made in the ground. A copper plate is connected to the earth continuity conductor with nuts and bolts. The size of the plate is about 60cm X 60cm X3.18mm.

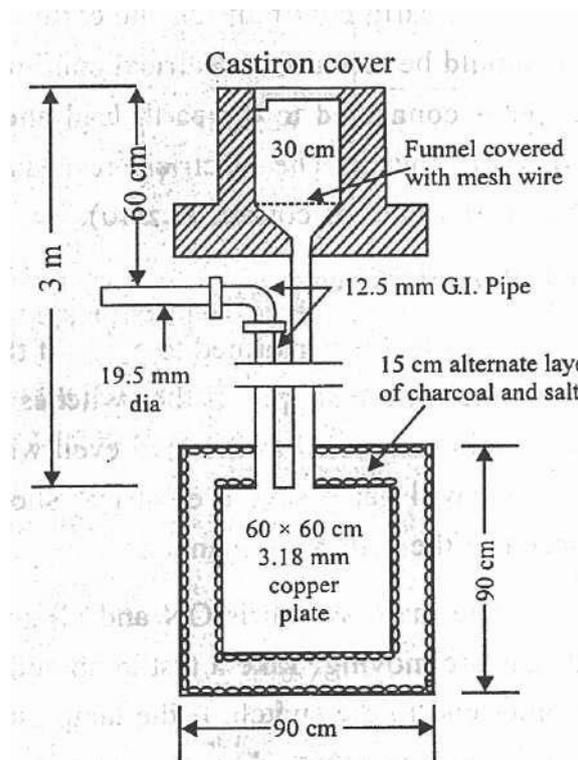


Fig. 5.3

After placing the plate at the bottom of the pit, it is covered with nearly 15cm thick alternate layers of salt and charcoal. Then the bolted earth wire is drawn through GI pipe to the body of the mains switch.

Generally pipe earthing is used for domestic, small commercial building and small workshop using single phase supply. Plate earthings are used for large buildings, big workshops, substations and industry using three phases supply.

.....XXXXX.....

# MEASURING INSTRUMENT

## CHAPTER-SEVEN

### **7.1 Introduction:**

Tests and measurements are important in designing, evaluating, maintaining and servicing electrical circuits and equipment. In order to detect electrical quantities such as current, voltage, resistance or power, it is necessary to transform an electrical quantity or condition into a visible indication. This is done with the aid of instruments (or meters) that indicate the magnitude of quantities either by the position of a pointer moving over a graduated scale (called an analogue instrument) or in the form of a decimal number (called a digital instrument).

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.

Electric measuring instruments and meters are used to indicate directly the value of current, voltage, power or energy. In this lesson, we will consider an electromechanical meter (input is as an electrical signal results mechanical force or torque as an output) that can be connected with additional suitable components in order to act as an ammeter and a voltmeter. The most common analogue instrument or meter is the permanent magnet moving coil instrument and it is used for measuring a dc current or voltage of an electric circuit.

*On the other hand , the indications of alternating current ammeters and voltmeters must represent the RMS values of current, or voltage, respectively, applied to the instrument.*

*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 Galvanometer and Rayleigh'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 Instr**

**uments:**

*Indicating instruments are those which indicate by movement of a pointer over a calibrated scale, the r.m.s value of the electrical quantity under measurement at the time of measurement. For example, voltmeter, ammeter, wattmeter etc. This is shown in Fig. 7.1(a) & (b).*

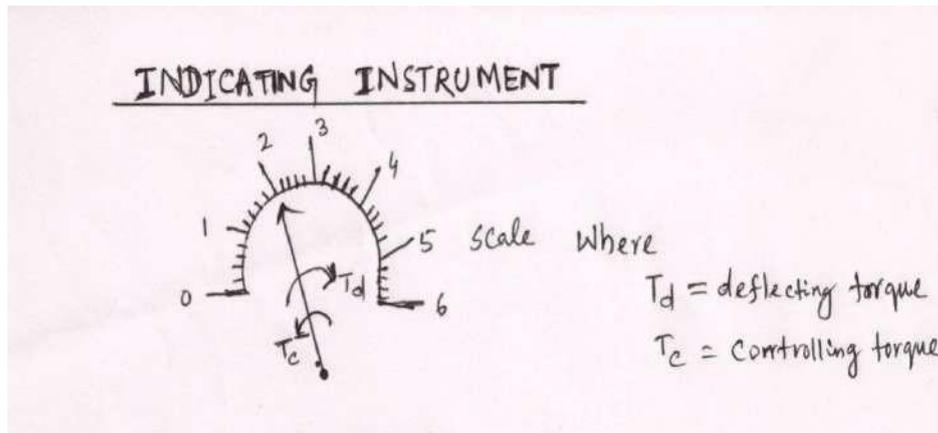


Figure: 7.1(a) Indicating Instrument.

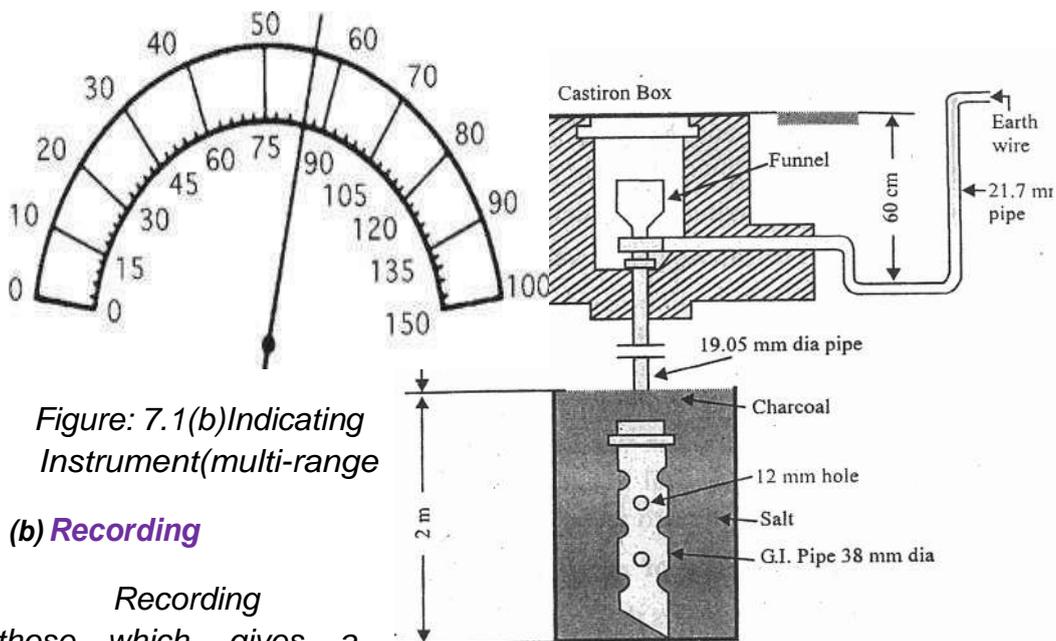


Figure: 7.1(b) Indicating Instrument (multi-range)

**(b) Recording**

Recording those which gives a record of the variation of some electrical quantity (such as current, voltage or power) with respect to time.

A pen attached to the moving system traces a graph on a sheet of paper by revolving drum. Example, a recording wattmeter gives daily and annual load curves. This is shown in Fig.7.1(c).

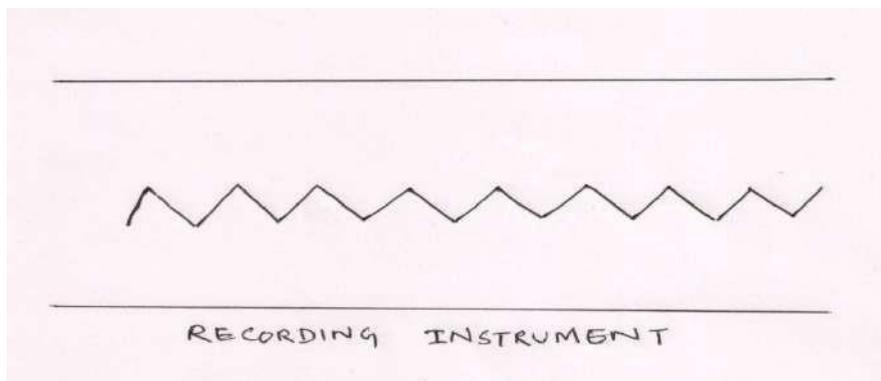


Figure: 7.1(c) Recording Instrument

type)

**Instruments:**

instruments are continuous

### **( c)Integrating Instruments:**

These types of instrument register the amount of energy or quantity of electricity supplied to a circuit over a period of time. Example : Watt-hour meter, Ampere-hourmeter.

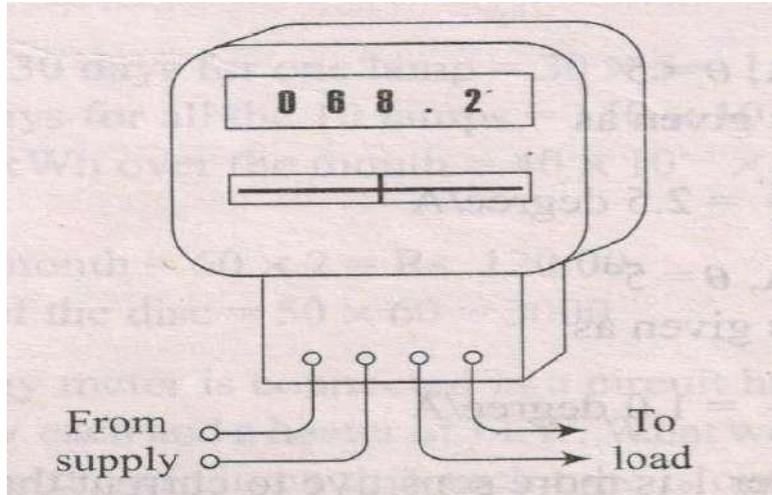


Figure: 7.1(d)Integrating Instrument

### **Analogue instruments**

All analogue electrical indicating instruments require three devices:

**(a) A deflecting or operating device.**

A mechanical force is produced by current or voltage which causes the pointer to deflect from its zero position.

**(b) A controlling device.**

The controlling force acts in opposition to the deflecting force and ensures that the deflection shown on the meter is always the same for a given measured quantity .it also prevents the pointer always going to the maximum deflection. There are two main types of controlling device-spring control and gravitycontrol.

**(c) A damping device :-**

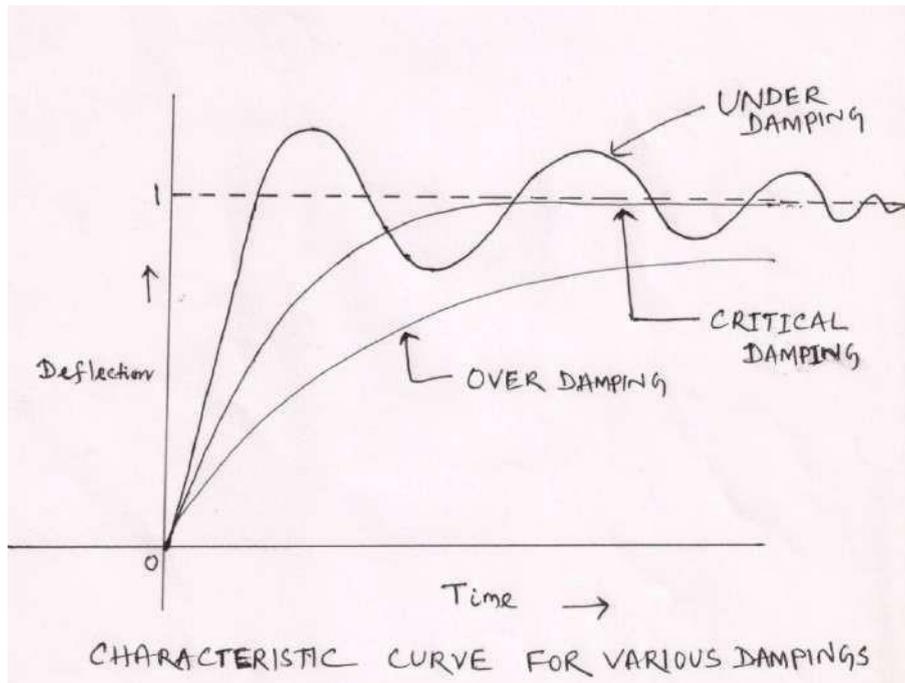


Figure: 7.1(e) Damping Characteristics

The damping force ensures that the pointer comes to rest in its final position quickly and without undue oscillation. There are three main types of damping used :

(i) **Eddy-current damping**:- Aluminum frame when moves in a magnetic field an eddy current emf is produced in the aluminum former. This circulate an eddy current in the former. The eddy current interacts with the magnetic field and produces an opposing torque called an eddy current damping torque. This is shown in Fig.7.1(f).

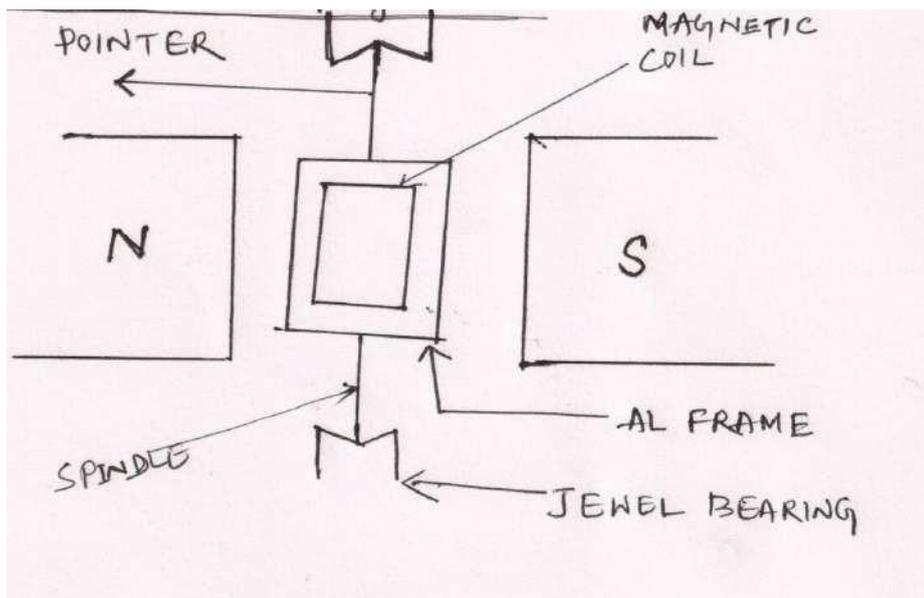


Figure: 7.1(f) Eddy-current damping

**(ii) Air-friction damping:-**

When the pointer moves clockwise, the piston is run out the air chamber and the pressure inside the air chamber decreases. This differential in pressure produces an opposing torque on the moving system. Once the position reaches steady state, the pressure difference becomes zero and the opposing torque becomes zero. This is shown in Fig.7.1(g).

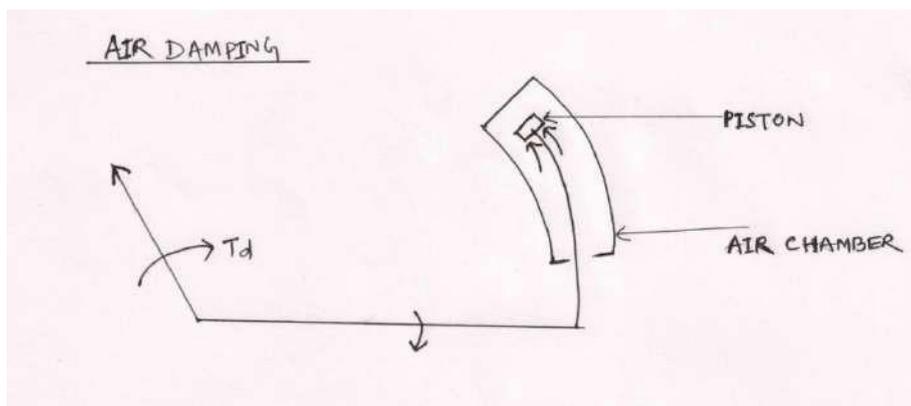


Figure: 7.1(g) Air friction damping

**(i) Fluid –frictiondamping.**

The movement of vanes in a viscous liquid produces damping torque. This arrangement is shown in Fig.7.1(h).

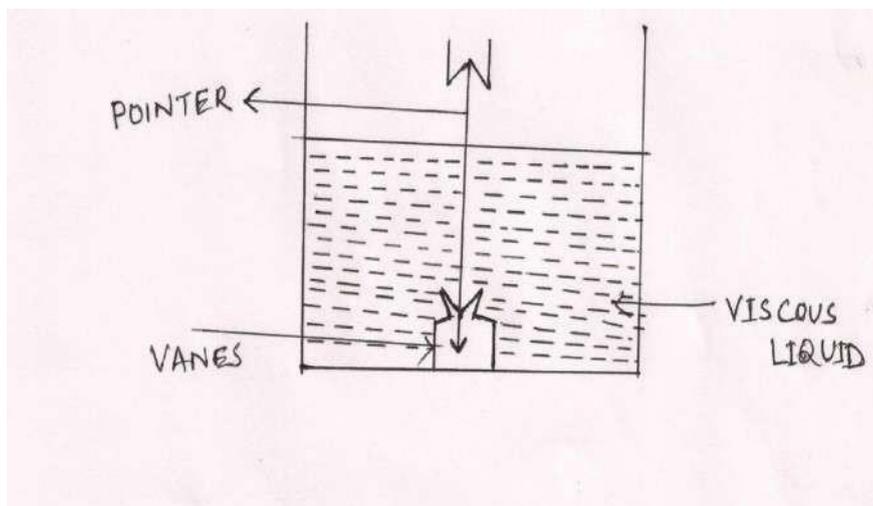


Figure: 7.1(h) Fluid friction damping

There are basically two types of scale –linear andnon-linear.A linear scale is shown in Fig.7.2(a),

Where the divisions or graduations are evenly spaced. The voltmeter shown has a range 0-100V, i.e, a full-scale deflection (f.s.d) of 100V. A non-linear scale is shown in Fig.7.2(b) where the scale is cramped at the beginning and the graduations are uneven throughout the range. The ammeter shown has a (f.s.d.) of 10A.

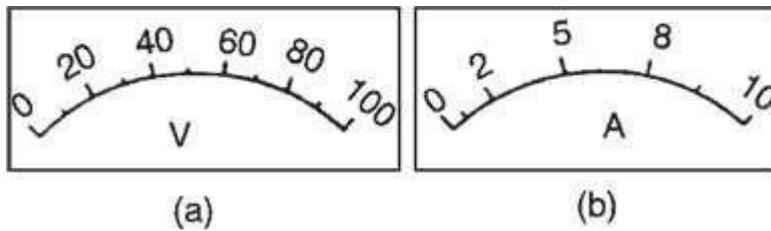


Figure 7.2 (a) Linear scale

7.2(b) Non-linear scale

## 7.2 Torques in instruments:

For operation of an indicating instrument three kinds of torques are required.

These are namely

- (a) Deflecting torque
- (b) Control torque
- (c) Damping torque

(a) Deflecting Torque or (Operating torque) ( $T_d$ ):

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.

(b) Control torque or Restoring torque ( $T_c$ ):

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. (c) Damping torque ( $T_a$ ):

Without damping torque the pointer makes oscillation about the steady state position.

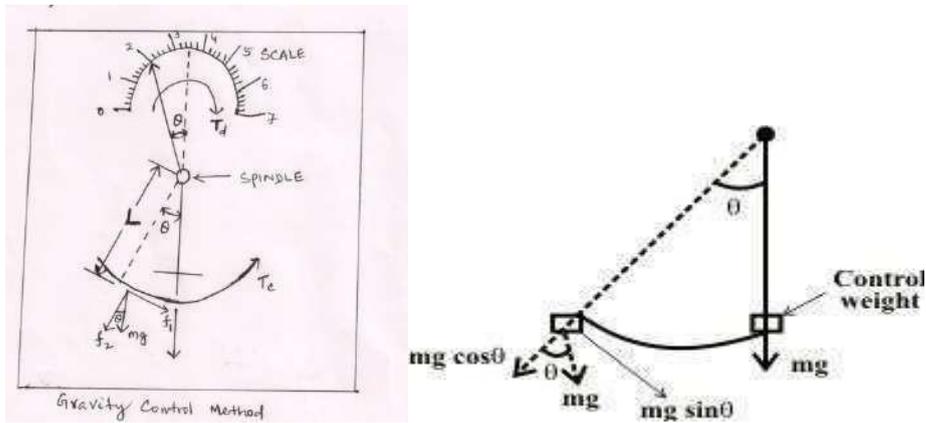
This oscillations are damped out by means of damping torque.

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

**(i) Gravity control method:**



**Figure 7.3.1(a)** gravity control

method Here we have considered  $f_1 = mg$  &  $f_2 = mg$

Here  $f_1$  force causes control torque where as  $f_2$  causes pulling force which balance the spindle. Control torque,  $T_c = \text{length} \times \text{force}$

$$= L \times f_1$$

$$= L mg \sin \theta$$

$$T_c \propto \sin \theta$$

Where mass = 'm', gravitational force = 'g' and 'L' length of the force point Here m, g, & L are taken constant value.

At equilibrium, i.e, for steady deflection,

Deflecting torque = Controlling torque.

If the instrument is gravity controlled, then  $T_c = T_d$

**(ii) Spring control method:-**

$$T_c \propto \theta$$

In spring control method, spring is made of phosphorous bronze and cross-section is a rectangular.

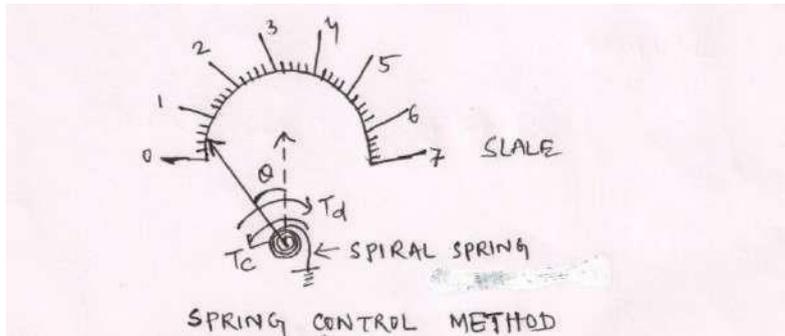


Figure 7.3.1(b) Spring Control Method

**Comparison between gravity control method and spring control method :**

Gravity control method	Spring control method
<ol style="list-style-type: none"> <li>1. It is very cheap</li> <li>2. Varying the constant is very easy.</li> <li>3. No fatigue.</li> <li>4. It can not be used passing through the moving coil.</li> <li>5. Reading is affected by latitude.</li> <li>6. It is not affected by temperature.</li> <li>7. The position of the instrument affects the reading and hence it is used in panel mounting.</li> <li>8. Scale is non uniform.</li> </ol>	<ol style="list-style-type: none"> <li>1. it is very costly.</li> <li>2. varying the constant is difficult.</li> <li>3. it is affected by fatigue.</li> <li>4. it can be used for passing current through the moving coil.</li> <li>5. it is not affected by latitude.</li> <li>6. it is affected by temperature.</li> <li>7. not affected by position and hence used as portable instrument.</li> <li>8. scale is uniform.</li> </ol>

There are different types of instrument used such as

- (1) Permanent Magnet Moving Coil (PMMC) Instrument
  - (2) Moving Iron Instrument (MI)
  - (3) Dynamometer Type Instrument
  - (4) Hot wire Instrument
  - (5) Thermocouple Instrument
  - (6) Single Phase Induction Type Energy Meter
- 7.3 PERMANENT MAGNET MOVING COIL (PMMC) TYPE

**INSTRUMENT: CONSTRUCTION:**

The moving-coil instruments may be dealt with considering a rectangular coil of  $N$  turns, free to rotate about a vertical axis.

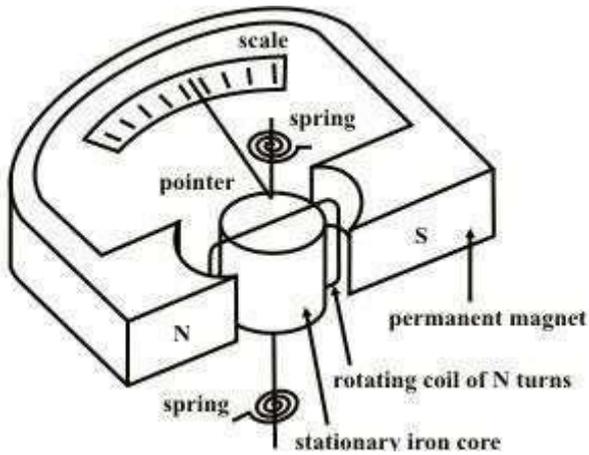


Figure 7.3(a) Permanent Magnet Moving Coil Instrument .

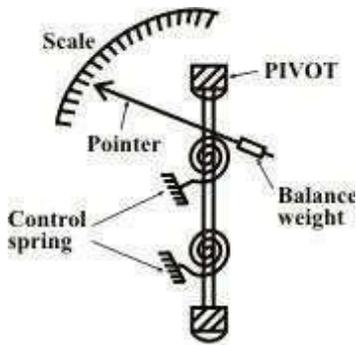


Figure 7.3(b) Spring control ,balance weight arrangement of PMMC instrument.

Figure 7.3(a) shows the construction of a PMMC instrument. A moving coil instrument consists of a permanent magnet to provide a magnetic field and a small light weight coil is wound on a rectangular soft iron core that is free to rotate around its vertical axis. When a current is passed through the coil windings, a torque is developed on the coil by the interaction of the magnetic field and the field set up by the current in the coil. The aluminium pointer attached to rotating coil and the pointer moves around the calibrated scale indicates the deflection of the coil.

To reduce parallax error a mirror is usually placed along with the scale . A balance weight is also attached to the pointer to counteract its weight shown in figure 7.3(b).

The use of hairsprings attached to each end of the coil as shown in Fig.7.3(a) to return the coil to its original position when there is no current through the coil . These hairsprings are not only supplying a restoring torque but also provide an electric connection to the rotating coil. With the use of hairsprings , the coil will return to its initial position when no current is flowing through the coil.

When the developing force between the magnetic fields (from permanent magnet and electromagnet) is exactly equal to the force of the springs, the coil rotation will stop. The coil set up is supported on the jeweled bearings in order to achieve free movement.

An iron core is placed inside the coil to concentrate the magnetic fields. The curved pole faces ensure the turning force on the coil increases as the current increases.

It is assumed that the coil sides are situated in a uniform radial magnetic field of flux density  $B \text{ wb/m}^2$ , let the length of a coil side (within the magnetic field) be  $L$  (meter), the distance from each coil to the axis be  $r$  (meter) and the distance between the two coilsides is  $b$ (meter),  $b=2r$ (meter).

### WORKING PRINCIPLE:

The interaction between the induced field and the field produced by the permanent magnet causes a deflecting torque, which results in rotation of the coil. The spiralspring produces a control torque. The induced currents in a metal former or core on which the coil is wound or in the circuit of the coil itself. As the coil moves in the field of the permanent magnet, eddy currents are set up in the metal former or core. The magnetic field produced by the eddy current opposes the motion of the coil. The pointer will therefore swing move slowly to its proper position and come to rest quickly with very little oscillation. Electromagnetic damping is caused by the induced effects in the moving coils as it rotates in magnetic field, provided the coil forms part of closed electric circuit.

### DEFLECTING TORQUE:

Let  $B$ =Flux density in the air gap ( $\text{wb/m}^2$ )

$I$ =Current flowing through the

coil(Amp)

$N$ =No of turns in the coil depends upon the design.

$L$ =Length of the coil or height of the coil in the magnetic

field(m)  $b=(2r)$  breadth of the coil or width of the coil in

'meter'

$\theta$ =Angle between the plane of magnetic field & current carrying conductor.

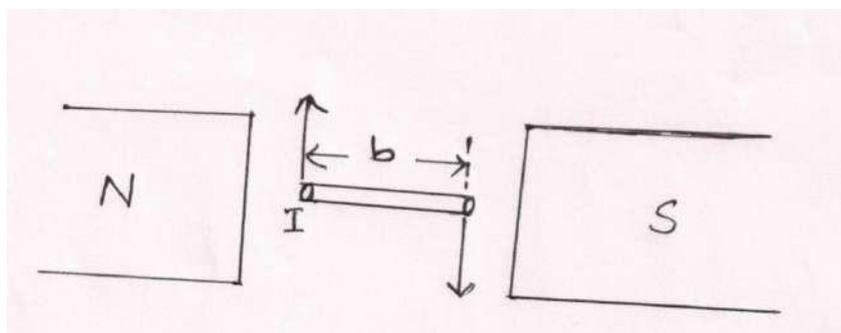


Fig. 7.3(c) Arrangement of conductor inside magnetic field

We know that when current carrying conductor placed in a magnetic field a force is experienced in it.

Force on each conductor is equal to

*BIL. Force on each side of the coil*

$$=BILxN$$

$$=BILN(\text{Newton},N)\text{-----}(7.31)$$

*Torque due to both coil sides= $bxF$*

$$\begin{aligned}
&= (2r)(BILN) \\
&= BILNxb \\
&= BI(Lb)N \\
&= BINA \quad (\text{Newton Meter}) \quad (N-M)
\end{aligned}$$

Where  $A = 2rL = bL = \text{Area, m}^2$

Now deflecting torque,  $T_d = BINA$  .....(7.32)

The above equation (7.32) is valid while the iron core is cylindrical and the air gap between the coil and pole faces of the permanent magnet is uniform. This result flux density  $B$  is constant and the torque is proportional to the coil current and instrument scale is linear.

Now control torque  $T_c = K_s \theta$ , for spring control

Where  $K_s = \text{spring constant}$ .

On  
steadystate,  
Controlling Torque = Deflecting Torque

i.e.,  $K_s \theta = BINA$

$\theta = (BAN/K_s)I$

$\theta \propto I$  .....(7.33)

- Note: (1) The scale is graduated uniformly.  
(2) it can be used only for DC.

**USES OF PMMC TYPE INSTRUMENTS:**

A Multi-range Ammeters and Voltmeters:-

An ammeter is required to measure the current in a circuit and it therefore connected in series with the components carrying the current. If the ammeter resistance is not very much smaller than the load resistance, the load current can be substantially altered by the inclusion of the ammeter in the circuit.

To operate a moving coil instrument around a current level in 50 milliamper range is impractical owing to the bulk and weight of the coil that would be required. So, it is necessary to extend the meter-range shunts (in case of ammeters) and multimeters (in case of voltmeters) are used.

*For higher range ammeters a low resistance made up manganin (low*

*temperature coefficient of resistance ) is connected in parallel to the moving coil as shown in Fig.7.4 and instrument may be calibrated to read directly to the total current.*

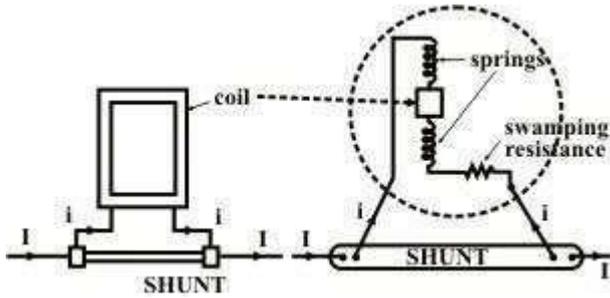


Fig.7.4 Multi-range ammeter circuit.

They are called shunts. The movement of PMMC instrument is not inherently insensitive to temperature, but it may be temperature-compensated by the appropriate use of series and shunt resistors of copper and manganin. Both the magnetic field strength and spring tension decrease with an increase in temperature. On the other side, the coil resistance increases with an increase in temperature. These changes lead to make the pointer read low for a given current with respect to magnetic field strength and coil resistance. Use of manganin resistance (known as swamping resistance which has a temperature coefficient practically zero) in series with the coil resistance can reduce the error due to the variation of resistance of the moving coil. The swamping resistance ( $r$ ) is usually three times that of coil thereby reducing a possible error of, say, 4% to 1%.

A multirange ammeter can be constructed simply by employing several values of shunt resistances, with a rotary switch to select the desired range.

Fig.7.5(a) shows the circuit arrangement.

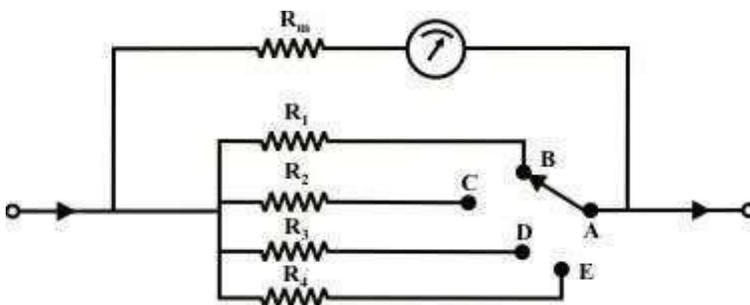


Fig. 7.5(a) Multi-range ammeter circuit.

When an instrument is used in this fashion, care must be taken to ensure that shunt does not become open-circuited, even for a very short instant. When the switch is moved from position 'B' to 'C' or moved any positions, the shunt resistance will remain open-circuited for a fraction of time, resulting in a very large current may flow through the ammeter and damage the instrument. To avoid such a situation, one may use the make-before-break switch as shown in Fig.7.5(b).

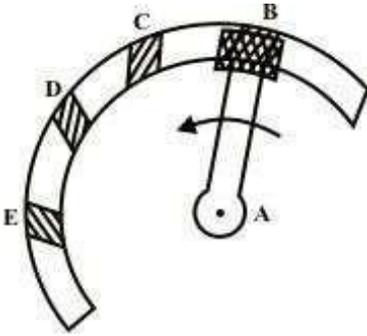


Fig.7.5(b) : Make-before break.

The wide-ended moving contact connected to the next terminal to which it is being moved before it loses contact with the previous terminals. Thus, during the switching time there are two resistances are parallel with the instrument and finally required shunt only will come in parallel to the instrument.

**ProblemNo.1** A PMMC instrument has a coil resistance of  $100\Omega$  and gives a Full-Scale Deflection (FSD) for a current of  $500\mu\text{A}$ . Determine the value of shunt resistance required if the instrument is to be employed as an ammeter with a FSD of  $5\text{A}$ .

Solution:- Taking the current flowing through the shunt is  $I_s$ . Using the following circuit shown in Fig.7.6.

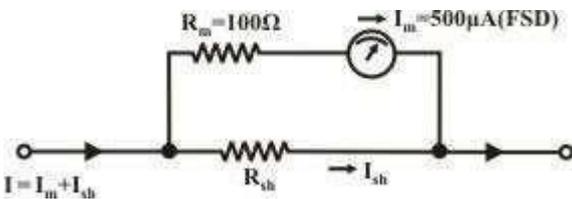


Fig.7.6.

$$I_m = \left( \frac{R_{sh}}{R_{sh} + R_m} \right) I \text{ .....(7.61)}$$

Where  $R_{sh}$  = shunt resistance,  $R_m$  = ammeter resistance =  $100\Omega$

$I_m$  = ammeter full scale deflection current =  $500\text{ A}$  and  $I$  = desired range of ammeter =  $5\text{A}$ .

Since  $I_m = \frac{R_{sh}}{R_{sh} + R_m} I$

or,  $500 \times 10^{-6} = \left( \frac{R_{sh}}{R_{sh} + 100} \right) \times 5$

$\frac{500 \times 10^{-6}}{5} = \frac{R_{sh}}{R_{sh} + 100}$  or,  $R_{sh} = 0.01\Omega$

**Problem No.2** Two PMMC instruments are used to measure the current in two different circuits and their readings are recorded as given below. Find a reason to compare them on the basis of their sensitivity.

Meter 1:  $I=2A, \theta=5^\circ$

Meter 2:  $I=5A, \theta=5^\circ$

Solution: -

For meter,  $I=2A, \theta=5^\circ$

So, the sensitivity is given as

$$K_1 = \theta/I = 5/2 = 2.5 \text{ degree/Amp.}$$

For Meter 2,  $I=5A, \theta=5^\circ$

So, the sensitivity is given as

$$K_2 = \theta/I = 5/5$$

$$= 1.0 \text{ degree/Amp.}$$

Since,  $K_1 > K_2$ , Meter 1 is more sensitive to current than Meter 2.

### APPLICATIONS :--

(1) PMMC IS USED AS AN AMMETER

(a) For low current range:--

Current is responsible for deflection for few millimeter used.

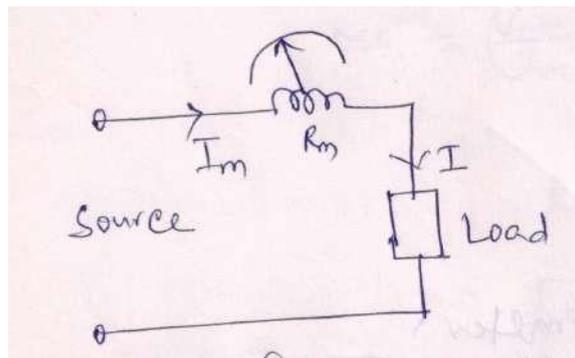


Fig. 7.7(a) PMMC with low current

rating Where  $I$  = measuring current

$I_m$  = meter current

$I_{sh}$  = shunt current

$R_m$  = meter resistance

$R_{sh}$  = shunt resistance.

(b) For high current range:--

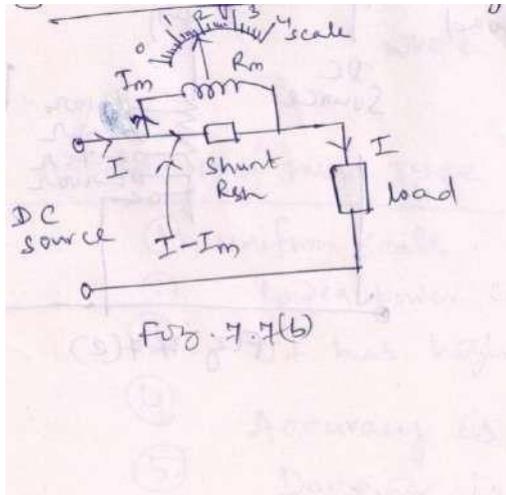


Fig. 7.7(b) PMMC with high current rating

Since  $I_m R_m = (I - I_m) R_{sh}$

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

$$= \frac{I_m R_m}{I/I - 1}$$

Where  $m = I/I_m$

$m$  = multiplication factor.

(c) Multiple range: --

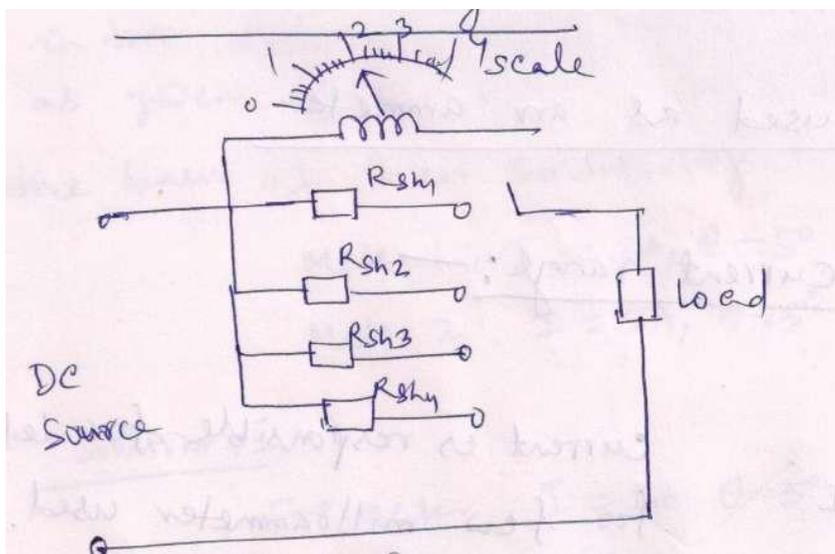


Fig.7.7 (c) PMMC with multiple range

(2) PMMC USED AS VOLTMETER:--

When PMMC is used as voltmeter, a resistance is connected in series with the voltmeter called multiplier.

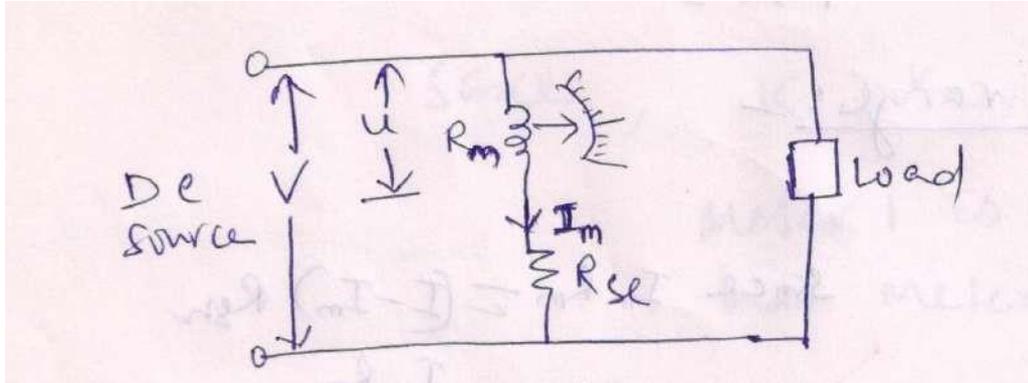


Fig.7.7(d)P

MMC as Voltmeter

Where  $I_m = V / (R_m + R_{se})$

$\theta \propto I_m$

$\propto V / (R_m + R_{se})$

i.e.  $\theta \propto V$

MULTIPLERANGE:--

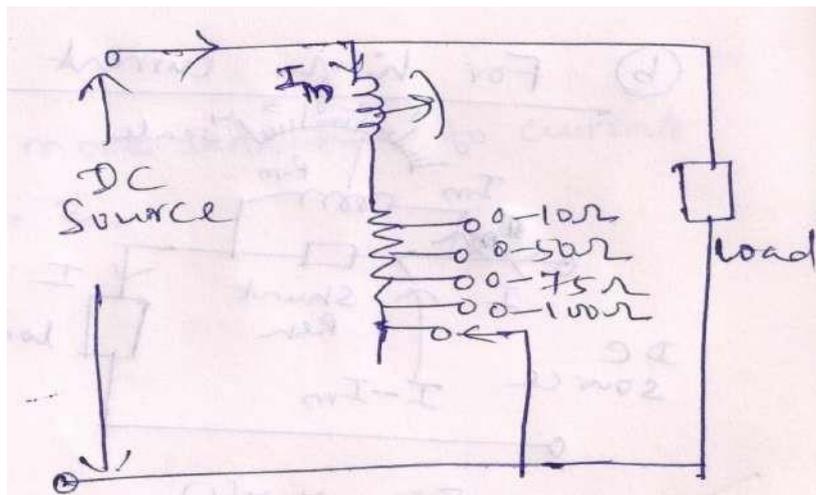


Fig.7.7(e) PMMC as Voltmeter (Multiple range)

$V = I_m R_m + I_m R_{se}$

$$=u+I_{m} R_{se}$$

$$V-u= I_{m} R_{se}$$

$$R_{se}=(V-u)/I_{m}=(V-u)/(u/R_{m})$$

$$R_{se}=(V/u)-1)R_{m}$$

$$R_{se}=(m-1) R_{m}$$

Since  $R_{m}$  and  $R_{se}$  are constant.

Where  $m=V/u$  is called multiplying factor .

### Advantages of PMMC Type Instrument:--

- (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

### Disadvantages:-

- (i) It can measure only DC.
- (ii) It is a delicate instrument.
- (iii) It is costly.
- (iv) Aging problem due to permanent

### 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.

### Error in PMMC Type Instrument:--

- (i) Frictional error
- (ii) Magnetic decay
- (iii) Thermo electric error
- (iv) Temperature error.

Errors can be reduced by following the steps given below:

- (i) Proper pivoting and balancing weight may reduce the frictional error.
- (ii) Suitable aging can reduce the magnetic decay.
- (iii) Use of manganin resistance in series (swamping resistance) can nullify the effect of variation of resistance of the instrument circuit due to temperature variation.
- (iv) The stiffness of spring, permeability of magnetic core (Magnetic core is the core of electromagnet or inductor which is typically made by winding a coil of wire around a ferromagnetic material) decreases with increases in temperature.

### **Ammeter Sensitivity:**

Ammeter sensitivity is determined by the amount of current required by the meter coil to produce full-scale deflection of the pointer. The smaller the amount of current required producing this deflection, the greater the sensitivity of the meter. A meter movement that requires only 100 microamperes for full-scale deflection has a greater sensitivity than a meter movement that requires 1mA for the same deflection.

### **Voltmeter Sensitivity:**

The sensitivity of a voltmeter is given in ohms per volt. It is determined by dividing the sum of the resistance of the meter ( $R_m$ ), plus the series resistance ( $R_{se}$ ), by the full-scale reading in volts. In equation form, sensitivity is expressed as follows:

$$\text{Sensitivity} = (R_m + R_{se}) / E$$

Sensitivity is equal to the reciprocal of the full-scale deflection current. This is expressed as follows:

$$\text{Sensitivity} = \frac{\text{ohms}}{\text{volt}} = \frac{1}{\text{volt/ohms}} = \frac{1}{\text{ampere}}$$

Therefore, the sensitivity of a 100-microampere movement is the reciprocal of 0.0001 ampere, or 10,000 ohms per volt.

$$\text{Sensitivity} = \frac{1}{\text{ampere}} = \frac{1}{0.0001} = 10,000 \text{ ohms per volt.}$$

## **7.4 MOVING IRON (MI) TYPE INSTRUMENTS:-**

The instruments are classified according to the principle of operation. Each class may be subdivided according to the nature of the movable system and method by which the operating torque is produced.

Specifically, the electromagnetic instruments are sub-classes as (i) moving-iron

*instruments*

*,(ii)electro-dynamic or dynamometer instruments, (iii)induction instruments. In this section ,we will discuss briefly the basic principle of moving –iron instruments that are generally used to*

measure alternating voltages and currents. In moving-iron instruments the movable system consists of one or more pieces of specially –shaped soft iron, which are so pivoted as to be acted upon by the magnetic field produced by the current in coil. There are two general types of moving –iron instrumentsnamely

(A )Attraction (or single–iron)type

(B) Repulsion (or doubleiron)type.

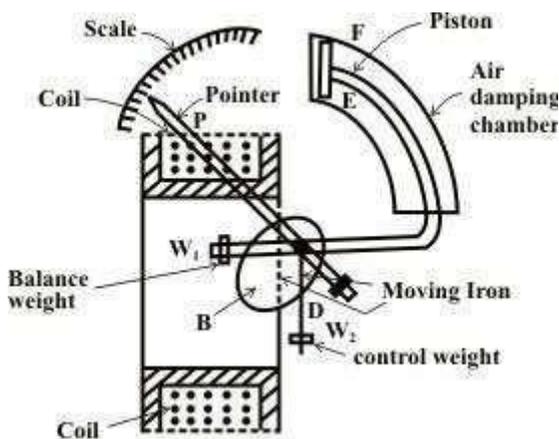
The brief description of different components of a moving-iron instrument is givenbelow.

- (i) **Moving element:** a small piece of soft iron in the form of a vane orrod.
- (ii) **Coil :** to produce the magnetic field due to current flowing through it and also to magnetize the ironpieces.
- (iii) **In repulsion type** , a fixed vane or rod is also used and magnetized with the samepolarity.
- (iv) **Control torque** is provided by spring or weight(gravity).
- (v) **Damping torque** is normally pneumatic , the damping device consisting of an air chamber and a moving vane attached to the instrumentspindle.
- (vi) **Deflecting torque** produces a movement on an aluminum pointer over a graduatedscale.

### (A )ATTRACTION (OR SINGLE-IRON) TYPE INSTRUMENTS:-

#### Construction:

The deflecting torque in any moving –iron instrument is due to forces on small piece of magnetically ‘soft’ iron that is magnetized by a coil carrying the operating current.



**Fig.7.9 Attraction type**

This instrument consists of a few soft iron discs(B) that are fixed to the spindle (D), pivoted in jeweled bearings. The spindle(D) also carries a pointer (P), a balance weight(  $W_1$  ), a controlling weight( $W_2$  ) and a damping piston(E),which moves in a curved fixedcylinder(F).Thespecialshape of the moving-iron discs is for obtaining a scale

*of suitable form.*

**Working Principle:**

When current flows through the coil, it produces a magnetic field along the axis of the coil. The soft iron piece is attracted inside the coil due to magnetic field and produces a deflecting torque. The control weight produces control torque and piston in the air chamber produces a damping torque.

Intensity of the magnetic field along the axis of the coil,  $\propto H I$

The induced magnetic pole strength 'm' is proportional to H & H is also proportional to I.

i.e.,  $H \propto I$

i.e.,  $m \propto H \propto I$

Force of attraction  $F \propto H m$

$\propto I^2$

Deflecting torque  $T_d \propto F \propto I^2$

Control torque  $T_c \propto \sin \theta$  (due to gravity

control) At steady state,

Deflecting torque = Controlling torque

i.e.,  $T_d = T_c$

i.e.,  $I^2 \propto \sin \theta$

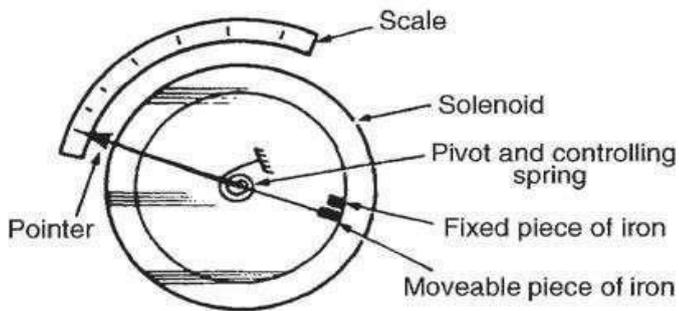
i.e.,  $\sin \theta \propto I^2$ ------(7.41)

**REMARKS:**

- (I) Moving iron instruments having scales that are nonlinear and somewhat crowded in the lower range of calibration.
- (II) The deflecting torque is proportional to the square of the current in the coil, making the instrument reading is a true 'RMS' quantity.
- (III) Used both for AC & DC supply.
- (IV) Used for ammeter and voltmeter.

**(B) REPULSION (OR DOUBLE –IRON) TYPE INSTRUMENTS:**

**Construction:** Two iron pieces one is fixed and other is movable taken inside the influence of the magnetic field. The magnetic field is produced by the bobbin shaped electromagnet. Moving iron is connected to spindle and fixed iron to bobbin. This instrument is shown in Fig. 7.10 below.



**Fig.7.10 Repulsion type instrument.**

**Working principle:**

When current flows through the coil, a magnetic field is produced along the axis of the coil. The two iron pieces are similarly magnetized and a repulsive force is produced between them. This produces a deflecting torque. The control weight produces control torque. The van and air chamber produces damping torque.

Intensity of the magnetic field 'H' is proportional to I  
 Magnetic pole strength on the moving iron  $\propto H \propto I$   
 Magnetic pole strength on the fixed iron  $\propto H \propto I$

Force of the repulsion  $F \propto m_1 m_2$

$$\propto I^2$$

Deflecting torque  $T_d \propto F \propto I^2$

$$T_d \propto I^2$$

Control torque  $T_c \propto \sin \theta$  (due to gravity

control) On steady state,

Controlling torque = Deflecting torque

$$T_c = T_d$$

$$\sin \theta \propto I^2$$

**Remark:**

- (i) Scale is non-uniform.
- (ii) Used for AC as well as DC supply.

(iii) *Also two terminals are available.*

(iv) Used for measurement of voltage, current and for multiple ranges.

### ADVANTAGES OF MOVING IRON INSTRUMENT:--

- (1) It is very cheap.
- (2) It can be used both for AC and DC measurement.
- (3) The instruments are robust, owing to the simple construction of the moving parts.
- (4) The stationary parts of the instruments are also simple.
- (5) Torque/weight ratio is high, thus less frictional error.

### DISADVANTAGES OF MOVING IRON INSTRUMENT:-

- (1) The scale is non-uniform.
- (2) Accuracy is moderate.
- (3) If gravity control is used then it is used for particular position.
- (4) It has hysteresis, eddy current and stray magnetic field error.

### ERRORS:

- (1) Error due to temperature variation.
- (2) Errors due to friction is quite small as torque-weight ratio is high in moving-iron instruments.
- (3) Stray fields cause relatively low values of magnetizing force produced by the coil. Efficient magnetic screening is essential to reduce this effect.
- (4) Error due to variation of frequency causes change of reactance of the coil and also changes the eddy currents induced in neighboring metal.
- (5) Deflecting torque is not exactly proportional to the square of the current due to non-linear characteristics of iron material.

### Problem No.3 :

The deflecting torque of an ammeter is directly proportional to current passing through it and the instrument has full scale deflection of  $70^\circ$  for a current of 10A. What deflection will occur for a current of 5A when the instrument is (a) spring control & (b) gravity control.

### Solution:-

$$(a) T_c \propto I, \quad 10A \rightarrow 70^\circ \\ 5A \rightarrow \theta = ?$$

$$T_c \propto \theta$$

$$\theta \propto I$$

$$70^\circ \propto 10$$

$$\theta \propto 5$$

$$\frac{70}{10} = \frac{\theta}{5}$$

$$\text{Or, } \theta = \frac{70}{2}$$

$$\theta = 35^\circ$$

$$(b) T_c \propto l$$

$$T_c \propto \sin \theta$$

$$\sin \theta \propto l$$

$$\sin 70 \propto 10$$

$$\sin \theta \propto 5$$

$$\frac{\sin \theta}{\sin 70} = \frac{5}{10}$$

$$\sin \theta = \frac{5}{10} \times \sin 70$$

$$= \frac{\sin 70}{2}$$

$$\theta = \sin^{-1} \frac{\sin 70}{2}$$

$$= \sin^{-1} \frac{1}{2} \sin 70$$

$$= 28.2^\circ$$

#### Problem No.4:

A moving coil ammeter has spring giving a control constant  $0.3 \times 10^{-6} \text{ Nm/degree}$ . If the deflecting torque on the instrument is  $28.8 \times 10^{-6} \text{ Nm}$ . Find the angular deflection of the pointer.

Solution:

$$K_c = 0.3 \times 10^{-6} \text{ Nm/degree}$$

$$T_c = 28.8 \times 10^{-6} \text{ Nm}$$

At steady state,

Deflecting torque = controlling

$$\text{torque i.e. } T_c =$$

$$\text{or, } 28.8 \times 10^{-6} = 0.3 \times 10^{-6} \times \theta$$

Now

$$\text{Angular deflection } \theta = 96^\circ$$

$$28.8 \times 10^{-6} / 0.3 \times 10^{-6}$$

#### Problem No.5:

A weight of 5g is used as a controlling weight in gravity controlled instrument. Find its distance from spindle if the deflecting torque corresponding to a deflection of  $60^\circ$  is  $1.13 \times 10^{-3} \text{ Nm}$ .

Solution:-

$$m = 5g = 5 \times 10^{-3} \text{ kg}$$

$$g = 9.81 \text{ N/m}^2$$

$$\theta = 60^\circ, T_d = 1.13 \times 10^{-3} \text{ Nm}$$

By gravity control,  $T_d = mg \sin \theta \times d$

$$d = \frac{T_d}{mg \sin \theta}$$

$$= \frac{1.13 \times 10^{-3}}{5 \times 10^{-3} \times 9.81 \times \sin 60}$$

$$= 0.0266 \text{ m}$$

$$= 26.6 \text{ mm}$$

### Assignments:--

A1. sketch the circuit of an electro-mechanical ammeter, and briefly explain its operation.

Comment on the resistance of an ammeter.

A2. Fig.7.12 shows a PMMC instrument has a coil resistance of  $200 \Omega$  and gives a FSD (full-scale-deflection) for a current  $200 \mu\text{A}$ . calculate the value of shunt resistance required to convert the instrument into a  $500 \text{ mA}$  ammeter. (Ans.  $0.08 \Omega$ )

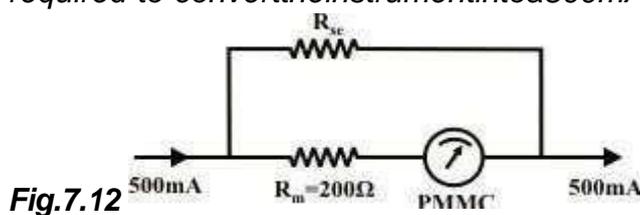


Fig.7.12

## 7.5 Integrating type instrument

### 7.5.1 Energy meter (1-φ type):

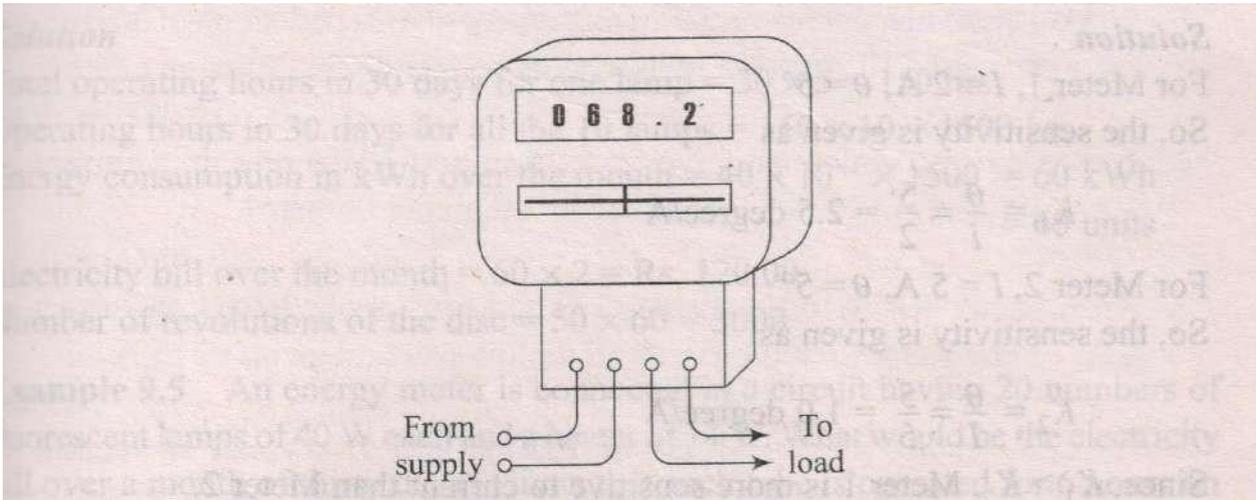


Fig. 7.5.1 External view of an energy meter

meter Workdone ,  $W = Pt$  wattsec. Or joule.....(1)

$$\text{Energy} \int N dt = \int VI = \int eBdI dt \dots\dots\dots(2)$$

Where  $N$  = speed of revolution in rpm

### 7.5.2 Wattmeter (Dynamometer type)

Dynamometer type wattmeters are suitable for measurement of power in DC as well as AC circuits.

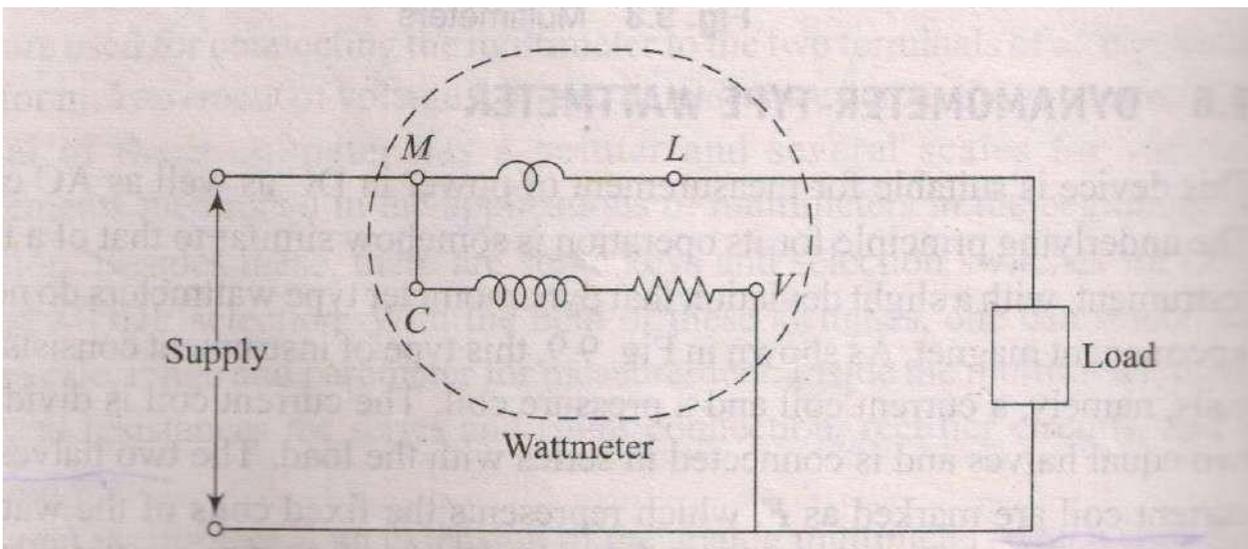


Fig. 7.5.2(a) Circuit diagram of a dynamometer type wattmeter.

*Here*

M=Main Terminal

L=load or line

terminal C=Common

terminal V=Potential

Terminal

Wattmeter has two types of coils. In the figure the coil between terminal M & L represents the **Current coil (CC)** and the coil between the terminal C & V represents **Pressure Coil (PC)**

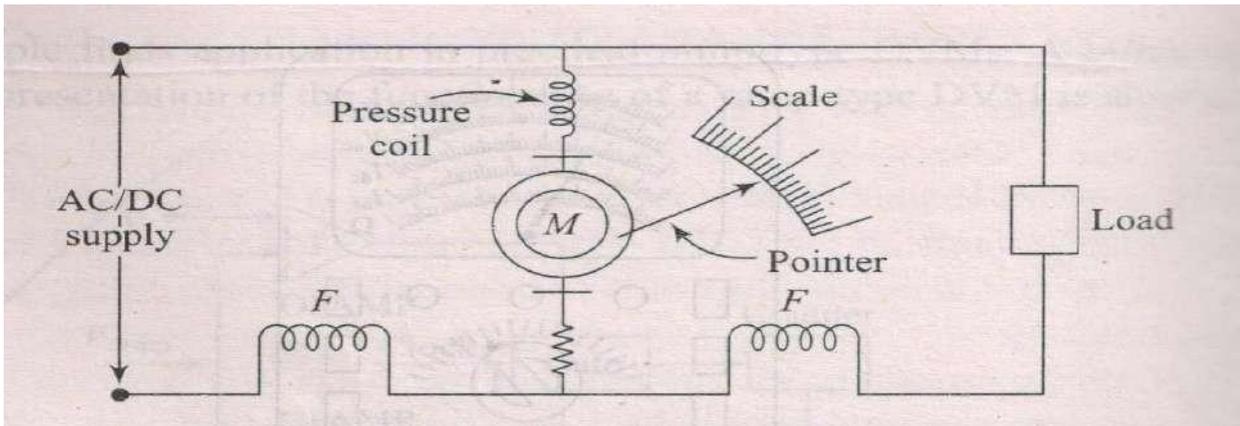


Fig. 7.5.2(b) Schematic of dynamometer type wattmeter

Here

F=Current

coil

M=Moving coil

### 7.5.3. Ammeter

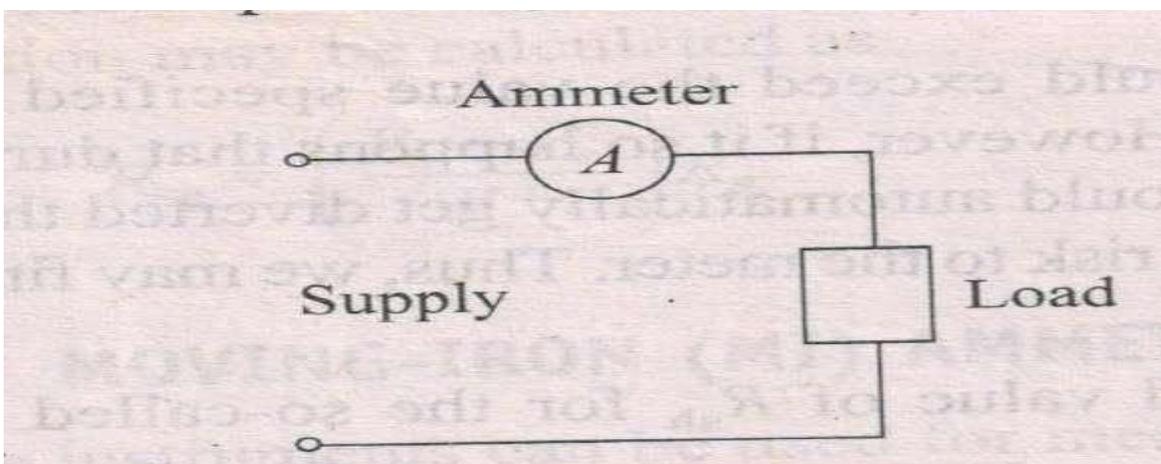


Fig. 7.5.3(a) Ammeter connection

**Ammeter Design:** While designing the PMMC instruments to be used as ammeters the coil should have the least resistance(thick coils with less turns) such that the instrument being connected in series with the load does not affect the load current much.

## 7.5.4. Voltmeter

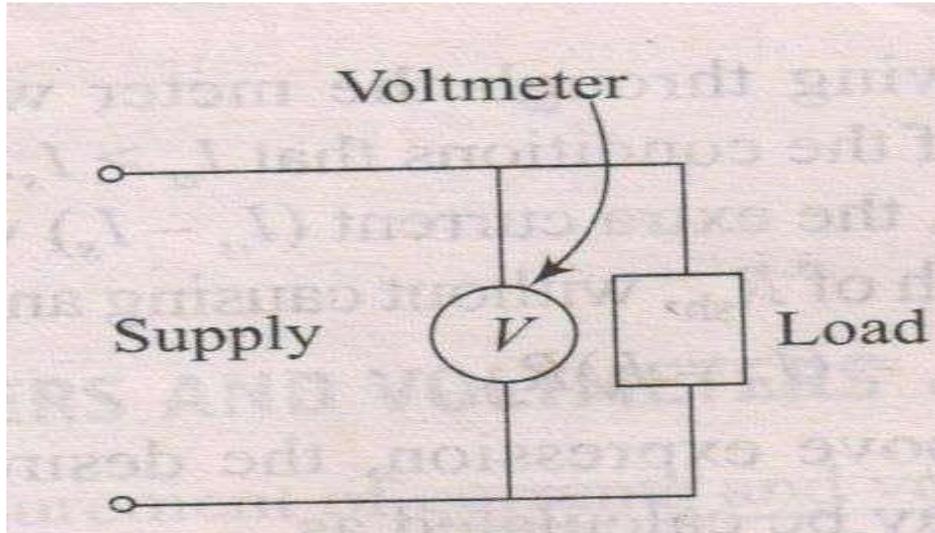


Fig. 7.5.4. Circuit diagram for voltmeter

*Voltmeter design:*

*PMMC instruments meant to be used as voltmeters should have coils with very high value of resistance (thin coils with more turns) such that it becomes capable to sustain the pressure of the applied potential and takes a current as small as possible without affecting much of the load current when connected parallel across load.*

*So Voltmeter should be connected in parallel to the load.*

.....XXXXXXXXXX.....

RENEWABLE

ENERGY

CHAPTER-EIGHT

### 8.1 (A) SOLARENERGY:-

*This is non-conventional energy source. On this planet, human life and all other forms of life are completely dependent on the daily flow of solar energy. The production of food and all other-life support systems of the natural environment are dependent on the sun.*

*Solar energy travels in small particles called photons. Converting even a part of the solar energy at even a very low efficiency can result in a far more energy that could conceivably be harnessed or utilised for power generation.*

*The amount of solar energy is expressed in solar constant. The solar constant is the total energy that falls on a unit area exposed normally to the rays of the sun, at the average sun-earth distance.*

*The most accepted value of solar constant is  $1.353\text{kW}/\text{m}^2$ . A number of scattering and absorption processes in the atmosphere reduce the maximum heat flux reaching the earth's surface to around  $1\text{kW}/\text{m}^2$ .*

*The heat flux reaches earth's surface by two modes:*

- (i) Direct*
- (ii) Diffuse*

*It is the only direct heat energy which can be collected through a 'collector'. The ratio of direct to total heat energy varies from place to place and depends on atmospheric conditions like dust, smoke, water vapour and other suspended matter. The ratio varies between 0.64 and 0.88 according to different investigators.*

Since the altitude of the sun and length of day vary with the season, the solar energy received on a summer day is many times the energy received on a winter day. As a result the total energy for most of the area in plains in India is around  $6000\text{MJ/m}^2$  per year.

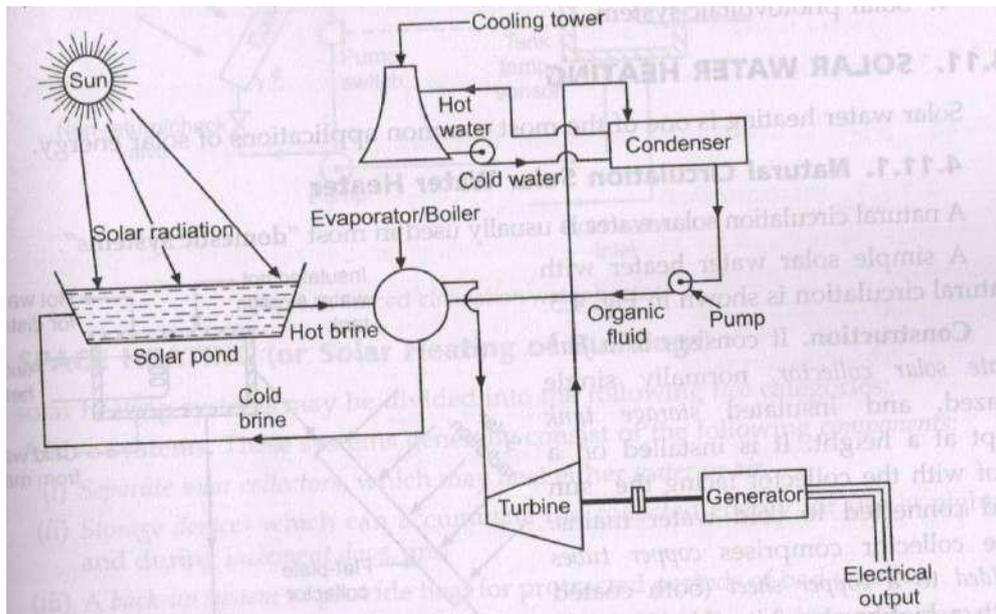


Fig. 8.1. Solar pond electric power plant

#### Advantages:-

- (i) It is a renewable source of energy.
- (ii) It is free of cost.
- (iii) Non-polluting source of energy.

