LEARNING MATERIAL OF

BASIC ELECTRICAL ENGG

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SYLLABUS

Th.4(a). BASIC ELECTRICAL ENGINEERING
(1st sem Common)

Theory: 2 Periods per Week
Total Periods: 30 Periods
Examination: 1.5 Hours

I.A   :   10 Marks
End Sem Exam   : 40   Marks
TOTAL MARKS : 50 Marks

Topic wise Distribution of Periods and Marks

Sl.No.	Topics	Periods
1	Fundamentals	05
2	A C Theory	08
3	Generation of Elect. Power	03
4	Conversion of Electrical Energy	07
5	Wiring and Power Billing	04
6	Measuring Instrument	03
	Total	**30**

Objective
1.   To be familiar with A.C Fundamental and circuits
2.   To be familiar with basic principle and application of energy conversion devices
3.   To be familiar with generation of Electrical power
4.   To be familiar with wiring and protective device
5.   To be familiar with calculation and commercial Billing of electrical power & energy
6.   To have basic knowledge of various electrical measuring instruments & conservation of electrical energy

1. FUNDAMENTALS

1.1   Concept of current flow.

1.2   Concept of source and load.

1.3   State Ohm"s law and concept of resistance.

1.4   Relation of V, I & R in series circuit.

1.5   Relation of V, I & R in parallel circuit.

1.6   Division of current in parallel circuit.

1.7   Effect of power in series & parallel circuit.

1.8   Kirchhoff"s Law.

1.9 Simple problems on Kirchhoff"s law.

2. A.C. THEORY

2.1   Generation of alternating emf.

2.2   Difference between D.C. & A.C.

2.3   Define Amplitude, instantaneous value, cycle, Time period, frequency, phase angle, phase difference.

2.4   State & Explain RMS value, Average value, Amplitude factor & Form factor with Simple problems.

2.5   Represent AC values in phasor diagrams.

2.6   AC through pure resistance, inductance & capacitance

2.7   AC though RL, RC, RLC series circuits.

2.8   Simple problems on RL, RC & RLC series circuits.

2.9   Concept of Power and Power factor

2.10 Impedance triangle and power triangle.

3. GENERATION OF ELECTRICAL POWER

3.1 Give elementary idea on generation of electricity from thermal , hydro & nuclear power station with block diagram

4. CONVERSION OF ELECTRICAL ENERGY

(No operation, Derivation, numerical problems)

4.1 Introduction of DC machines.

4.2 Main parts of DC machines.

4.3 Classification of DC generator

4.4 Classification of DC motor.

4.5 Uses of different types of DC generators & motors.

4.6 Types and uses of single phase induction motors.

4.7 Concept of Lumen

4.8 Different types of Lamps (Filament, Fluorescent, LED bulb) its Construction and Principle.

4.9 Star rating of home appliances (Terminology, Energy efficiency, Star rating Concept)

5. WIRING AND POWER BILLING

5.1 Types of wiring for domestic installations.

5.2 Layout of household electrical wiring (single line diagram showing all the important component in the system).

5.3 List out the basic protective devices used in house hold wiring.

5.4 Calculate energy consumed in a small electrical installation

6. MEASURING INSTRUMENTS

6.1 Introduction to measuring instruments.

6.2 Torques in instruments.

6.3 Different uses of PMMC type of instruments (Ammeter & Voltmeter).

6.4 Different uses of MI type of instruments (Ammeter & Voltmeter).

6.5 Draw the connection diagram of A.C/ D.C Ammeter, voltmeter, energy meter and wattmeter. (Single phase only).

CONTENTS

CHAPTER-1
FUNDAMENTALS

CHARGE:-

- The most basic quantity in an electric circuit is the electric charge.
- Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C). Charge, positive or negative, is denoted by the letter q or Q.
- All matter is made of fundamental building blocks known as atoms and that each atom consists of electrons, protons, and neutrons. We also know that the charge „e" on an electron is negative and equal in magnitude to $1.602x10^{-19}$ C, while a proton carries a positive charge of the same magnitude as the electron and the neutron has no charge. The presence of equal numbers of protons and electrons leaves an atom neutrally charged.

CURRENT:-

- Current can be defined as the motion of charge through a conducting material, measured in Ampere (A). Electric current, is denoted by the letter i or I.
- The unit of current is the ampere abbreviated as (A) and corresponds to the quantity of total charge that passes through an arbitrary cross section of a conducting material per unit second.

    Mathematically,

    $$I = \frac{Q}{t} \quad \text{or} \quad Q = It$$ ....(1.1)

    Where Q is the symbol of charge measured in Coulombs (C), I is the current in amperes (A) and t is the time in second (s).

- The current can also be defined as the rate of charge passing through a point in an electric circuit. Mathematically,

    $$i = \frac{dq}{dt}$$ ....(1.2)

- The charge transferred between time t_1 and t_2 is obtained as

 $$q = \int_{t1}^{t2} idt$$ .... (1.3)

- A constant current (also known as a direct current or DC) is denoted by symbol I whereas a time-varying current (also known as alternating current or AC) is represented by the symbol i or i (t).
- Current is always measured through a circuit element in ammeter as shown in Fig.1.1
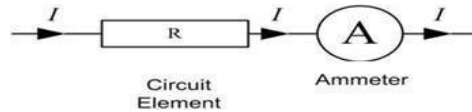
(**Fig. 1.1.** Current through Resistor (R))

- Two types of currents:
  1) A direct current (DC) is a current that remains constant with time.
  2) An alternating current (AC) is a current that varies with time.

(a)   (b)
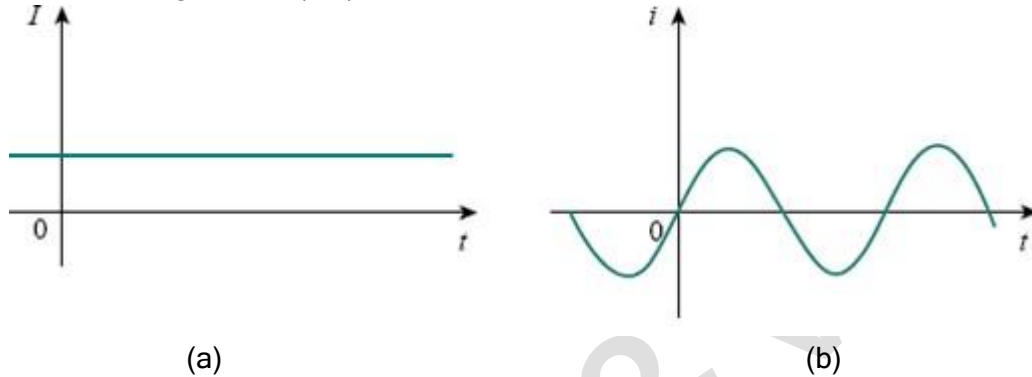
(**Fig.1.2.** Two common types of current: (a) Direct Current (b) