

## **LECTURE NOTES**

**ON**

**BASIC ELECTRICAL ENGINEERING**

**Compiled by**

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## FUNDAMENTALS CHAPTER-1

### 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.

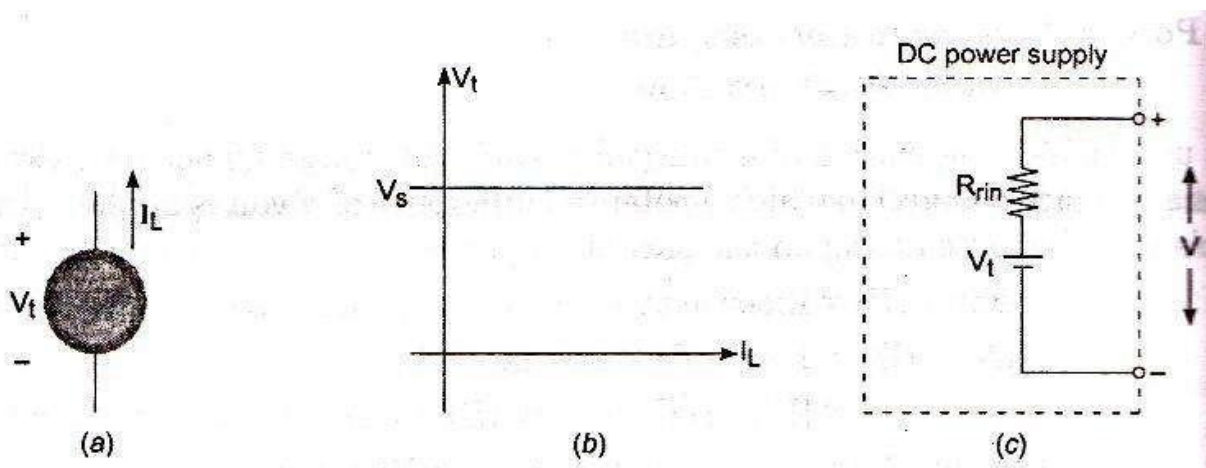
## Concept of Source & Load

### 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.

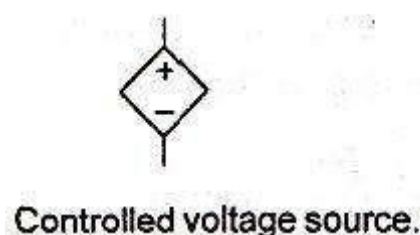
A Real/practical voltage source is represented by an ideal voltage source with a series resistance ( $r_{in}$ ) with it as shown in Fig.(c) below.



(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.

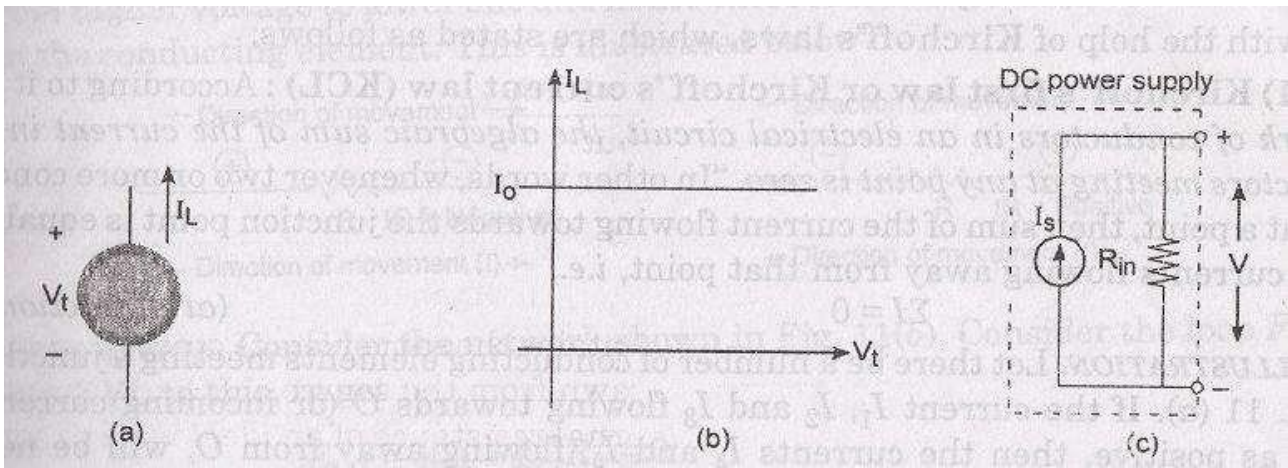


(Figure d)

## 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.

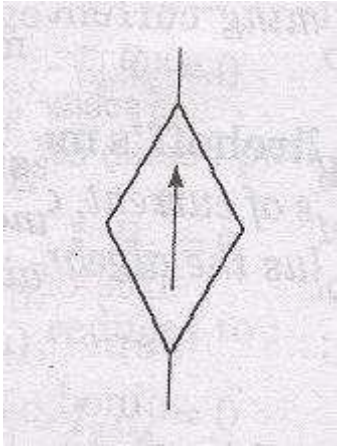
A Real/practical current source is represented by an ideal current source in parallel with a resistance( $r_{in}$ ) as shown in Figure (c) below.



(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 current Source

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.

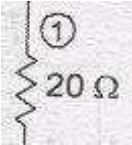


(Controlled or Dependent Current Source)

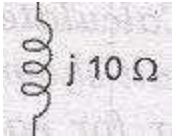
Figure(d)

# Load

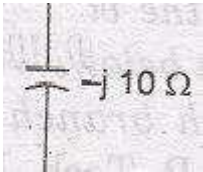
The electrical load is an application consuming electrical power and is represented by R(Resistance),L(Inductance),C(Capacitance),E( back EMF) etc. or combination of these circuit elements.



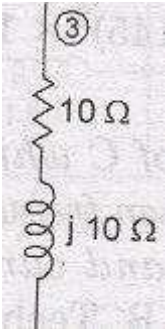
(Resistance)



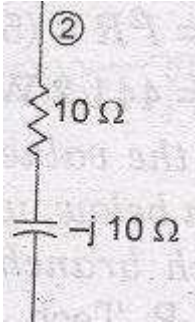
(Inductance)



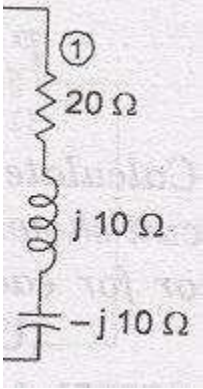
(Capacitance)



(R-L Load)



(R-C Load)



(R-L-C Load)

## 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 :  $R = \rho L/A$

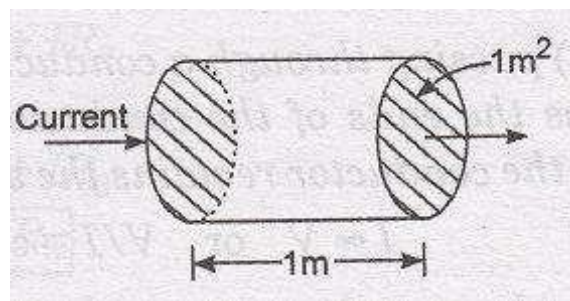
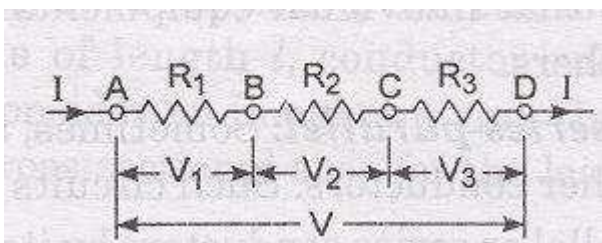


Figure (a)

[In the figure(a) above a conductor is shown with its length(L) = 1 metre & Area of cross-section(A) = 1m<sup>2</sup>]

### 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,

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

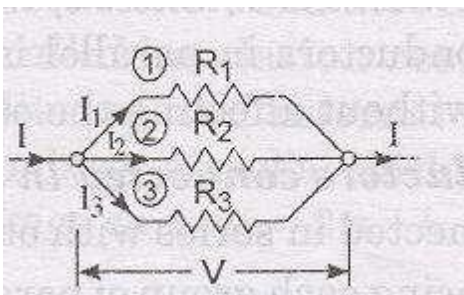
From equation 1s & 2s we get  $IR = I R_1 + IR_2 + IR_3$

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

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

Hence,





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

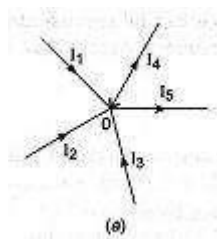
Hence, It is observed that in a parallel connected circuit of two resistances the current through a branch is the product of total current entering the combination & the Ratio of resistance of opposite side of the side through which the current is determined & the sum of individual resistances .

### 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.

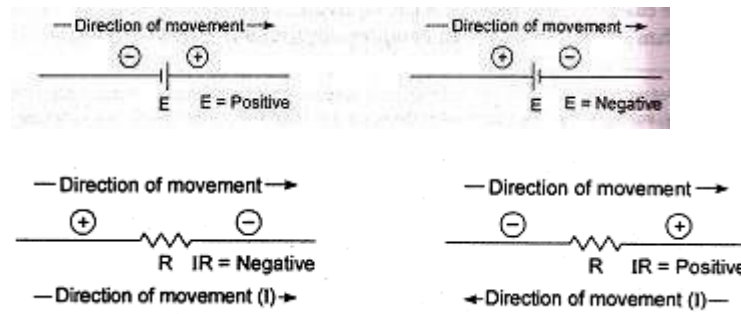
### Kirchoff's voltage Law

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

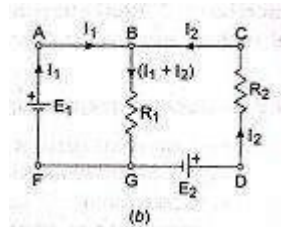
$$\sum IR + E = 0$$

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.



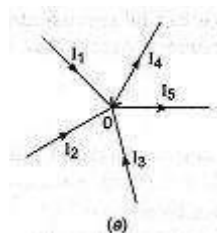
Considering the loop FABGF & applying KVL to this, we get

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

Similarly applying KVL to loop BCDGB, we get

$$-E_2 + (I_1 + I_2)R_1 + I_2R_2 = 0 \dots\dots\dots B$$

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



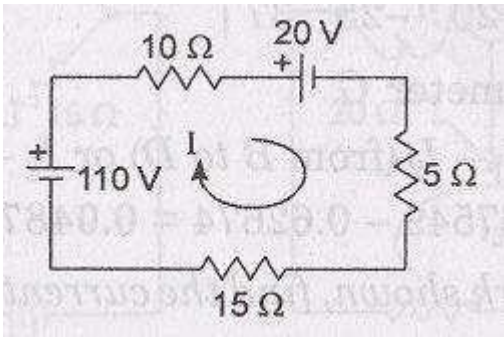
Solution : Application of KCL to node A in figure with proper sign convention results in the following equation:

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

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 shown below.



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.

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

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

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

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

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

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.

## ELECTRO-MAGNETIC INDUCTION

In 1831, M. Faraday discovered that a current is generated whenever the magnetic flux linked with a circuit changes.

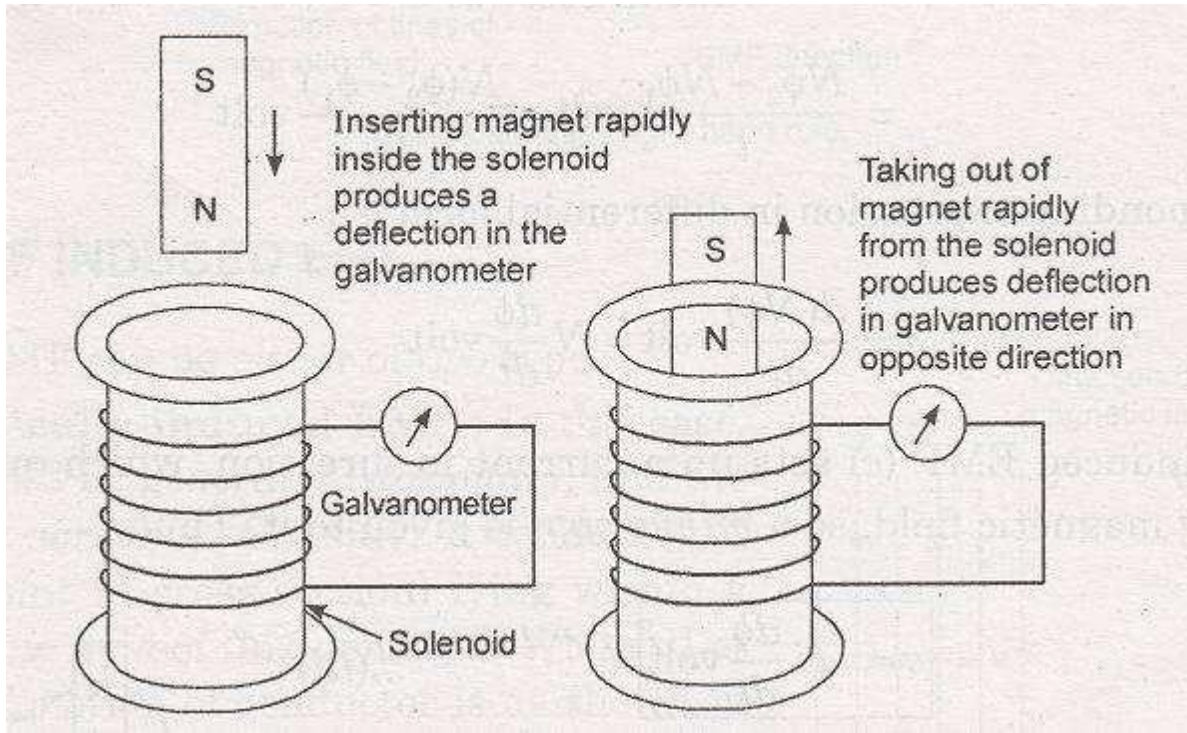
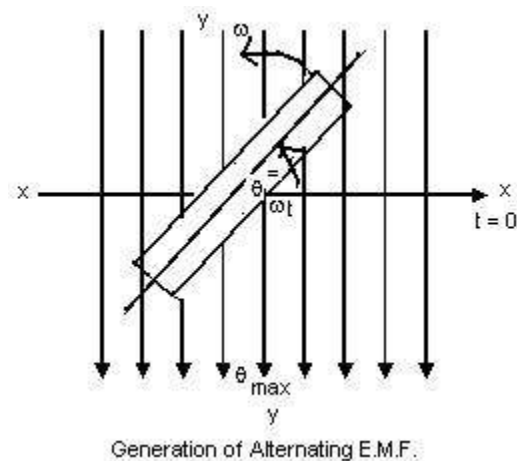


Illustration of electromagnetic induction.

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  $e = d(N\phi/dt) = Nd\phi/dt$  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.

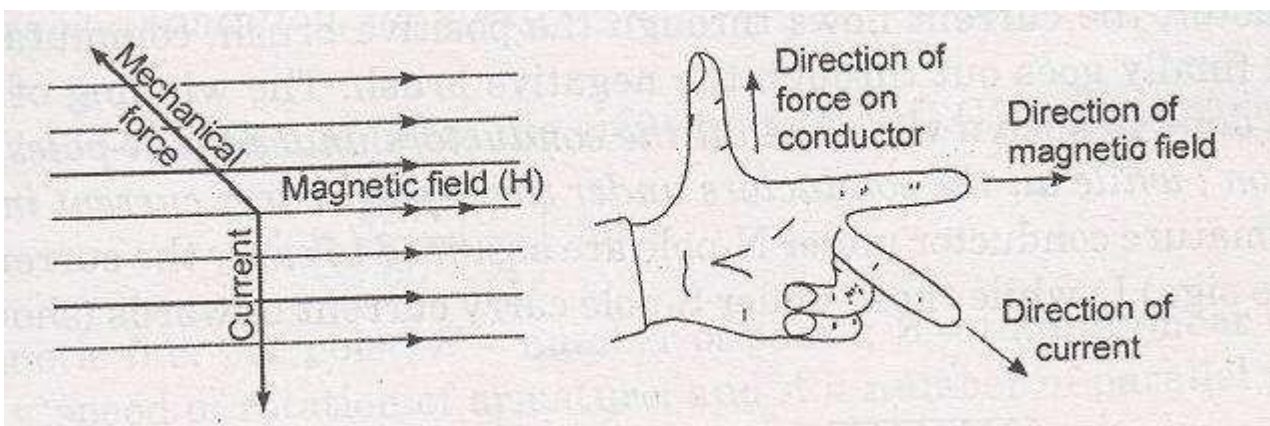
Thus  $e = -N d\phi/dt$  volt

## 2. LENZ'S law

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

### FLEMMING 's LEFT-HAND RULE

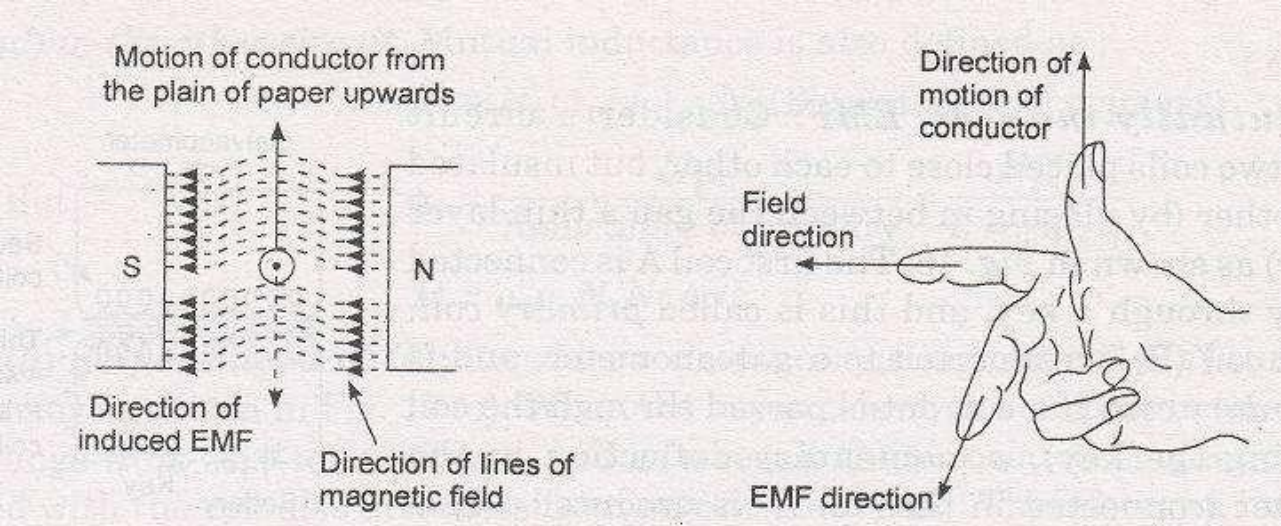
Flemming's left hand rule states that If we stretch out the thumb, the fore-finger & the middle finger of the left hand so that they are at right angles to each other then if the fore-finger points in the direction of magnetic field, the middle finger in the direction of current then the thumb points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



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

**FLEMMING'S RIGHT-HAND RULE**

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



Fleming's right-hand rule.

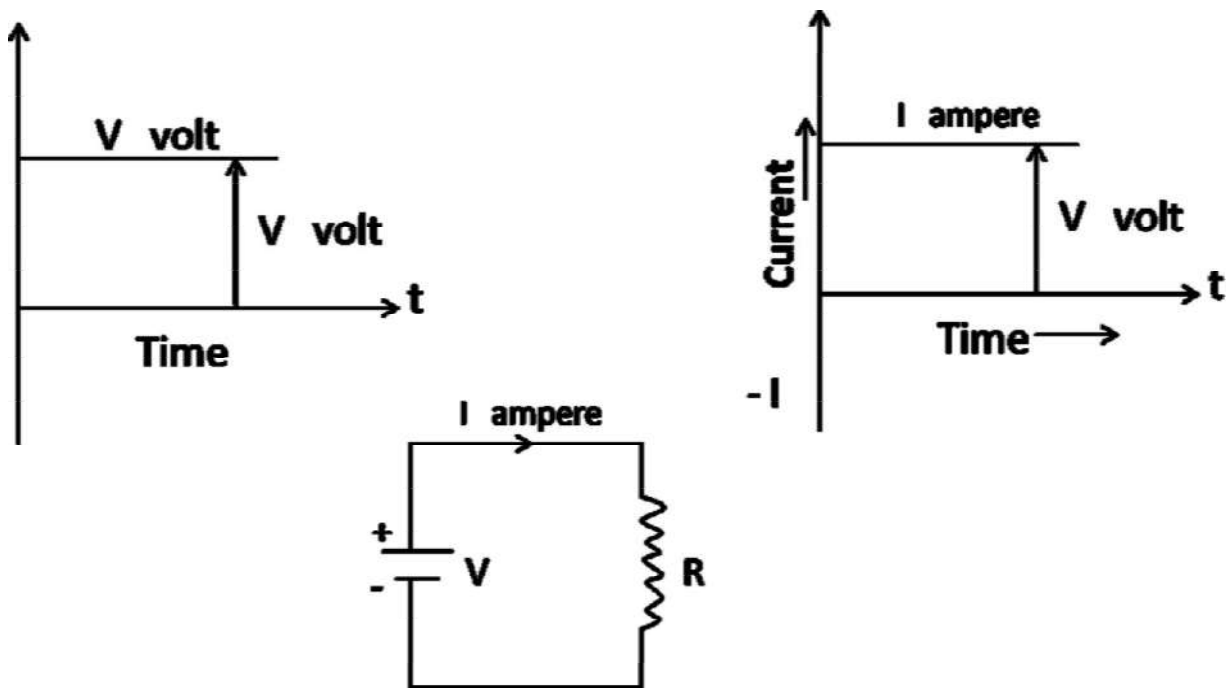
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## ALTERNATING CIRCUIT THEORY CHAPTER-2

### what is D.C.

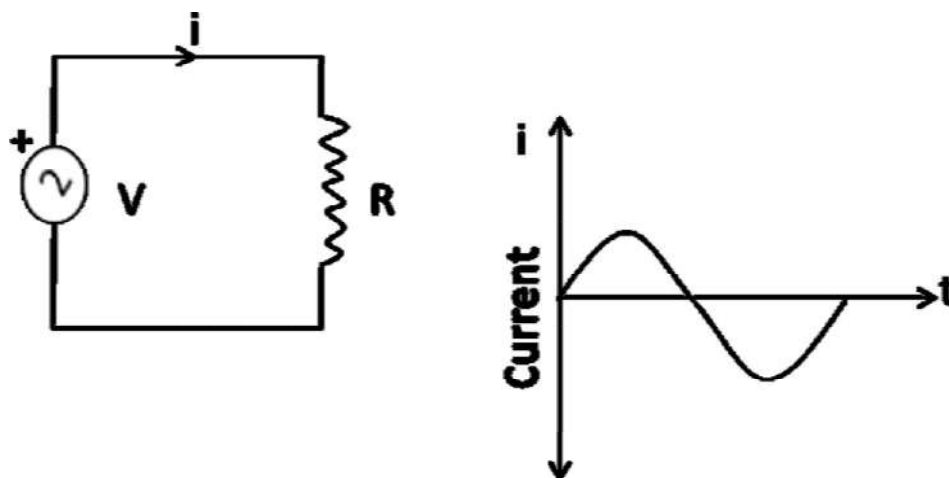
1. The Direct current or D.C. always flows in one direction & its magnitude remains unchanged
2. Here you see the voltage value is  $V$  volts & Current value is  $I$  amperes for all time to come i.e. as the time progresses.



[ 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**

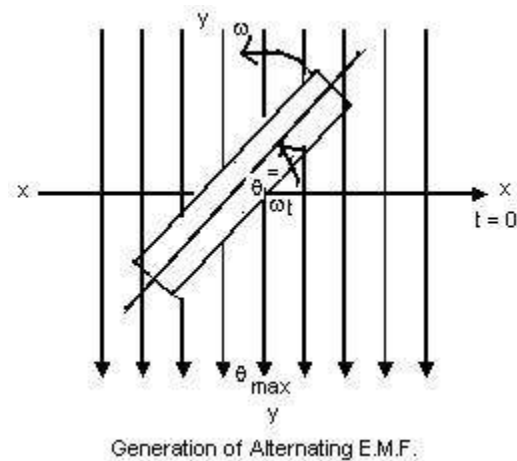
<b>Alternating Current</b>	<b>Direct Current</b>
<ol style="list-style-type: none"> <li>1.The magnitude and direction both changes .</li> <li>2. By using transformers, A.C. voltages can be increased or decreased as desired.</li> <li>3. A.C. circuit current can be decreased by using choke or capacitor without any appreciable power loss.</li> <li>4. A.C. can be converted into D.C. by using a device, called convertor (rectification circuit)</li> <li>5. A.C. cannot be used directly for electroplating, electrotyping, etc.</li> </ol>	<ol style="list-style-type: none"> <li>1.Both magnitude &amp; Direction remain constant.</li> <li>2. No such provision can be made.</li> <li>3.For decreasing D.C. circuit current, a resistance has to be used, whose power dissipation factor (<math>I^2R</math>) is large.</li> <li>4. D.C. can be converted to A.C. by using choppers (inverters).</li> <li>5. D.C. can be used directly for carrying out such operations.</li> </ol>

**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.

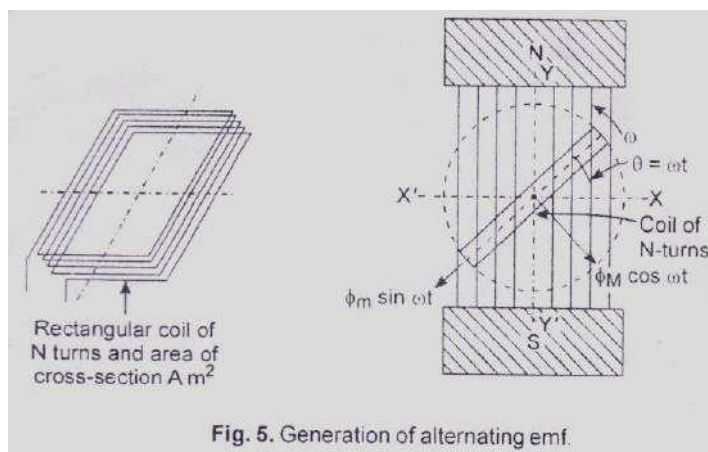
EMF Induced in a coil of N turns =  $e = - N d\phi/dt$

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.

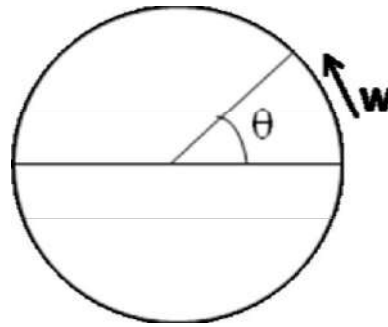
Component of flux perpendicular to the plane of the coil is :-

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

Angle subtended by the coil in time  $t$  is

$$\theta = \omega t$$

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



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

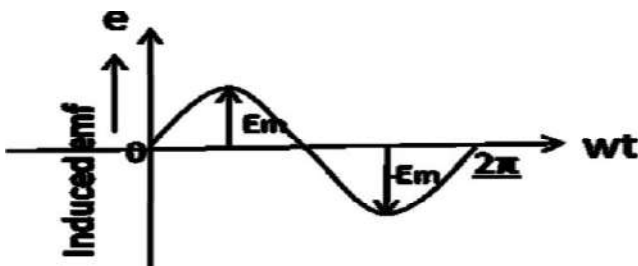
For N turns  $N\Phi = N \Phi_m \cos \omega t$

Induced emf in the coil according to Faradays Law =

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

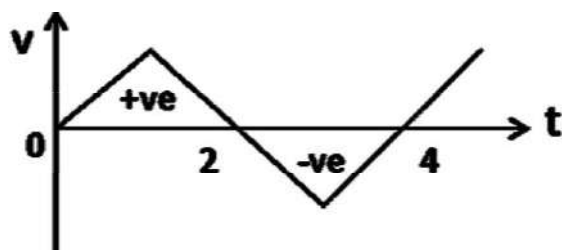
$$= -N\Phi_m d(\cos \omega t)/dt \text{ volts} = \omega N\Phi_m \sin \omega t \text{ volt}$$

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

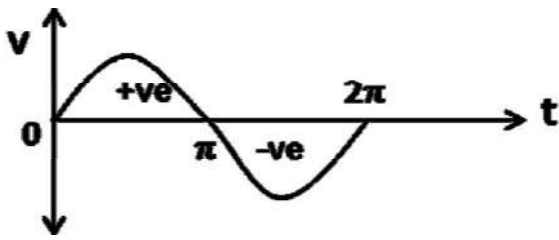


Questions/Answers

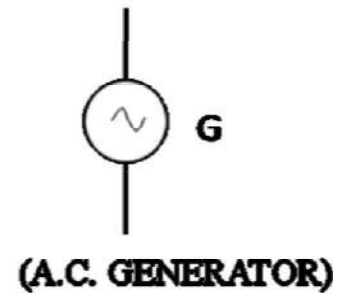
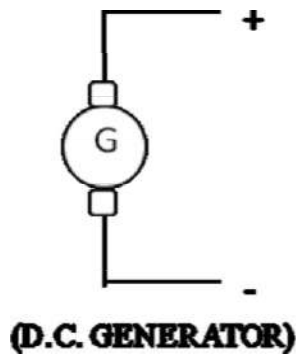
1. Is this wave forms AC?



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



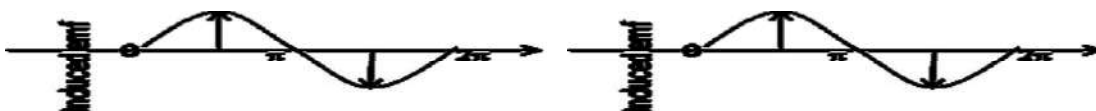
3. What is happening in a Generator or a Cell.



### 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.

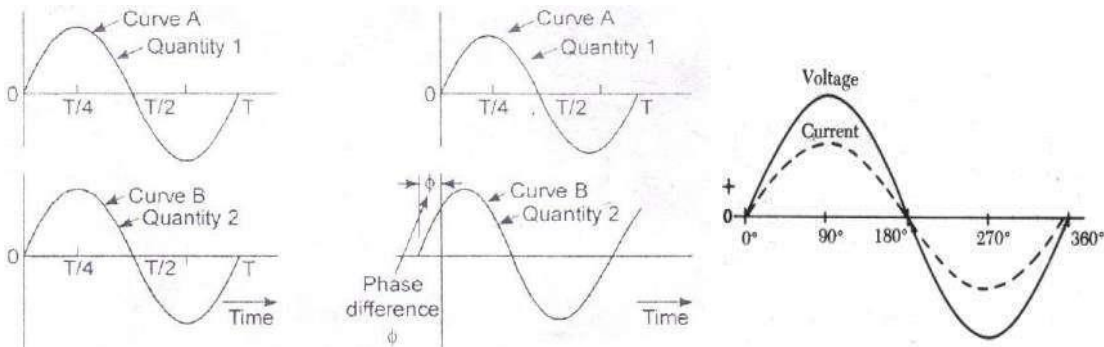
**TIME PERIOD (T):** The time period taken in seconds to complete one cycle of an alternating quantity is called its time period.

**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.

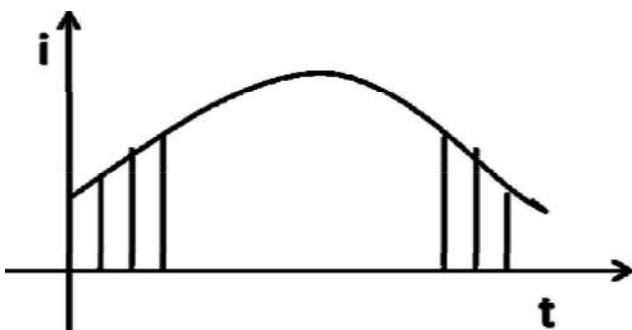
$$I_{av} = \frac{1}{T} \int_0^T i(t) dt \text{ or } I_{av} = \frac{1}{2\pi} \int_0^{2\pi} i d\theta$$

### 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 there after.

### Solution

Do YOU KNOW

$$2\pi f = 628$$

$$100 = 141.4 \sin 628 t$$

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

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

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

## 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.

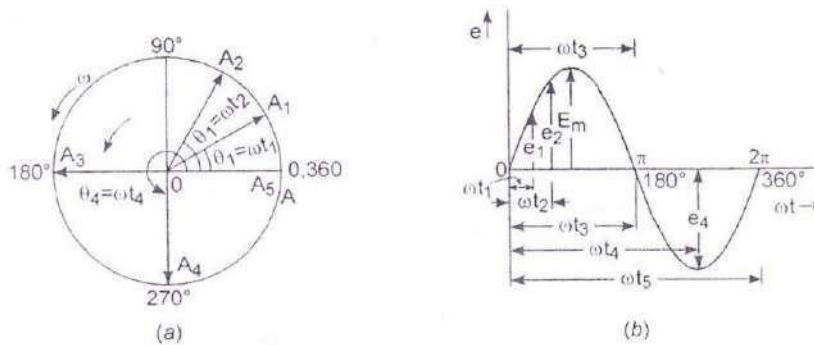


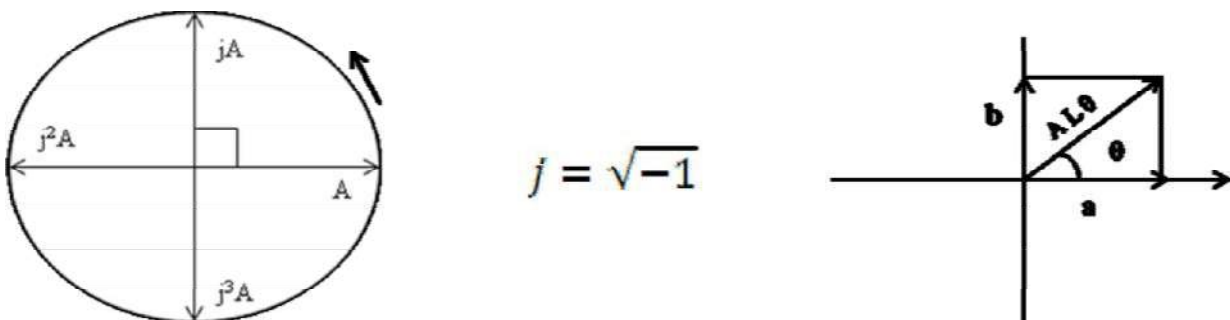
Fig. 7. Phasor (or vector) representation of alternating emf

**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.



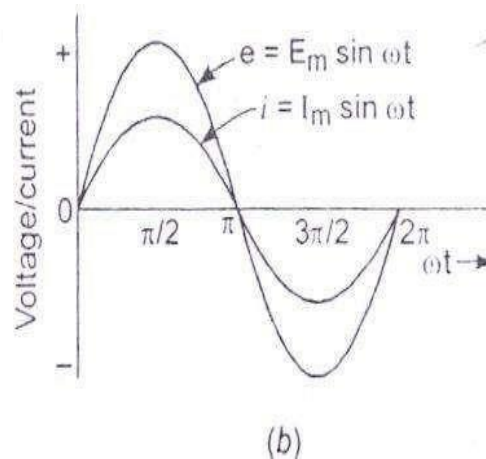
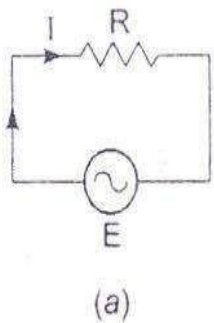
### REPRESENTATION OF PHASOR IN COMPLEX PLANE

- 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:  $A = A \angle \theta$



**Discussion :**

- Convert  $7+j24$  to Polar coordinate? Modulus  $=\sqrt{7^2 + 24^2} = 25$ , But Argument\Angle =?
- Convert  $5 /_{-53.13^0}$  to Rectangular coordinate . $[5(\cos 53.13^0 +j\sin 53.13^0)]$

**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 :**

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

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

$$iR = E_m \sin \omega t$$

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

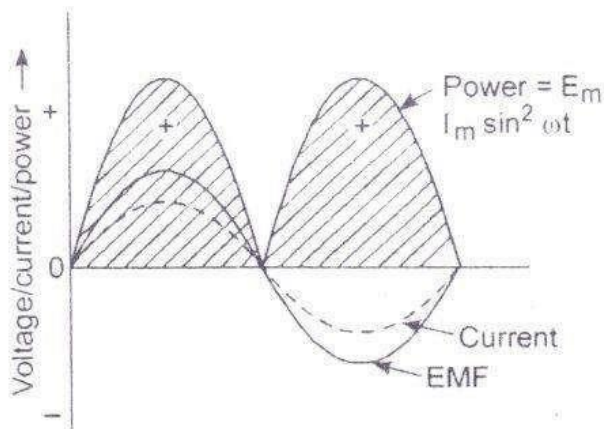
**CONCLUSION: IN A PURELY RESISTIVE CIRCUIT THE APPLIED A.C. VOLTAGE & CIRCUIT CURRENT ARE IN-PHASE.**

**POWER IN A PURELY RESISTIVE CIRCUIT**

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

**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

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

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

$$e = L \frac{di}{dt} = E_m \sin \omega t$$

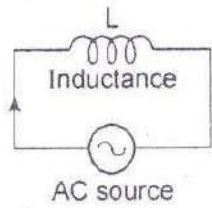
$$di = (E_m/L) \sin \omega t \cdot dt$$

On integration

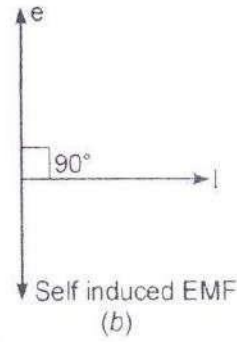
$$i = E_m/L \int \sin \omega t \cdot dt = E_m/\omega L (-\cos \omega t) = (E_m/\omega L) \sin(\omega t - \pi/2)$$

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

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



(a)



(b)

A.C. circuit with inductance only.

**CONCLUSION:**

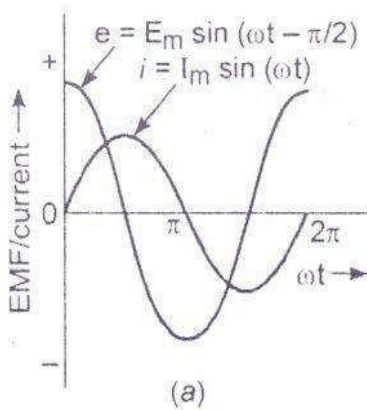
IN A PURELY INDUCTIVE CIRCUIT THE CIRCUIT CURRENT (I) LAGS BEHIND THE APPLIED A.C. VOLTAGE (e) BY AN ANGLE OF  $\pi / 2$  OR  $90^0$ .

**POWER IN A PURELY INDUCTIVE CIRCUIT**

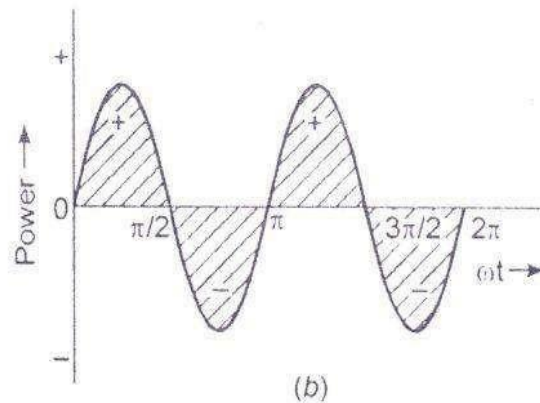
$$p = ei = E_m \cdot I_m \sin wt \cdot \sin (wt - \pi / 2)$$

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

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:**

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

Discussion/Assignment

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

Solution :

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

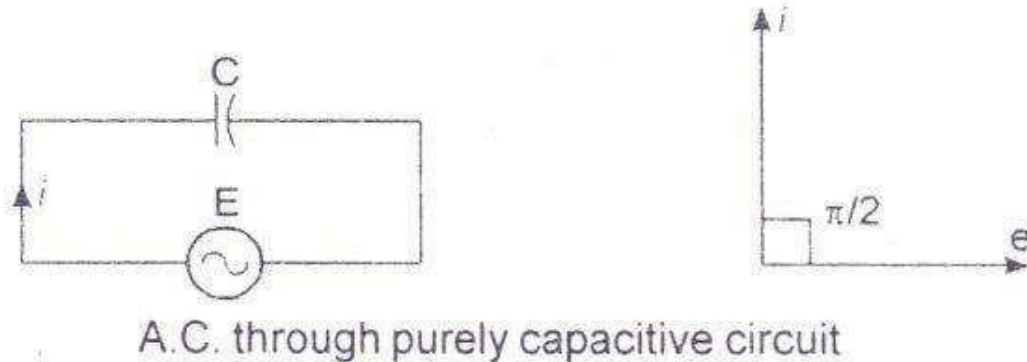
i.e.,  $X_L = \text{INDUCTIVE REACTANCE} = 314 \times 0.1 = \text{WHAT}$

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

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

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

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

A.C. THROUGH PURELY CAPACITIVE CIRCUIT

A.C. through purely capacitive circuit

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

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

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

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

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

$$= \frac{E_m}{\frac{1}{\omega C}} \sin(\omega t + \pi/2) = \frac{E_m}{X_C} \sin(\omega t + \pi/2)$$

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

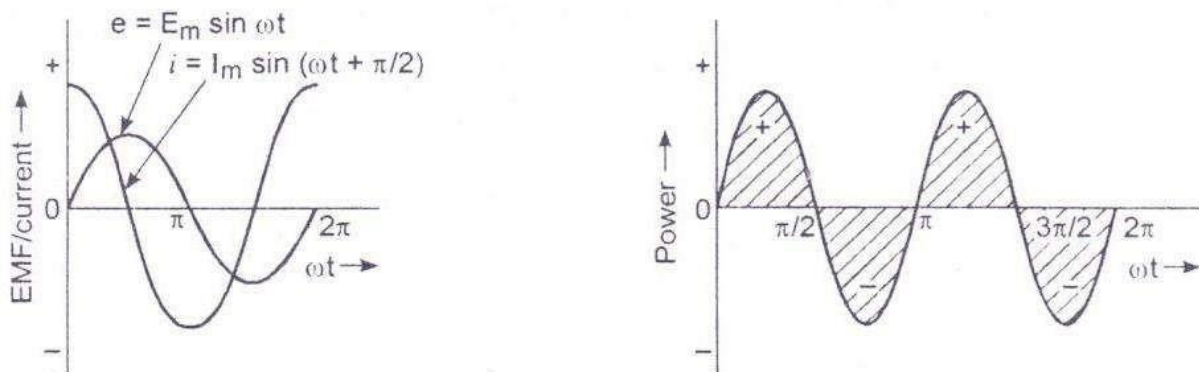
Where ,  $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \text{Capacitive Reactance}$

**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  $X_C$ ,  $i$ ,  $I_{\text{rms}}$ ,  $I_{\text{MAX}}$

**SOLUTION:**

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

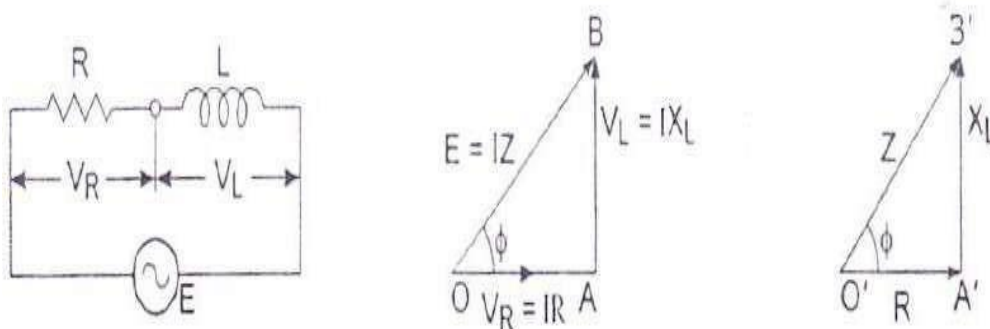
$$i = (141 / 318.47) \sin (314t + (\pi / 3) + (\pi / 2))$$

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

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

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

**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 =  $V_L = IX_L$

Supply voltage :=  $E = \sqrt{V_R^2 + V_L^2}$

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

=  $I \sqrt{R^2 + X_L^2}$

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

=  $E / Z$

Where ,  $Z = \text{IMPEDANCE} = \sqrt{R^2 + X_L^2}$

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

**CONCLUSION:**

**IN A SERIES R-L CIRCUIT CONNETED 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. CURRENT.

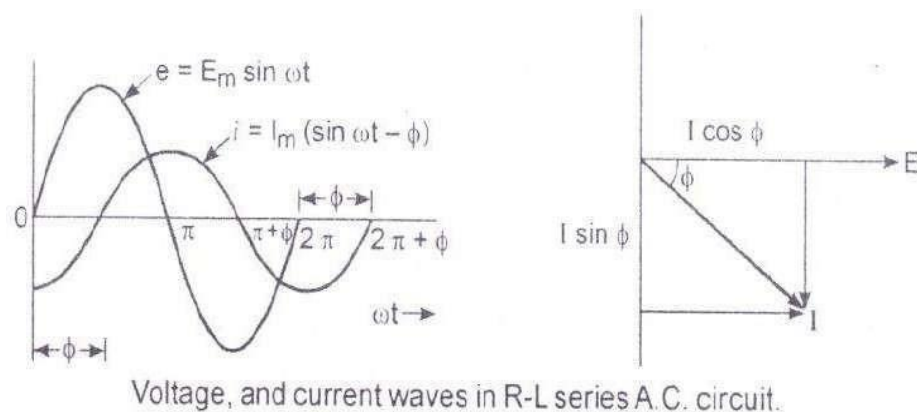
P.F. =  $\text{Cos } \phi = (R / Z)$

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

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

$S = V.I = IZ.I = I^2 Z$  (APPARENT POWER)

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



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:

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

$$P = VI \cos \theta$$

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

$$\sin \theta = 0.917$$

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

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

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

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

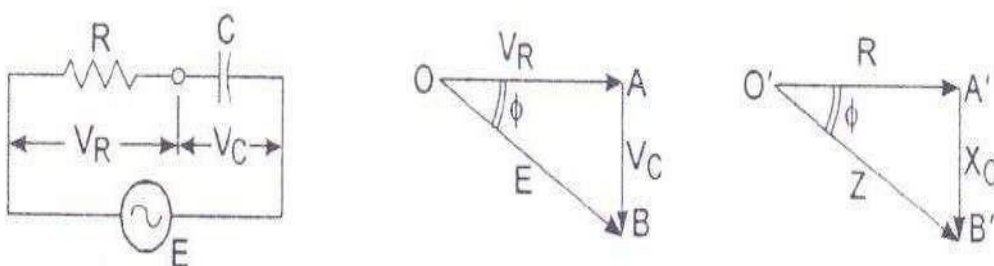
$$(c) \text{ App Power} = S = VI = 2500 \text{ VA}$$

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

$$(d) \cos \theta = 0.4$$

$$\theta = 66.42^\circ$$

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.

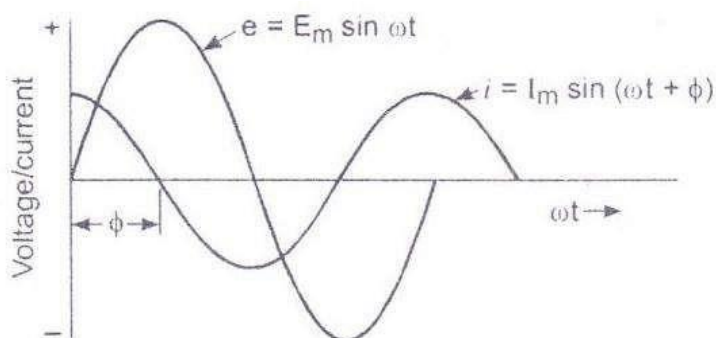
$$\text{P.F.} = \cos \phi = (R / Z)$$

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

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

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

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



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  $C = 100 \mu\text{F}$ .

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



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

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

$$(b) Y = (1 / Z) = \text{Admittance} = (1 / 37.59 \angle -57.86^\circ) = 0.0266 \angle 57.86^\circ \\ = 0.01415 + j 0.0225 \text{ Siemens}$$

$$Y = G + jB$$

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

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

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

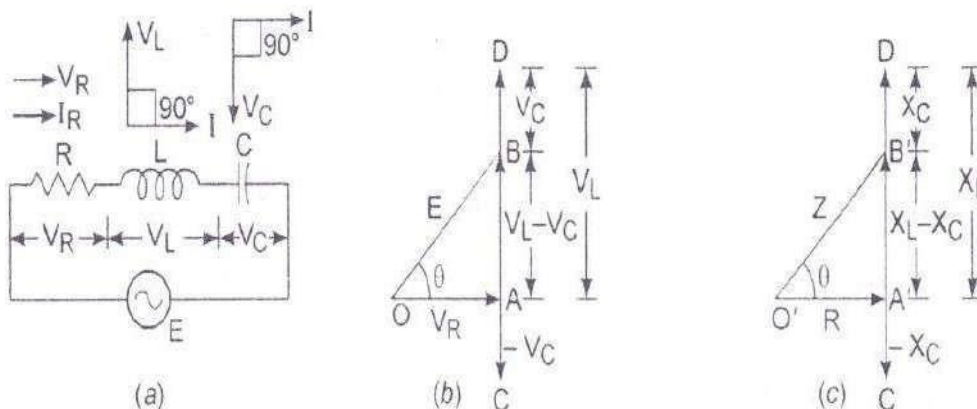
$$(d) \text{ App Power} = S = VI = 230 \times 6.12 = 1407.6 \text{ VA}$$

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

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

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

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



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

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

$$\text{Voltage across Inductance} = V_L = IX_L$$

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

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

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

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

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

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

**CONCLUSION:**

**IN A SERIES R-L-C CIRCUIT CONNECTED 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  $X_L = X_C$ .**

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

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

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

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

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

**PROBLEM-**

A resistance of 10  $\Omega$ , 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:**  $V = 230 \text{ L } 0^\circ$

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

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

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

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

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

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

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

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

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

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

$$= 0.00877 + j 0.0283 \text{ Siemens}$$

$$Y = G + jB$$

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

.....xxx.....

## **GENERATION OF ELECTRICAL POWER CHAPTER-3**

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.

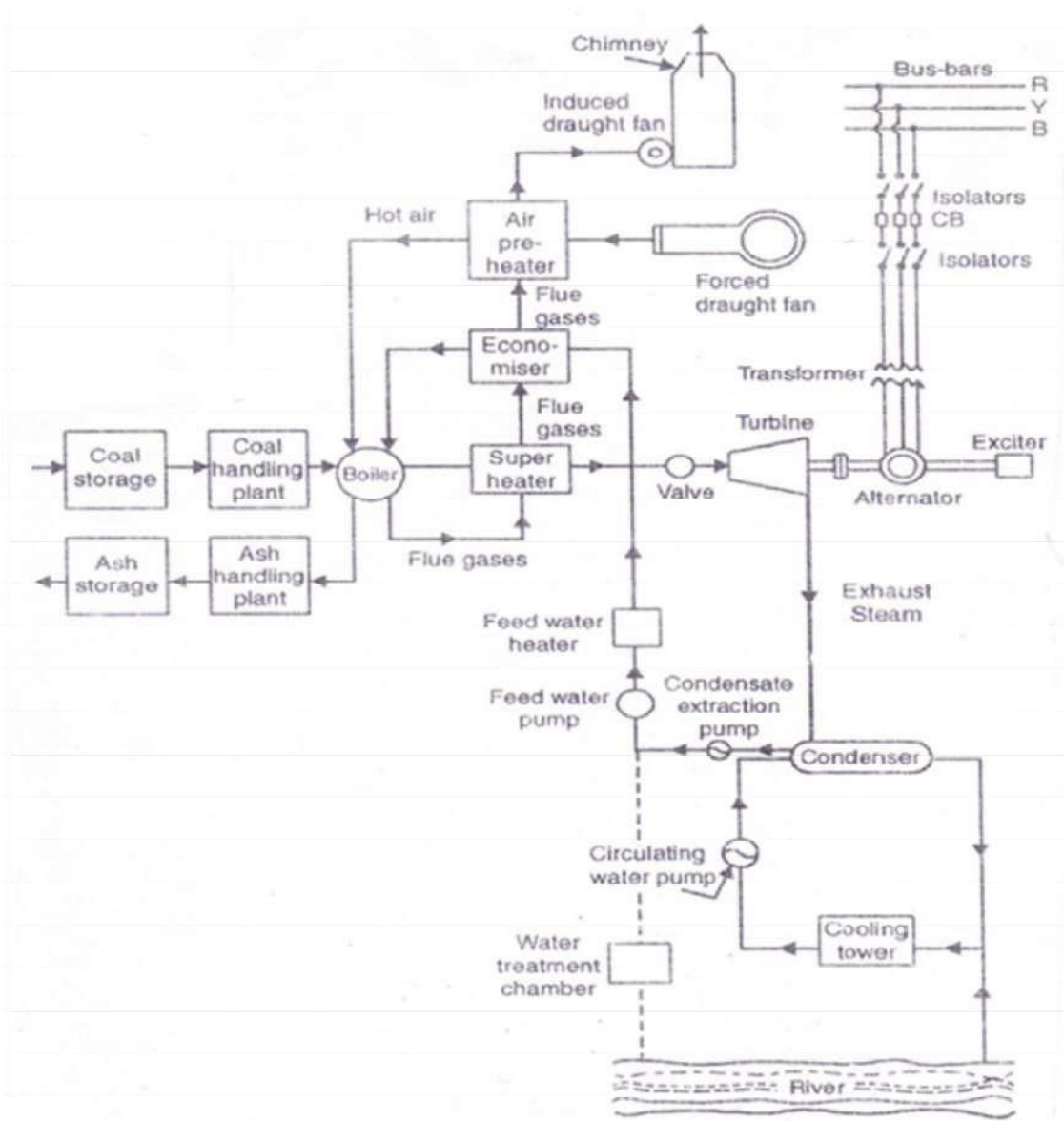
4. **COST AND TYPE OF LAND**:- The steam power station should be located at a place where land is cheap and further extension if necessary is possible.
5. **NEARNESS TO LOAD CENTRES**:- In order to reduce transmission cost the plant should be located near the center of load.
6. **DISTANCE FROM POPULATED 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 locate 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 with out using excess amount of air.
3. **ASH STORAGE PLANT**:- The coal is burnt in the boiler & the ash produced after the complete combustion of coal is removed to the ash handling plant.
4. **ASH HANDLING PLANT**:- the ash from ash handling plant is then delivered to the ash storage plant for subsequent use as fertilizer etc.
5. **BOILER**:- The heat of combustion of coal in the boiler is utilized to convert water into steam at very high temperature and pressure.The flue gases from the boiler makes their journey through superheater,economizer, air pre-heater & are finally exhausted to the atmosphere through the chimney.
6. **SUPERHEATER**:- The steam produced in the boiler is wet and is passed through super heater where it is dried and super heated.
7. **ECONOMISER**:- An economizer is essentially a feed water heater & derives heat from the flue gases for the purpose.
8. **AIR PREHEATER**:- Air pre-heater increases the temperature of the air supplied for coal burning by deriving heat from flue gases.
9. **FORCED DRAUGHT FAN** :-It draws air from atomosphere which is supplied to the boiler for effective combustion.
10. **INDUCED DRAUGHT FAN** : it draws the flue gas and sends to chimney.
11. **CHIMNEY**:- The hot flue gases go to the atmosphere though chimney.
12. **STEAM TURBINE**:- The dry and super heated steam from the super heater is fed to the steam turbine which converts the heat energy of steam tto mechanical energy.
13. **ALTERNATOR**:- The alternator converts the mechanical energy of steam turbine to electrical energy.

14. **CONDENSER** :- In order to improve the efficiency of the plant the steam exhausted from the turbine is condensed by means of a condenser. The condensate from the condenser is used as feed water to the boiler.
15. **COOLING TOWER** : The cooling tower provides a cooling arrangement for the feed water to be reused in boiler.

## **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

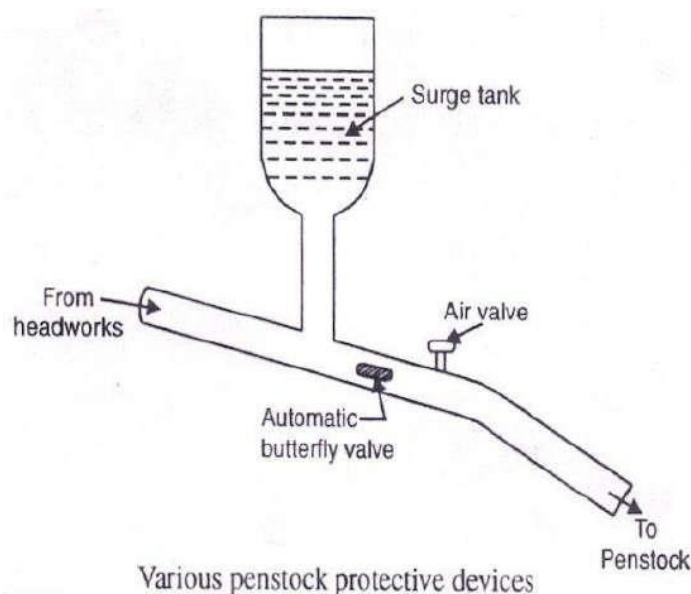
#### CHOICE OF SITE

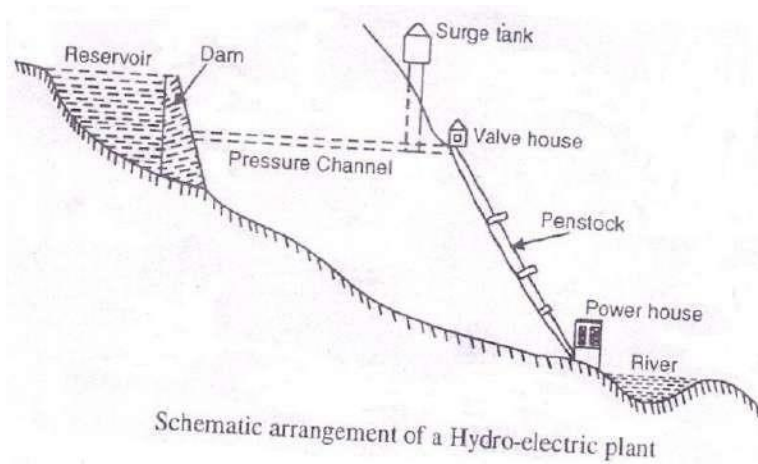
1. **AVAILABILITY OF WATER**:- Since the primary requirement of a hydro-electric power station is the availability of huge quantity of water at a good head this requirement is very essential.
2. **STORAGE OF WATER**:-There are wide variations in water supply from a river or canal during the year.This 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 rock fill.

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 Valve house. 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 Electrical Energy.

### **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 Electrical Energy.
- 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 cost 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 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( $Th^{232}$ )

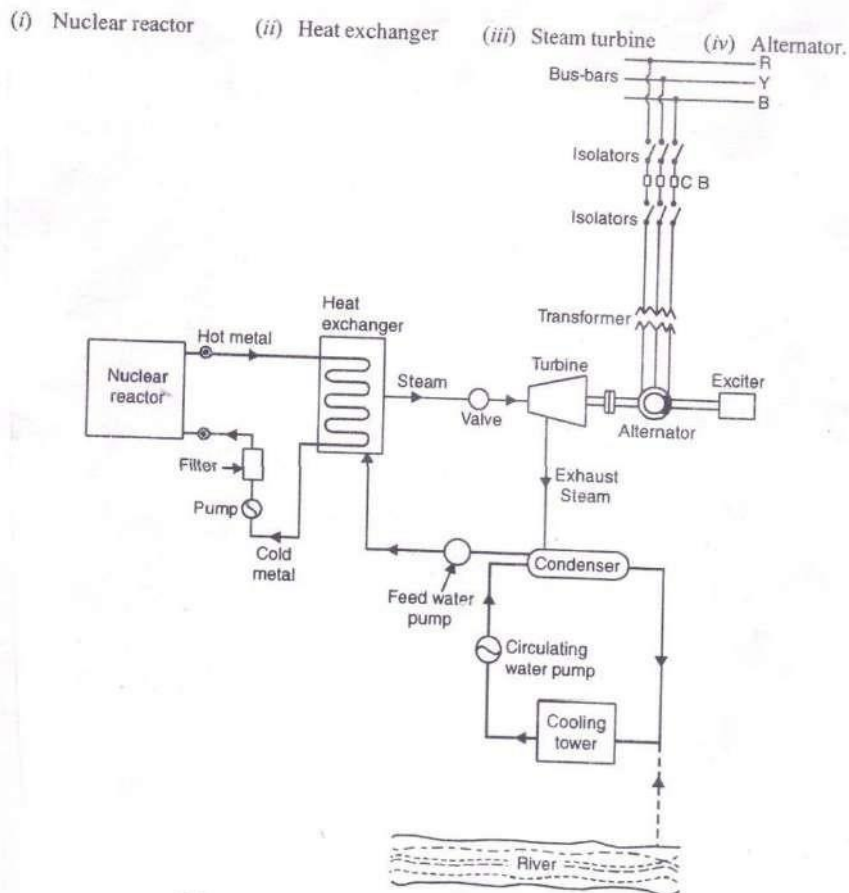
### FISSION & CHAIN REACTION

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.

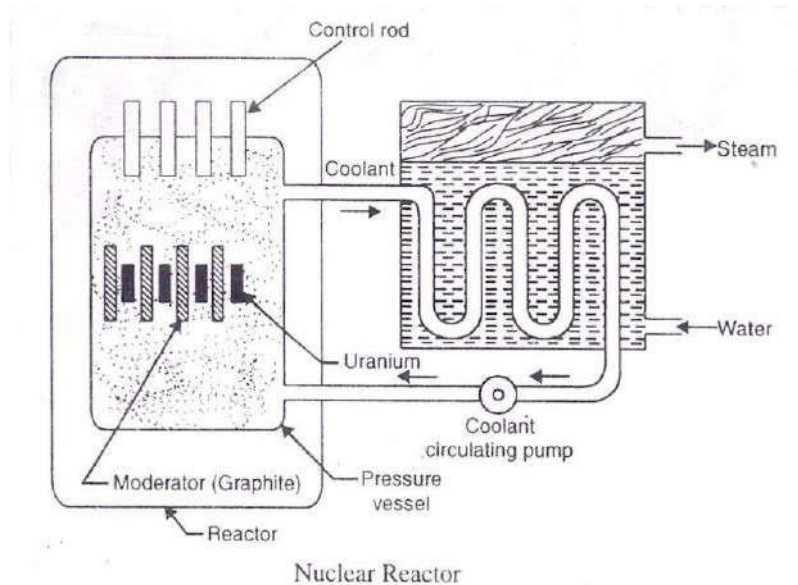
### MAIN UNITS OF PLANT

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 the reactor.

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.



Schematic arrangement of Nuclear Power Station



**Working of Nuclear Power Plant :** 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 as before.

**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 big problem.

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## **CONVERSION OF ELECTRICAL ENERGY**

### **CHAPTER-4**

#### **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.

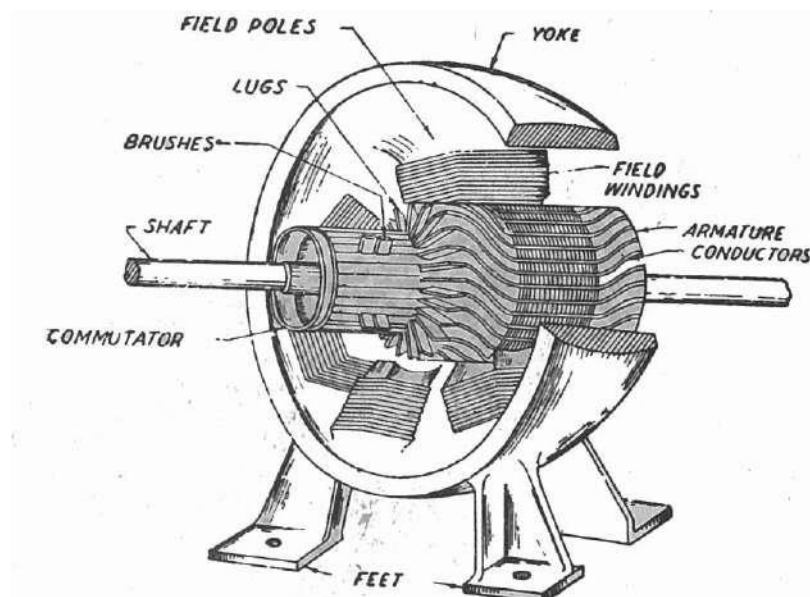


Fig. 4.1

### 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.

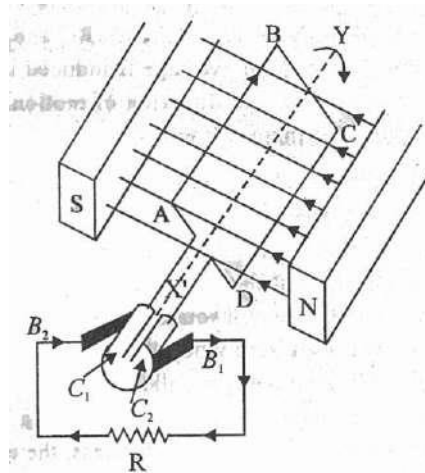


Fig. 4.2

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 another  $90^\circ$  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 wave rectifier.

### 4.4. EMF Equation of Generator :

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

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.

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

Now flux cut/ conductor in one revolution.

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

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

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

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

For wave - wound Generator

No of parallel path ( $A$ ) = 2

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

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

For Lap wound generator

No of Parallel Paths =  $P$

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

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

In general, generated EMF  $E_g = \frac{\phi Z N}{60} \times \left(\frac{P}{A}\right)$

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.

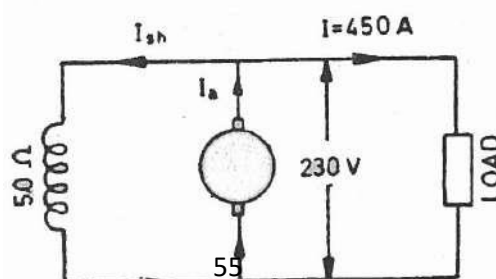


Fig.4.3

$$\text{Current through the field winding} = \frac{230}{50} = 4.6\text{A}$$

Load current  $I = 450\text{A}$

Armature Current  $I_a = I + I_f$

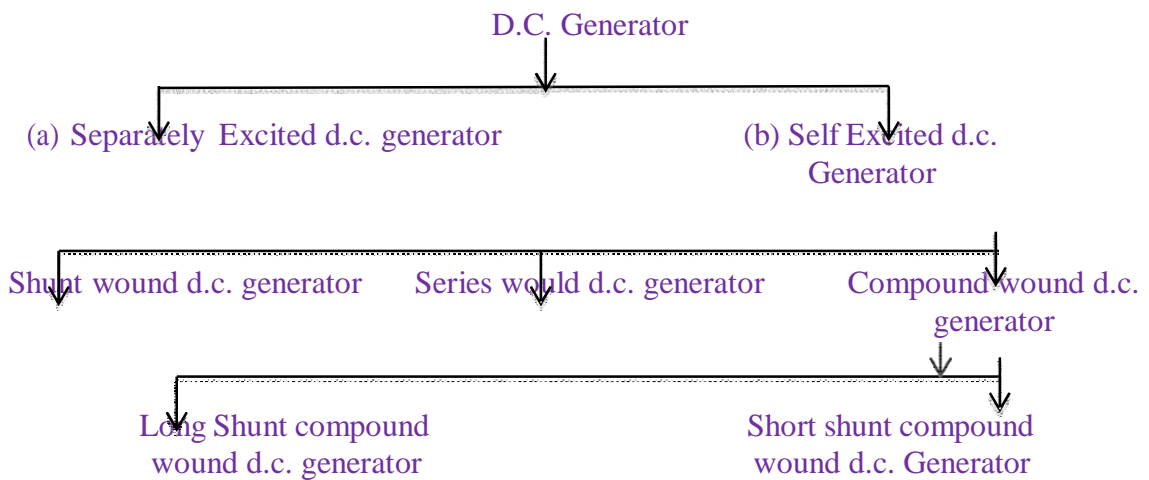
$$I_a = 450 + 4.6 = 454.6\text{A}$$

Armature voltage drop  $(I_a R_a) = 454.6 \times 0.03 = 13.6\text{V}$ .

$E_g =$  terminal voltage + Armature drop

$$E_g = V + I_a R_a = 230 + 13.6 = 243.6\text{ V}$$

**4.6 Classification of D.C. Generator**



**4.7 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.  $E_b$ .

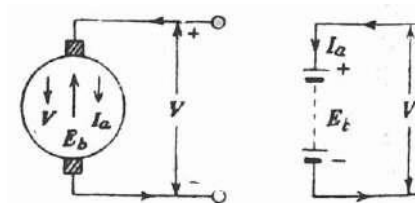


Fig. 4.4

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

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

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

$$\text{So } V = E_b + I_a R_a.$$

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

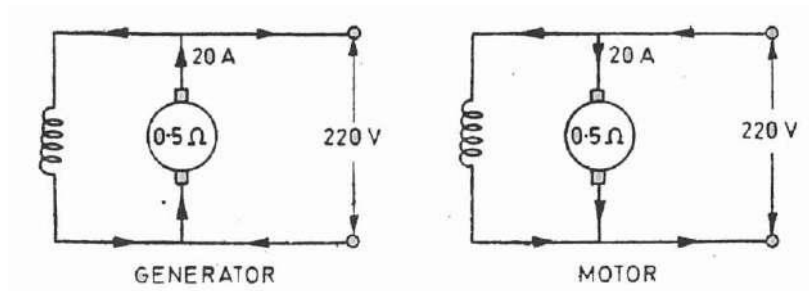
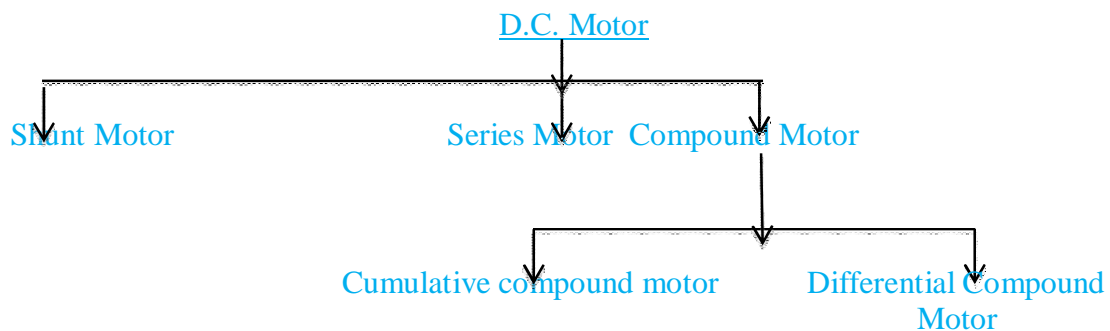


Fig.4.5

- (a) As Generator  $E_g = V + I_a R_a$   
 $= 220 + (0.5 \times 20) = 220 + 10 = 230\text{V}$
- (b) As motor  $E_b = V - I_a R_a = 220 - (0.5 \times 20)$   
 $E_b = 220 - 10 = 210\text{ V}$

#### 4.8 Classification of D.C. Motor



#### 4.9 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 self starting.

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

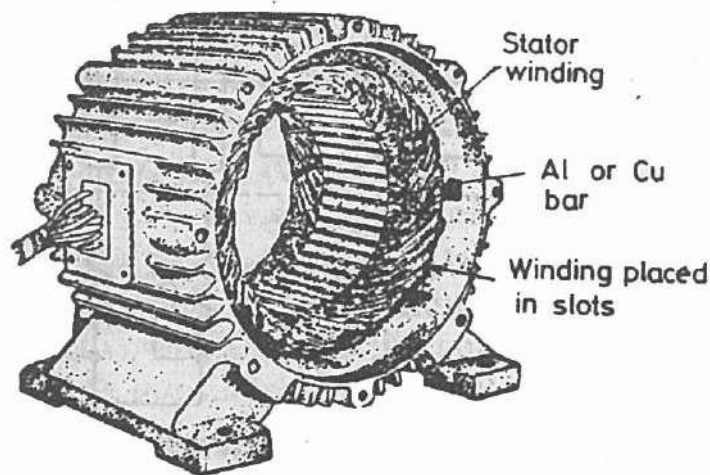
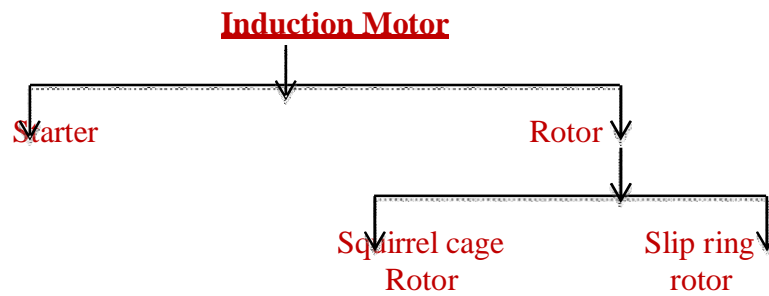
- (1) Split phase motor  
(2) Capacitor start motor  
(3) Capacitor start – Capacitor run single phase Induction Motor.  
(4) Shaded Pole Motor -  
(5) Repulsion Motor

#### Uses :

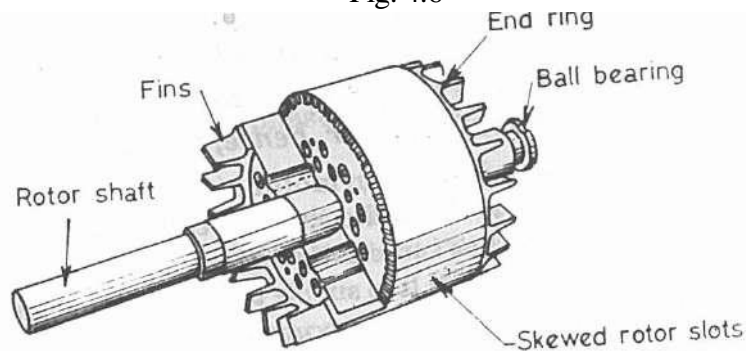
- (1) Split phase motor :  
(i) Small Pumps  
(ii) Grinders  
(2) Capacitor start motor

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

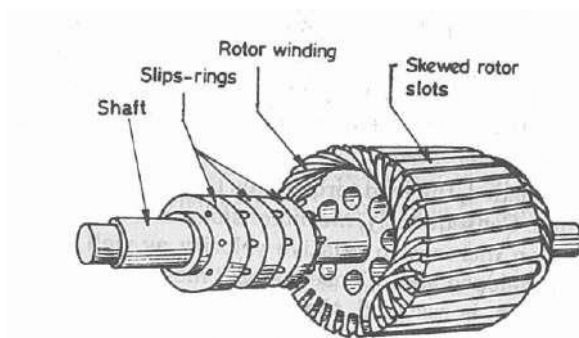
4.13 **Parts of Three – Phase Induction Motor**



Stator  
Fig. 4.6



Squirrel cage Rotor  
Fig. 4.7



Slipring 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-5**

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

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

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

#### **(1) Cleat Wiring**

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

**Merits**

- (i) It is cheapest system of wiring.
- (ii) A little skill is required to lay the 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 rewire.

**Demerits**

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

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

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

**Merits**

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

**Demerits**

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

**4. Lead Sheathed Wiring**

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

**Merits**

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

**Demerits**

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

**5. Conduit wiring**

There are two types of conduit wiring

- (i) Surface conduit wiring
- (ii) Concealed conduit wiring

In surface conduit wiring the conduit run over the wall supported by means of saddles where as in concealed conduit wiring the conduit is embedded in the walls and ceilings by placing in the premade cavity in them.

**Merits**

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

**Demerits**

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

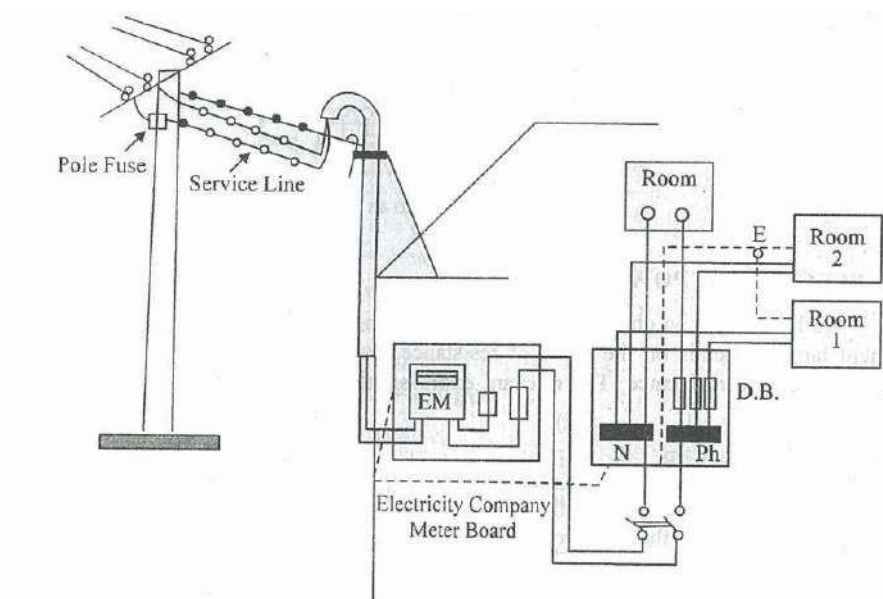
**5.2 Layout of House hold Electrical Wiring (Single Line Diagram)**

Fig. 5.1

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

1. Fuse
2. MCB (Miniature Circuit Breaker)
3. Lightening arrester
4. Earthing Wire

**5.4 Electrical Power**

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

$$P = VI$$

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

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 Electrical Installation**

Ex. A building has the following electrical appliances (i) 1 KW Motor. (ii) 2 bulbs 100w rating each (iii) Two fans having 60w each (iv) one heater 1.5 KW. Calculate the total Power Consumed by the building if all loads are switched on.

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

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

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

$$P = 1000 + 200 + 120 + 1500$$

$$P = 2820 W = 2.82 KW$$

**5.6 Electrical Energy**

Energy = Power X Time

$$E = P \times t$$

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

When P = 1 watt, t = 1 Second

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

When P = 1 Watt, t = 1 hour

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

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

1 watt hour = 3600 Watt Second = 3600 J =  $3.6 \times 10^3$  Joules

Similarly for bigger unit 1 Kw hr = 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 =  $255.9 \times \text{Rs.}2.5 = \text{Rs. } 639.75\text{P.}$



## **MEASURING INSTRUMENT CHAPTER-6**

### **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 Instruments:**

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).

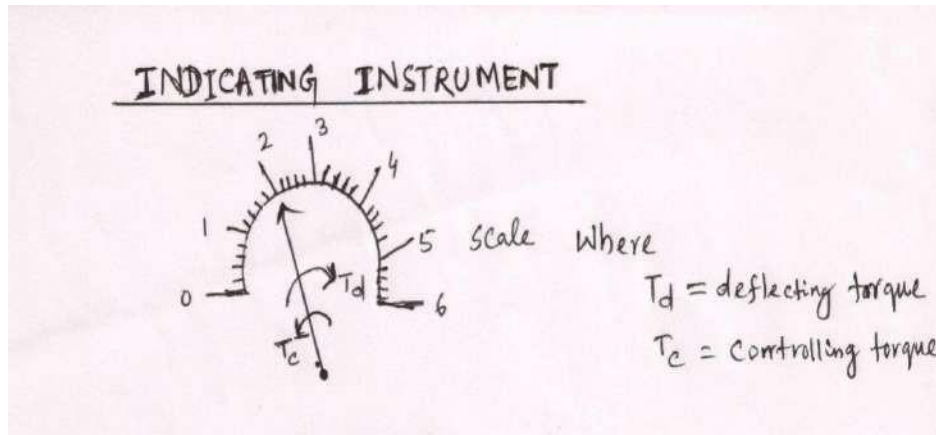


Figure: 7.1(a) Indicating Instrument.

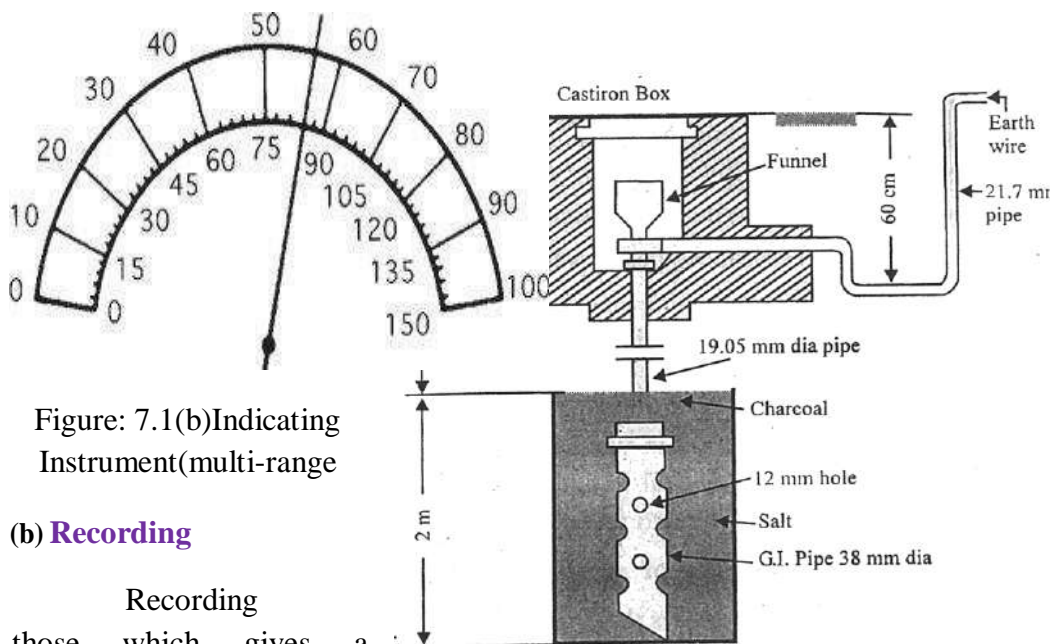


Figure: 7.1(b) Indicating Instrument (multi-range)

**(b) Recording**

Recording instruments are those which give a continuous 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).

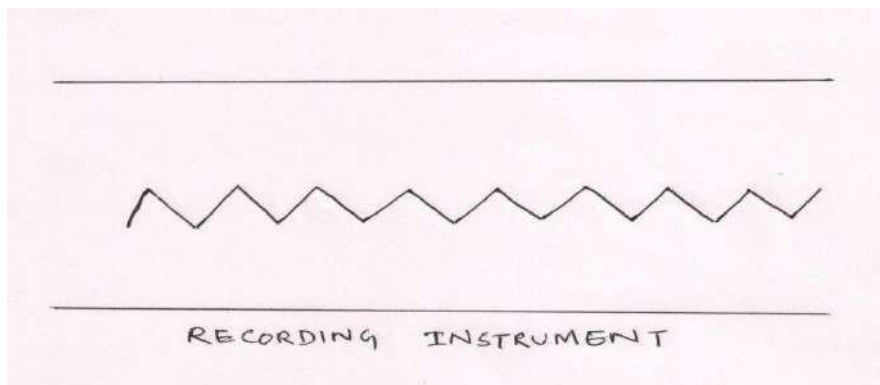


Figure: 7.1(c) Recording Instrument

**(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-hour meter.

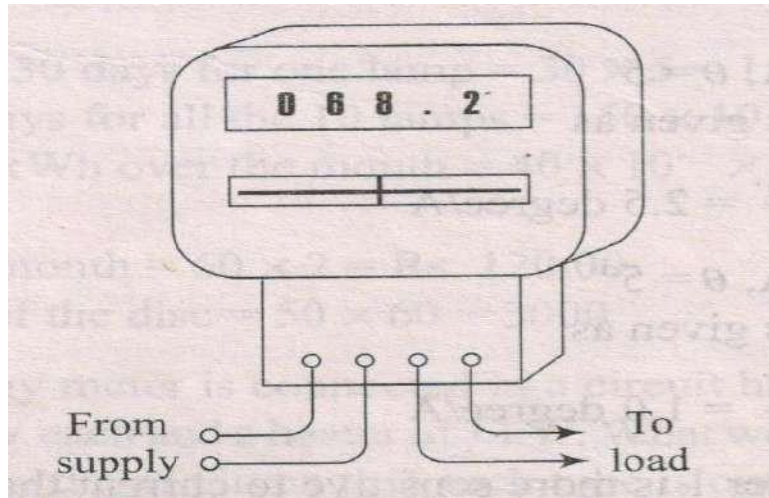


Figure: 7.1(d) Integrating Instrument

**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 gravity control.

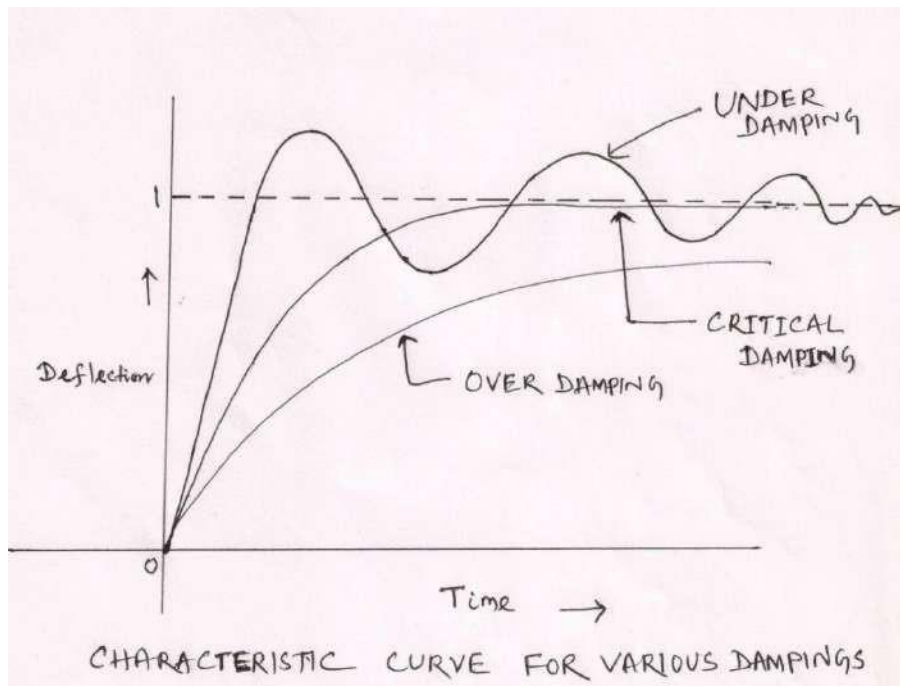
**(c) A damping device :-**

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).

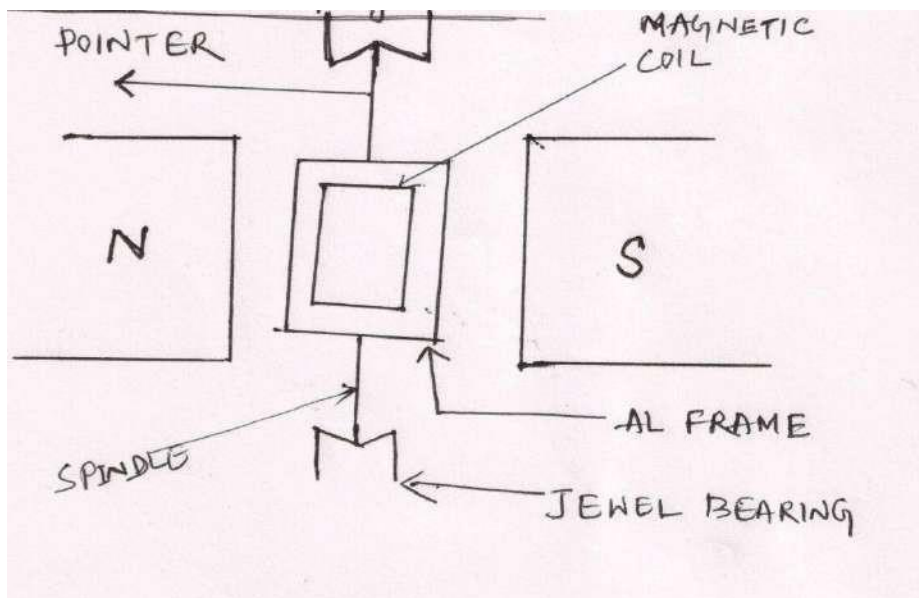


Figure: 7.1(f) Eddy-current damping

**(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).

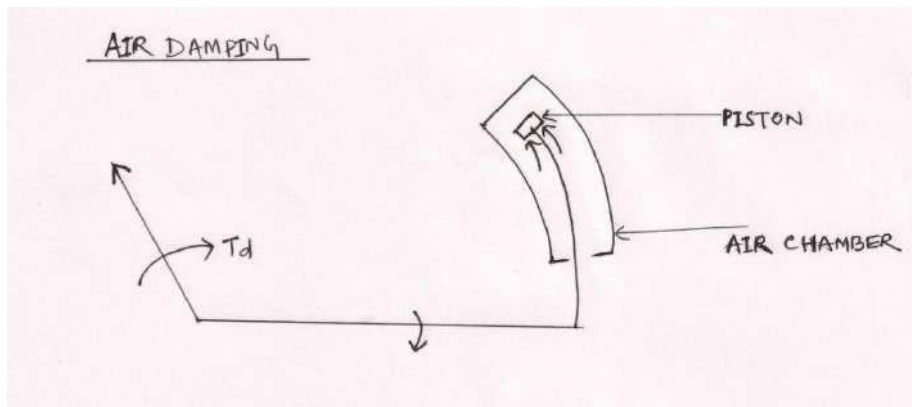


Figure: 7.1(g) Air friction damping

**(i) Fluid –friction damping.**

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

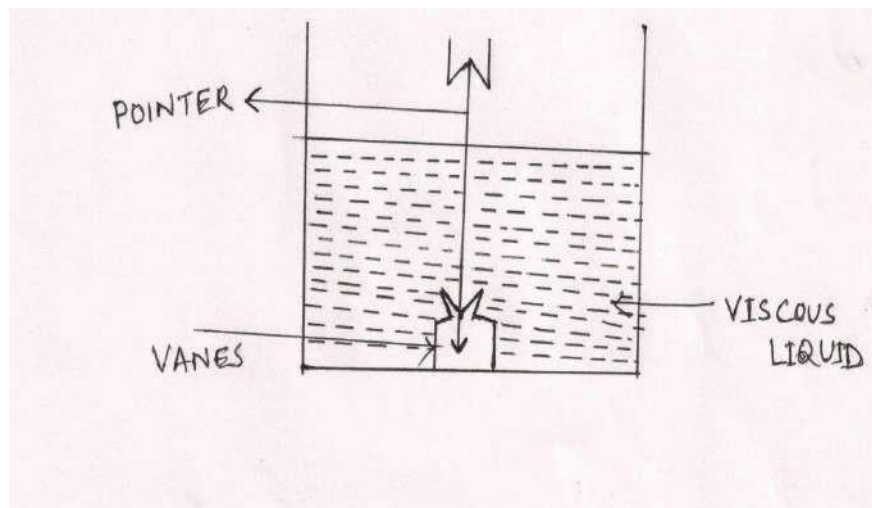


Figure: 7.1(h) Fluid friction damping

There are basically two types of scale –linear and non-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.

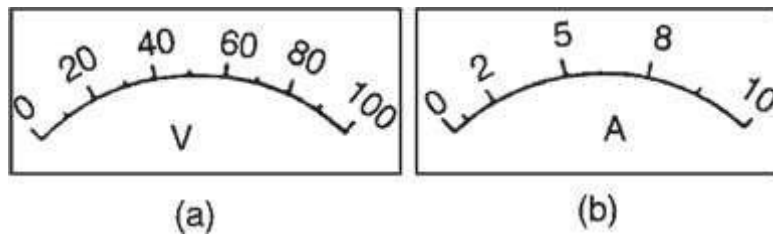


Figure 7.2 (a) Linear scale

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 ( $T_d$ ):

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

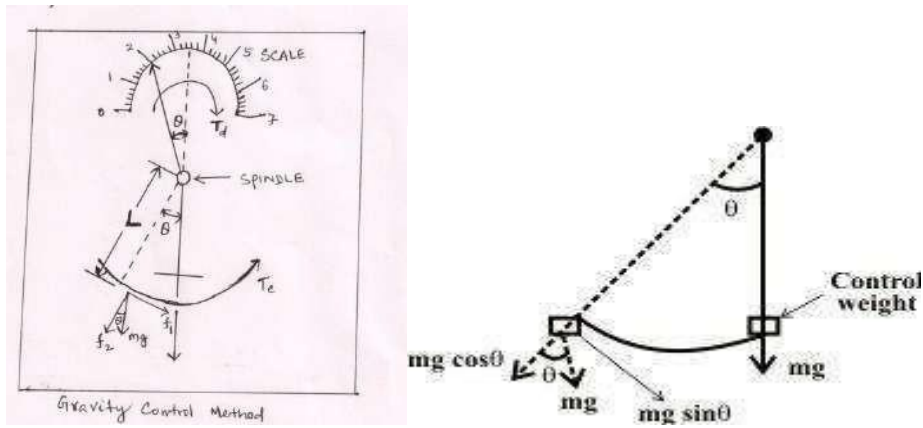
This oscillations are damped out by means of damping torque.

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 consider  $f_1 = mg \sin \theta$  &  $f_2 = mg \cos \theta$

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  $T_d = T_c$

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

$$T_c \propto \theta$$

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



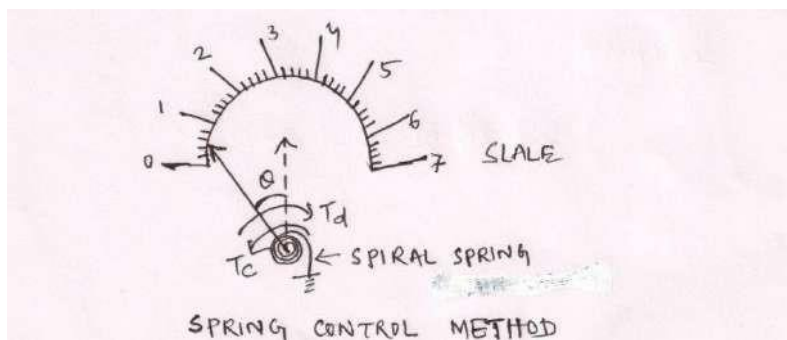


Figure 7.3.1(b) Spring Control Method

### 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.

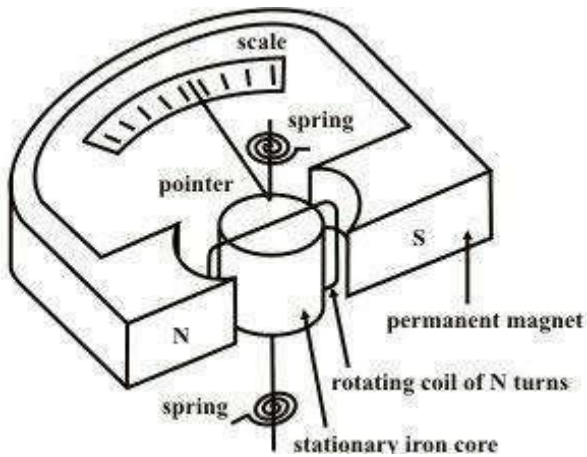


Figure 7.3(a) Permanent Magnet Moving Coil Instrument .

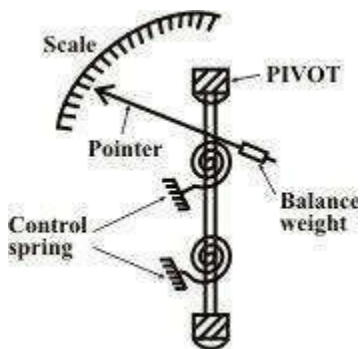


Figure 7.3(b) Spring control, balance weight arrangement of PMMC instrument.

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  $B$   $\text{wb}/\text{m}^2$ , 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 coil sides 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 spiral spring 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 coil 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 ( $\text{wb}/\text{m}^2$ )

$I$ =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.

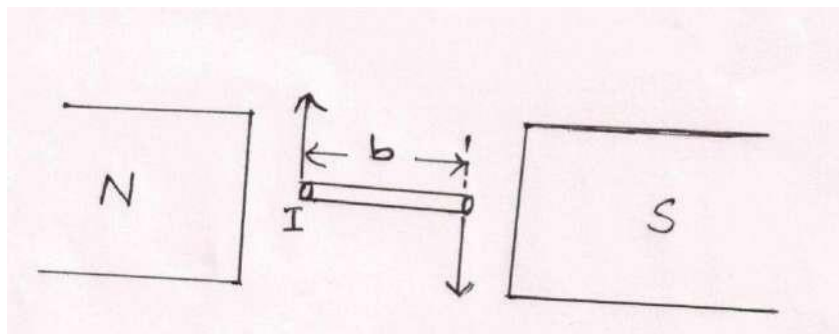


Fig. 7.3(c) Arrangement of conductor inside magnetic field

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  $=BIL \times N$

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

Torque due to both coil sides  $=b \times F$

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

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  $K_s$ =spring constant.

On steady state,

Controlling Torque =Deflecting Torque

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

$\theta=(BAN/K_s)I$

$$\theta \propto I \text{-----}(7.33)$$

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.

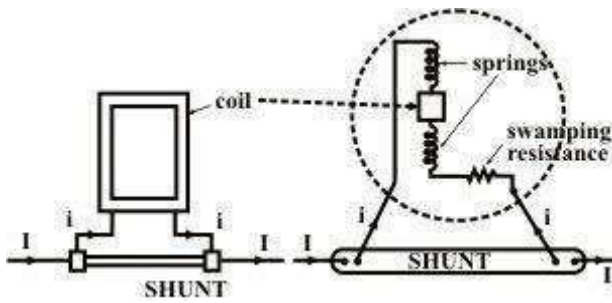


Fig.7.4 Multi-range ammeter circuit.

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 co-efficient 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.

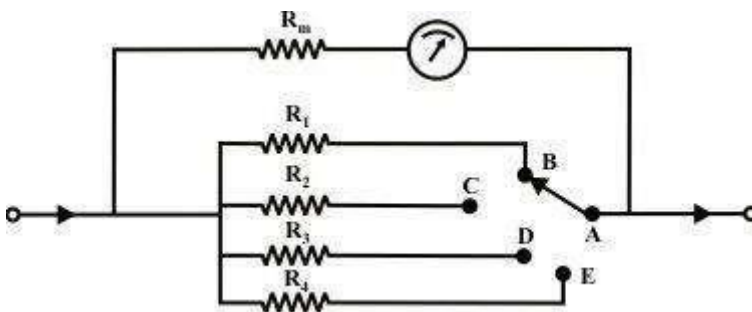


Fig. 7.5(a) Multi-range ammeter circuit.

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).

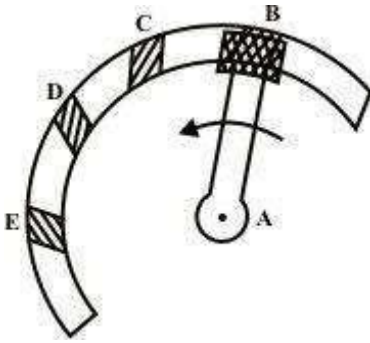


Fig.7.5(b) : Make-before break.

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.

**Problem No.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.

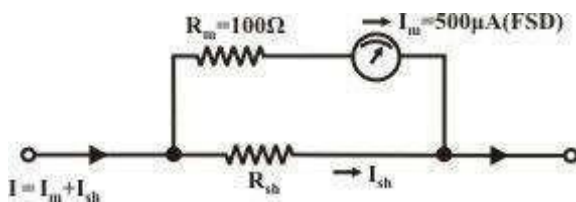


Fig.7.6.

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

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

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

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

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

$$\text{or, } R_{sh} = 0.01\Omega$$

**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 milliammeter used.

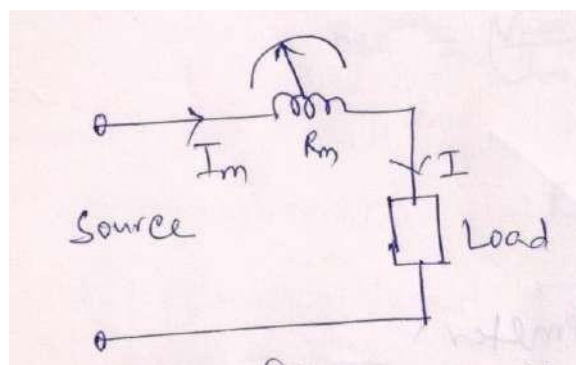


Fig.7.7(a) PMMC with low current rating

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:--

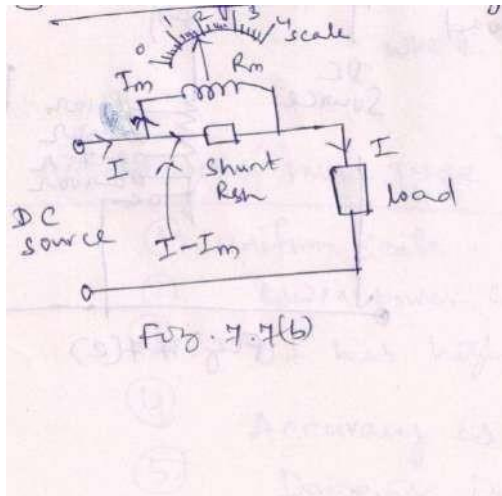


Fig.7.7(b)PMMC with high current rating

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

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

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

Where  $m = I/I_m$

$m$  = multiplication factor.

(c) Multiple range: --

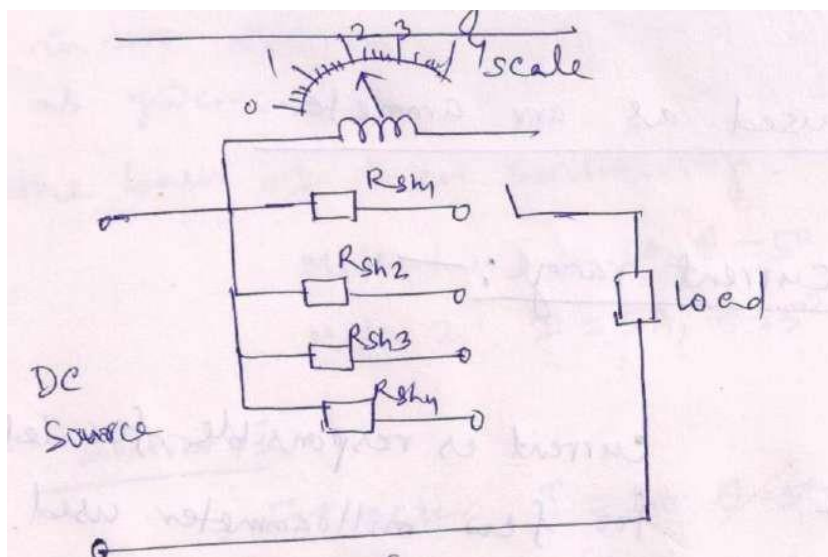




Fig.7.7 (c )PMMC with multiple range

(2) PMMC USED AS VOLTMETER :-

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

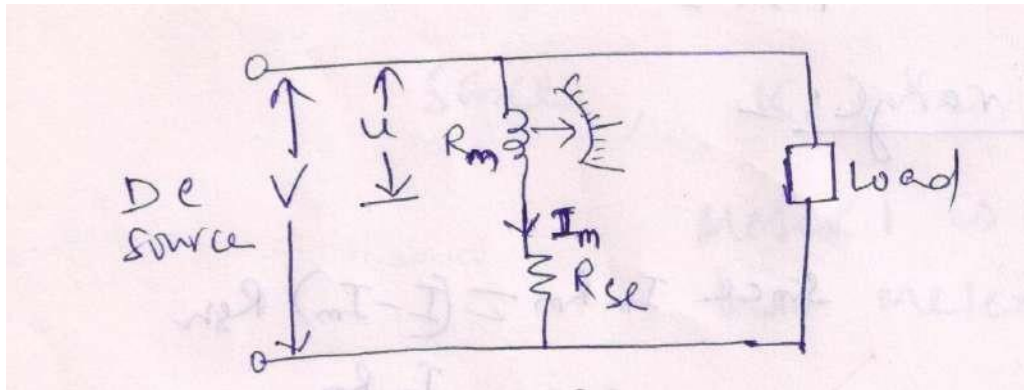


Fig.7.7(d)P

MMC as Voltmeter

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

$\theta \propto I_m$

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

i.e.,  $\theta \propto V$

MULTIPLE RANGE:--

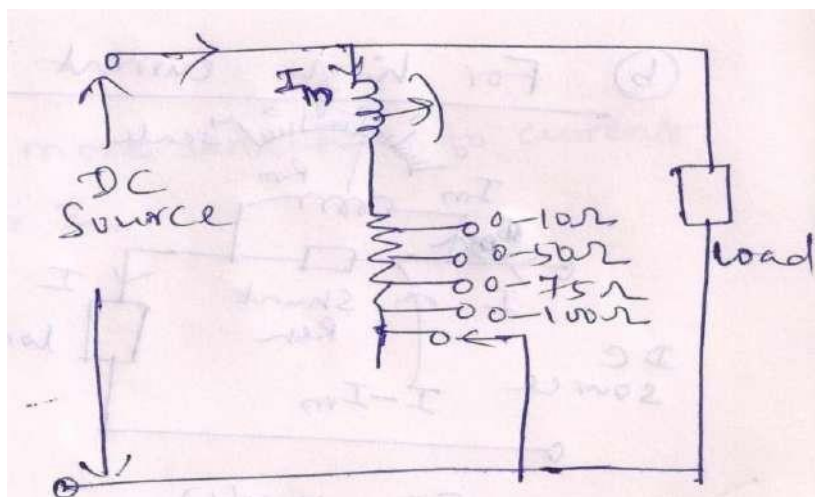


Fig.7.7(e)PMMC as Voltmeter(Multiple range)

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

$$=u+I_m R_{se}$$

$$V-u=I_m R_{se}$$

$$R_{se}=(V-u)/I_m=(V-u)/(u/R_m)$$

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

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

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 position.