#### Disadvantages:-

- (i) Low efficiency.
- (ii) It is of intermittent type in nature, so for night hours this energy is not available, and as such, storage is required.

#### Impact on Environment:-

- (i) Solar thermal system may pose a health hazard because of the careless disposal of the heat transfer fluids. (e.g., glycol nitrates and sulphates; CFCs and aromatic alcohols) used.
- (ii) Solar photovoltaic modules pose disposal problems owing to the presence of arsenic and cadmium.
- (iii) The total system comprising solar power generator with accessories contain several pollutants.
- (iv) Solar reflectors cause hazard to eyesight.

## 8.1(B) WIND ENERGY:-

*The difference in incidence of solar radiation on earth surfaces causes variation in heat and thereby the heating –up of surrounding air. The air in the hot region of the earth expands faster and builds up high pressure and similarly the air at the less-hot region produce low pressure. This situation of pressure gradient causes movement of air from high pressure region to the low pressure area and this phenomenon is known as ‘wind’. The formation of winds are continuous as the hot air on the earth tends to move upwards allowing cold air to reach the surface of earth determines the ‘wind direction’. Wind possesses kinetic energy and this is to an extent of about 2% of the solar energy incident on the earth.*

*Wind power was harnessed since early times for useful purposes such as driving and directing small vessels over rivers, pumping the water from wells, grinding the paddy in the fields and cutting the wood through levered /gearing saws in rural areas in India , Egypt and European countries.*

*However the industrial revolution in Europe facilitated the discovery of generating electricity from the wind power since the year 1925. Thousands of devices known as ‘wind mills’ came into operation in Germany, Switzerland, Denmark, England and Holland since then.*

*A distinction between ‘wind power’ and ‘wind energy’ has to be made at this stage. Wind power is actually the ability of the available wind to do work (which may be much more) and wind energy is the measure of actual work done (which is partial) when any wind-powered device is operated. Wind power is thus expressed in terms of electrical power. Watts per square meters of air drift. Thus the available wind power at many locations in western countries has been established and some important conclusions drawn. A location where wind power shows lower than 100watts per square meter is unsuitable. Areas with available power of 100 to 200 watts per square meter fall under moderate zones and those exceeding 200watts per square meters are considered the best locations.*

*Again , these parameters are to be integrated to the wind speeds at the region and final assessment made. It has been experimentally established that the wind power generated is proportional to the air density, the area that is swept out by the wind device (i.e., the blade length) and the cube of the speed of the prevailing wind. The natural winds moving at higher speeds therefore produces greater energy as compared to winds of lower speeds, the result being eight fold. One empirical generalisation drawn from these studies is that a minimum wind speed of 16km per hour is required for establishing an effective wind mill at any location .*

*The kinetic energy of the wind is partly converted into the mechanical energy of the rotor (to an extent of about 60%) which in turn transforms into electric power (to an overall 30-40%).*

## WIND ROSE:-

A 'WIND ROSE' is a pictorial design on board that depicts the information on wind direction , speed and prevalence of calm conditions over a specified zone during a particular season or the whole year shown in Fig.8.2

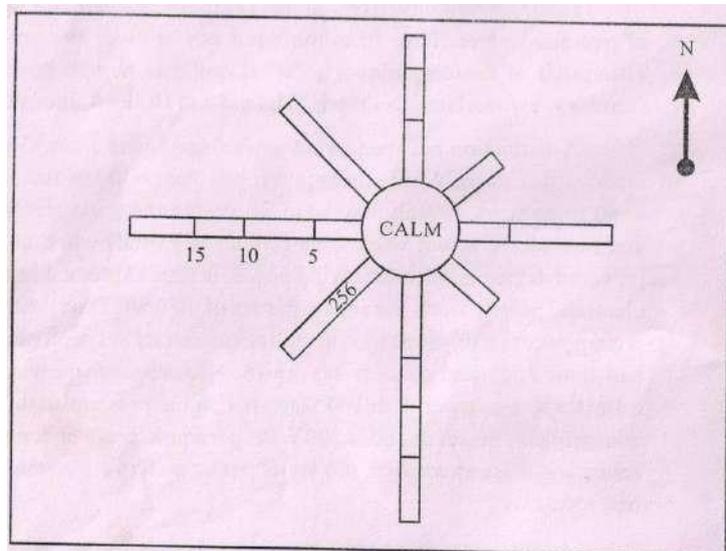


Fig.8.2. Wind Rose

The basic data needed for drawing the wind rose is obtainable from the local meteorological stations. Once the wind rose digram is drawn , it is possible to interpret the atomspheric pollution and weather data ,or selecting sites to install wind mills or any other type of activity.

## METHOD:-

The diurnal wind speed, direction data at a selected site 'x' is collected for a period of at least five years. An eight directional cycle wheel is drawn and the directions, namely N, S, E , W,SW,NW,NE and SE are marked as the arms. The different values of wind speed are segregated under the categories 0-5mph, 5-10,10-20,20-25, and so on for the entire five year period. Now, each of the arms showing the direction scaled in linear fashion as 0,5,10,15,20,and 25 and a box is created against each of the category. At the centre of the wheel a circular box is drawn.

The figures written within the boxes indicate the number of occasions on which a wind of that particular direction has attained that specified speed. All occasions when the wind speed values shown were less than 5, irrespective of the direction, were pooled together and placed in the central circle, which depicts 'clam' condition . a wind rose drawn inthis fashion offers at aglance,the nature of the wind in the area for years to come and will be a guideline for establishing a wind mill.

## **WIND MILL:-**

The system which harnesses the speedy wind into electricity is known as 'wind mill'. Wind mills work very efficiently at uninterrupted locations, generally at the tip of mountains or on high towers. Some of the general guidelines for siting the wind mills are discussed here.

The first step is to gather meteorological data pertaining to wind speed and direction at the location of interest. This is usually obtained from the nearest weather station. Seasonal 'wind roses' are then drawn for ready reference. This will help in deciding whether the requisite wind potential exists at the location. If the wind pattern, i.e., wind speed and direction are apt for construction of wind mill at the site, further preparations are made. Generally the tower of the mill is raised at a location which is at least 30 feet higher than the nearest obstacle situated in a 300 feet radial zone. Places where tall trees or buildings are situated in the neighborhood are avoided. Hill tops where the turbulences are minimum are more convenient than the slopes. A reasonable height of 60-80 feet has to be the tower elevation.

Topographical elements such as hills, trees, valleys and water sources which are in the direction of the wind influence the speed. The properties of sea winds and mountain winds are also to be taken into account while siting a wind mill.

## **WIND MILL COMPONENTS:-**

The three structural components of a wind mill are :

- (1) The Tower,
- (2) The Rotor,
- (3) The Generator

A description of various types of three systems and their functions has been made in the following paragraphs.

### **The Tower:-**

The tower gives a good show of the wind mill. It is grouted on the earth firmly, generally over an area of approximately one fifth of the tower height. A 80 feet high tower should normally be grouted in a floor area of 16 square feet in the earth. Steel is the material of construction of the tower. Soft metals should not be used in the fabrication of towers. Towers have to be robust to withstand the speedy winds, bear the load of rotor and ancillary machinery. It should be vibration – proof and with stand shocks. It should regulate the turbulence of wind also. Never a tower should be positioned on the roof tops of buildings. Towers have to be painted with corrosion resistant paints and maintained in good condition.

In figure 8.2 are shown three types of tower which are in present day use. These are

- (i) Pole Tower

(ii) *Lattice  
Tower*  
(iii) *GuyedTower*

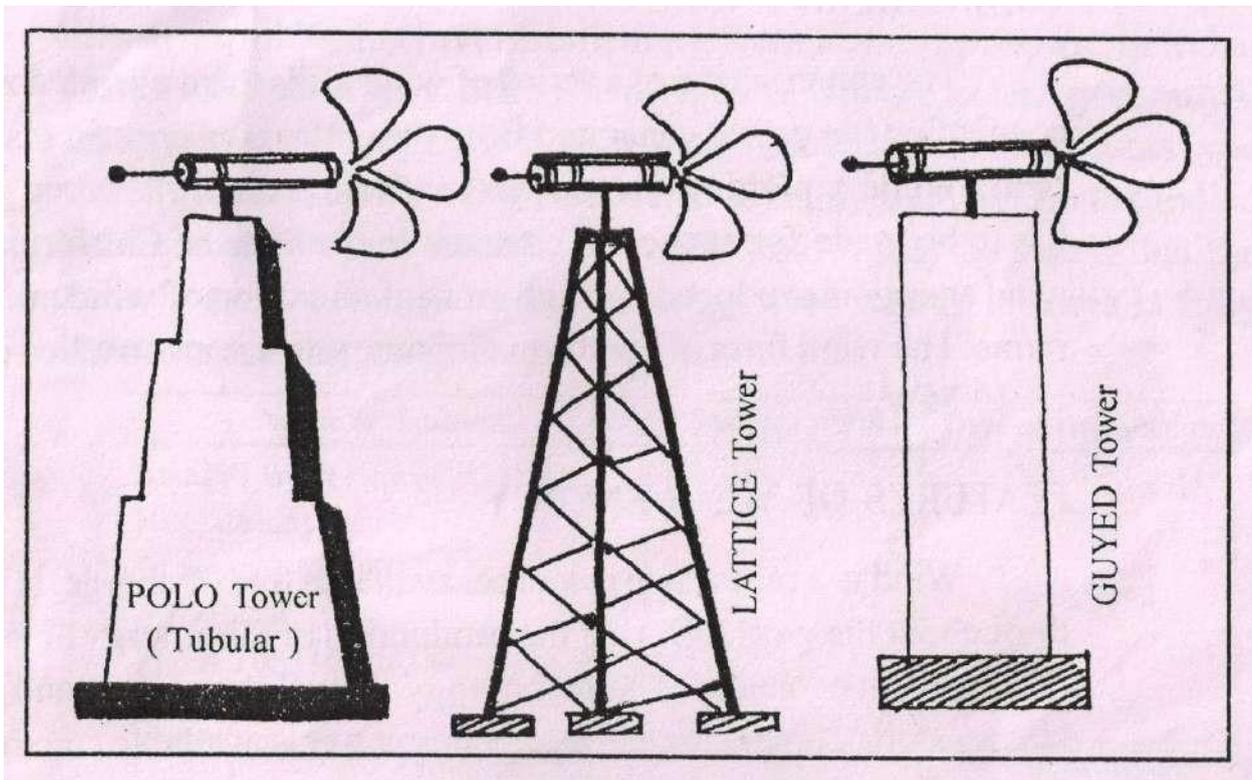


Fig.8.3 Wind mill Towers

### **The Rotor:-**

The rotor is an important system in the wind mill. It actually determines the quantum of prospective energy that an optimum speed to generate maximum power. A rotor consists of blades arranged in a radial manner. The blades are set at a slight angle in the wind direction to facilitate fast rotation.

Usually the outer tip of the blade attains five times greater speed than the actual wind, and fans a lot of air for causing rotation. It means that if the wind speed is 12 mph the rotational tip speed of the blade is 60 mph. The rotor tip speed ratio is thus the ratio of tip blade speed to actual wind speed. It is observed that a rotor tip speed ratio of 5-8 affords uniform and reasonable power generation. Further, the rpm of the rotor is dependent on the length of the blade, the longer the blade the lesser the rpm it makes. The power output from a large blade rotor is considerably greater as compared to a small blade-constituted rotor. Power output is proportional to the square of the length of the blade. Rotor blades are made up of stainless steel, FRP, steel, wood, aluminium and other light alloys, the criteria being light and sturdy.

The arrangement of blades of a rotor in space is generally in two forms,

- (i) Horizontal axis and
- (ii) Vertical axis.

When the axle (shaft) of the rotor carrying the blades is in a parallel position to the horizon, the system is called "horizontal axis" type.