#### Disadvantages :-

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

#### Application:-

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

#### 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 ( $R_{ss}$ ), by the full-scale reading in volts. In equation form, sensitivity is expressed as follows:

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

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 instruments namely

(A) Attraction (or single –iron) type

(B) Repulsion (or double iron) type.

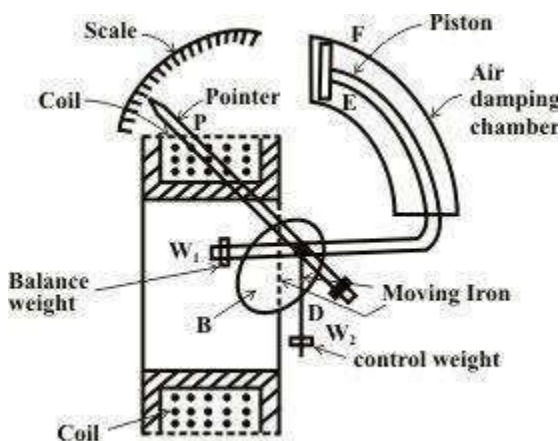
The brief description of different components of a moving-iron instrument is given below.

- (i) **Moving element:** a small piece of soft iron in the form of a vane or rod.
- (ii) **Coil :** to produce the magnetic field due to current flowing through it and also to magnetize the iron pieces.
- (iii) **In repulsion type** , a fixed vane or rod is also used and magnetized with the same polarity.
- (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 instrument spindle.
- (vi) **Deflecting torque** produces a movement on an aluminum pointer over a graduated scale.

### (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 fixed cylinder (F). The special shape 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,  $H \propto I$

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

$$\text{i.e., } H \propto I$$

$$\text{i.e., } m \propto H \propto I$$

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

$$\text{i.e., } T_d = T_c$$

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

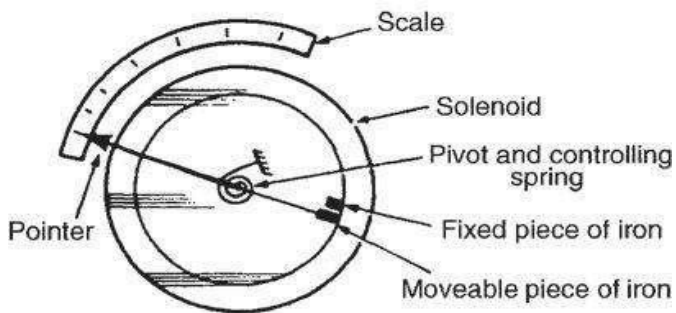
$$\text{i.e., } \sin \theta \propto I^2 \text{-----(7.41)}$$

**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  $m_1 \propto H \propto I$

Magnetic pole strength on the fixed iron  $m_2 \propto H \propto I$

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 simpl 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:-

$$(a) T_d \propto I, \quad 10A \rightarrow 70^\circ$$

$$5A \rightarrow \theta = ?$$

$$T_c \propto \theta$$

$$\theta \propto I$$

$$70^\circ \propto 10$$

$$\theta \propto 5$$

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

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

$$\theta = 35^\circ$$

$$(b) T_d \propto I$$

$$T_c \propto \sin \theta$$

$$\sin \theta \propto I$$

$$\sin 70^\circ \propto 10$$

$$\sin \theta \propto 5$$

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

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

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

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

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

$$= 28.2^\circ$$

#### Problem No.4:

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

Solution:

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

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

At steady state,

Deflecting torque = controlling torque

$$\text{i.e., } T_d = K_s \theta$$

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

Now

$$\text{Angular deflection, } \theta = \frac{28.8 \times 10^{-6}}{0.3 \times 10^{-6}} = 96^\circ$$

#### 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:-

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

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

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

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

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

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

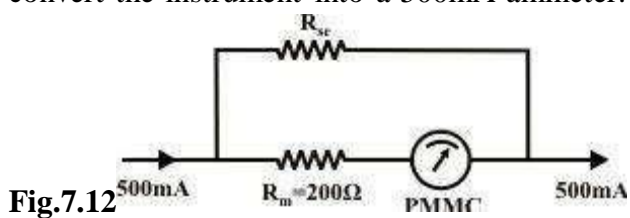
$$= 0.0266 \text{ m}$$

$$= 26.6 \text{ mm}$$

**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.  $0.08\Omega$ )



## 7.5 Integrating type instrument

### 7.5.1 Energy meter (1-φ type):

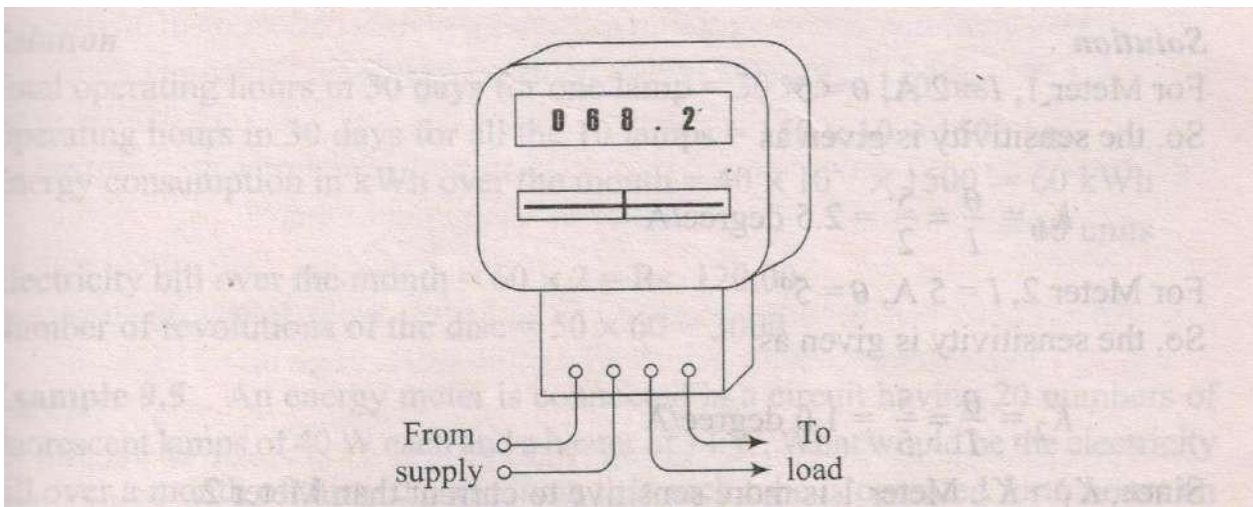


Fig. 7.5.1 External view of an energy meter

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

$$\text{Energy } \int N dt = \int VI \cos \theta dt = \int P dt \text{-----(2)}$$

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.

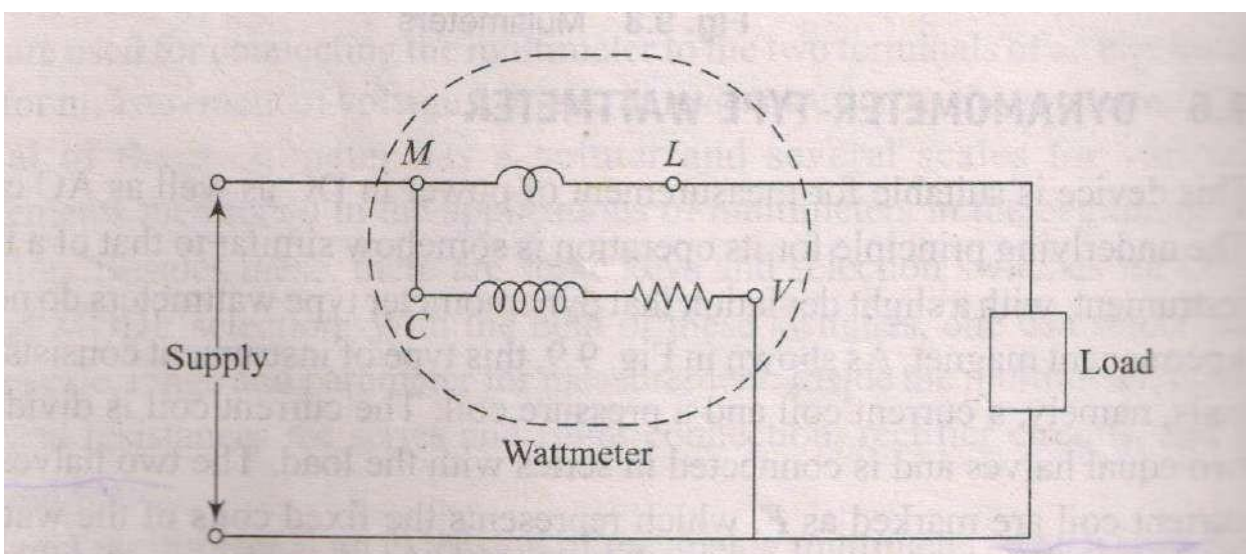


Fig. 7.5.2(a) Circuit diagram of a dynamometer type wattmeter.

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)**

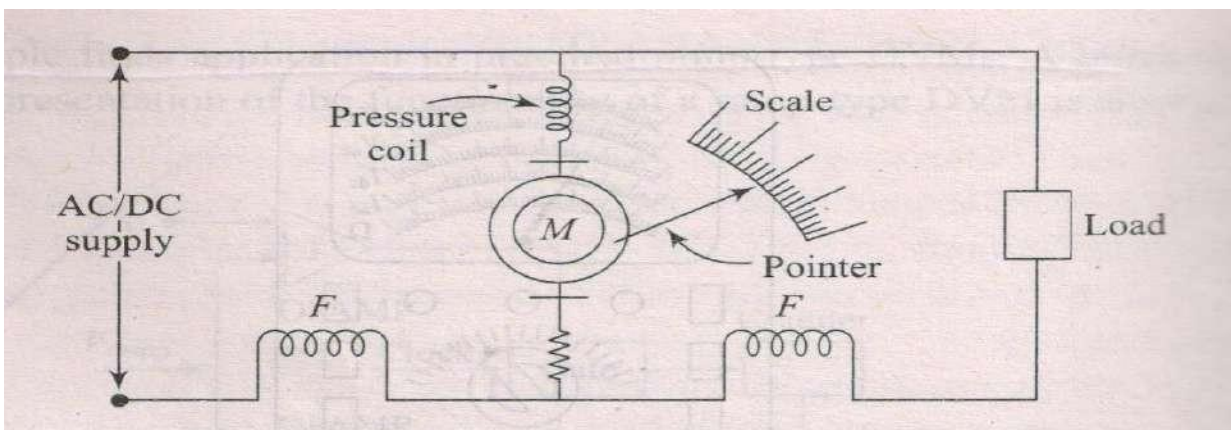


Fig. 7.5.2(b) Schematic of dynamometer type wattmeter

Here

F=Current coil

M=Moving coil

### 7.5.3. Ammeter

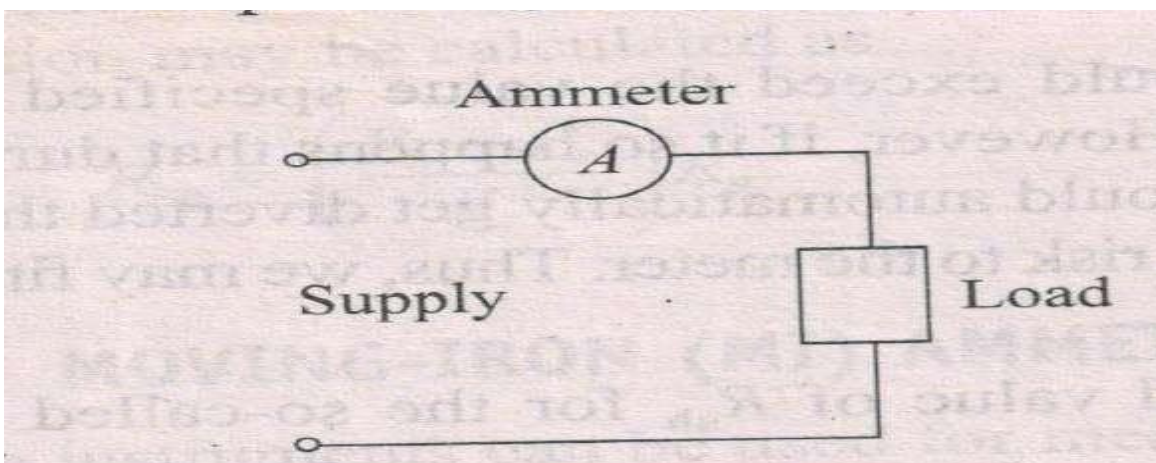


Fig. 7.5.3(a) Ammeter connection

**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

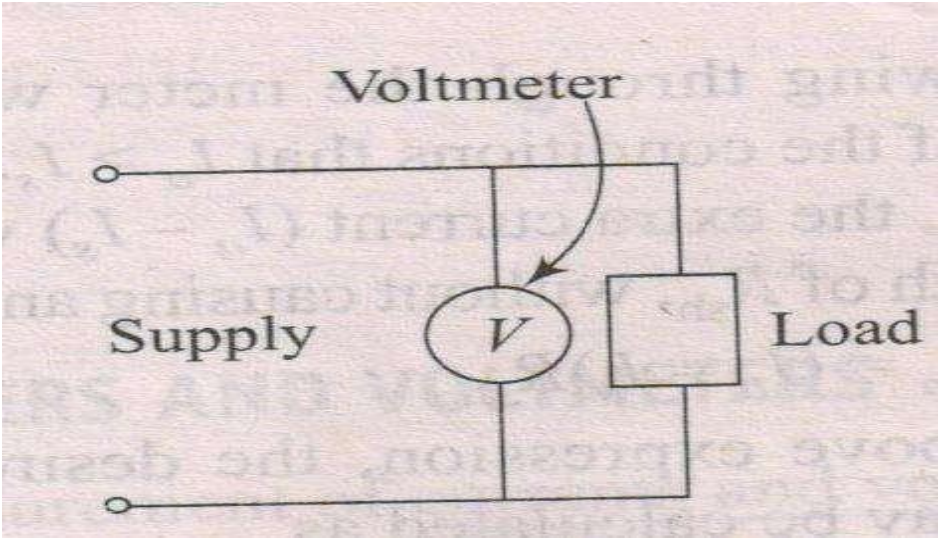


Fig. 7.5.4. Circuit diagram for voltmeter

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.

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