If the axle is in vertical position to the horizon, it is known as 'vertical axis' type. These forms of rotor positions are shown in Fig. 8.3.

Most of the wind mill rotors are designed to work at wind speeds between 8-40mph. sometimes overspeedings of rotor takes place and this will spoil the turbine. Also , it is not possible to predict the impacts of weather at short notice. Therefore adequate automatic controls are incorporated in the rotor systems to orient in such a manner as to avoid the greater wind speeds . These are achieved following the techniques such as :

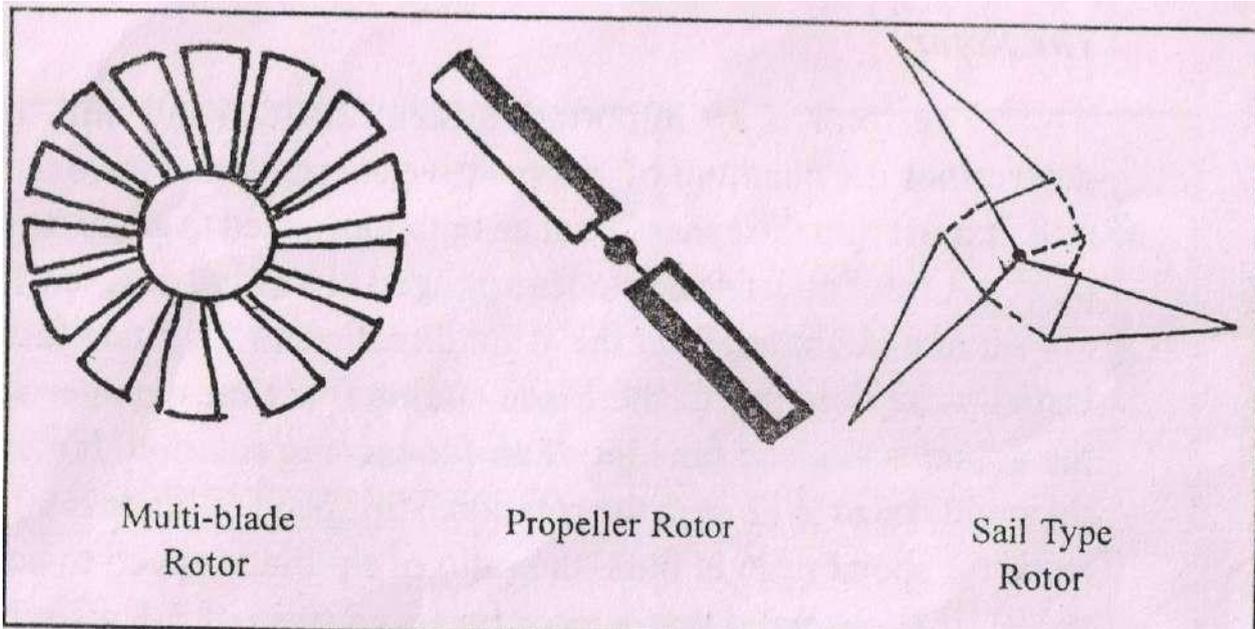


Fig.8.4 Wind mill rotors

- (i) Variable axis control-turning the rotor side ways or upwards away from thewind.
- (ii) Coning speed control-wherein the blades are actually made to bend in cone form due to wind.
- (iii) Spoiler flaps –by ejecting flap that slows down and acts asabrake.
- (iv) Blade pitch control –by the action of weights that change the pitch of therotor.
- (v) Brakes-by mechanicalmeans.

Both horizontal axis type and vertical axis type rotors have reasonable aerodynamic stability while functioning with the adequate fittings.

### The Generator :-

Wind power can be used to generate either DC or AC electricity through the operation of suitable generators. The principle of operation of a DC generator is as follows:

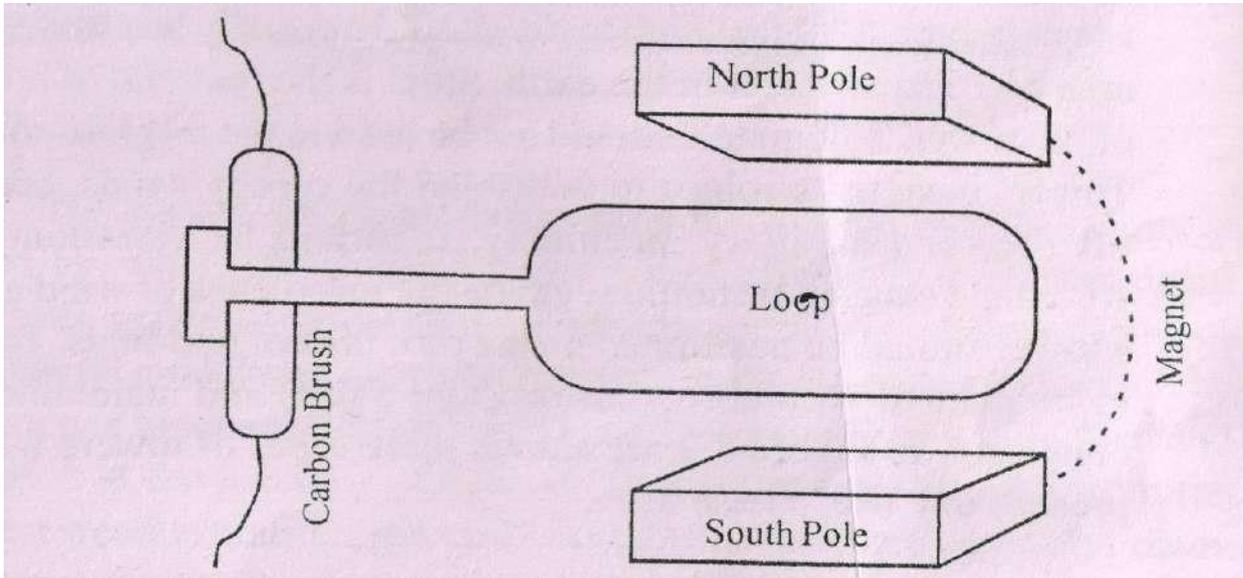
A coil of wire rotates between the north and south poles of a magnet. The coil gets inducted with electric current and it is regulated at the end of the coil in a commutator segment to flow in a single dirction. The design of an AC generator is similar to the DC generator except that the commutator segment at the end of coil is changed by copper rings, called 'slip rings'.

In practice, an ac generator has the armature (coil, i.e., stator) fixed and the field poles

*(rotor) rotated. Theac current is generated when the coil is kept in perpendicular position to the field of the*

magnet and as rotation occurs, current changes direction with each cycle. In Fig.8.4. are shown the components of a dc generator.

**WIND FARM:-**



Fi

g 8.5 Line drawing of a DC generator(moved by wind)

The construction of a series of wind mills in an elevated zone and connecting the power generated from the entire area constitutes a 'wind farm'. While exploiting this non-conventional energy, this group planning has to be made for economic reasons.

In the state of California, USA, wind energy is produced through an agglomeration of wind mills of the farms. The wind farm at Lamba in Gujarat state has an installed capacity of 10MW.

**FEATURES OF WIND ENERGY:-**

Wind is a renewable resource available free of charge. It is plenty throughout the world. During the production of this energy no pollution of air or water occurs. The technology is well developed and proven. Necessary machinery for harnessing this power is available commercially.

As regards India, the wind data assessment of several sites in states was made by the Indian Institute of Tropical Meteorology, Bangalore, in association with the ministry of Non-Conventional Energy Sources (MNES) and the list of suitable sites where the average wind speed throughout the year exceeded 18 kmph was published. Furthermore, it was concluded that the annual mean wind power density at the site of selection shall be at least 150watts/sq.meter at a specified height of 30 meters of the wind mill or farm. Site –specific information on wind direction, frequency, shear, gusts and turbulence in addition to wind speed requirement is necessary to make a concrete selection.

The MNES since then launched several demonstrations of 'wind farms' projects at prospective sites and popularized the establishment of wind mills with an objective of achieving 45,000MW powergeneration.

Subsequently , the Centre for Wind Energy Technology (C-WET) of MNES entered into a contract with a INDO-DANISHjoint venture company, namely, vestas RRB India Ltd, Chennai, for the installation of its V39-500kW wind generator with 47m rotor diameter and issued the First Indian Approval Certificate to the firm. The Vestas type WEG , a popular design throughout the world , has thus enerted the Indian soil and today, the compay installed several Vestas WEG Type wind mills is the states of Gujurat, Maharashtra, Madhya Pradesh, Orissa, Tamil Nadu(first installation) Kerala and Karnataka. In India , Vestas RRB Company offers two types of wind electric generators, namely, Vestas Type V39-500kW with 47 meter rotor and Vestas Type V27- 225kW. The former is considered tobe more suitable to the Indian wind conditions and seasons. In conclusion,it may be statedthat the technology and logistics for harnessing wind energy in India is fully understoodand applied.

Name and Address	Capacity (MW)	Date of Instalation
Ramagiri Wind Farm, HLC Colony ,Anantapur-515001 Anathapur(Dt.) Phone: 08554-276541	2	10/10/1994
Total Capacity:	2	

Wind farms can be located where strong dependable winds are available most of the year. On account of the uncertainty of strong winds throughout, generation of wind power is intermittent. Therefore this type of energy has to be either augmented with the regular town power supply or used as a stored energy , e.g.,chemical energy in batteries, or generation of high energy material – hydrogen.

The noise produced from the mills is annoying and sometimes interfere with the radio waves. Even the aviary is affected in these regions. Lastly , Wind energy

is costly as the infrastructural frame work is expensive.

### **ASSIGNMENTS:**

A1. How are winds formed in the atomsphere ?

A2. How is wind power harnessed to produce electricity ?

A3. Explain the components of the wind mill and how does it operate to move the turbines ? A4. Write the salient features of wind rose ?

A5. Discuss the potential of installing wind power stations in Indian states.

### 8.1(C) TIDAL ENERGY:-

The rise and fall of tides offers a means for storing water at the rise and discharging the same at fall. Of course the head of water available under such cases is very low with increased catchment area considerable amounts of power can be generated at a negligible cost.

(i) The use of tides for electric power generation is practical in a few favourably situated sites where the geography of an inlet of bay favours the construction of a large scale hydroelectric plant. To harness the tides, a dam would be built across the mouth of the bay in which large gates and low head hydraulic turbines would be installed. At the time of high tide the gates are opened and after storing water in the tidal basin the gates are closed. After the tide has receded, there is a working hydraulic head between the basin water and open sea/ocean and the water is allowed to flow back to the sea through water turbines installed in the dam. With this type arrangement the generation of electric power is not continuous. However by using reversible water turbine can be run continuously as shown in figure below.

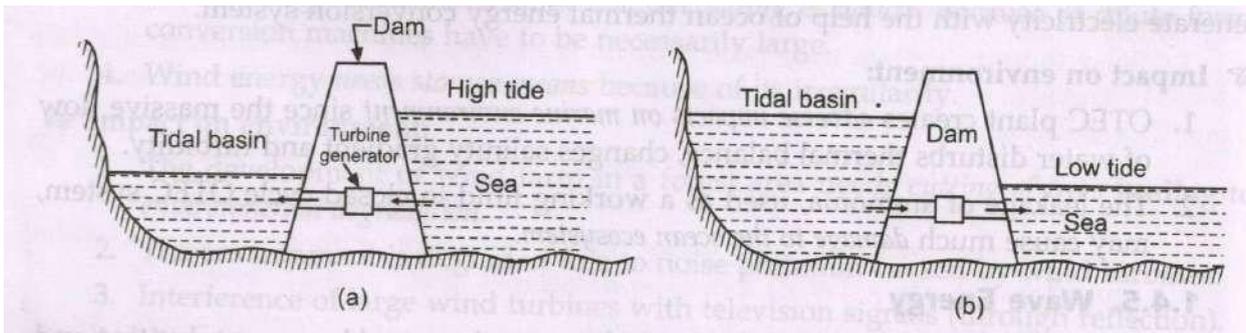


Fig.8.5 Generation of power by tides

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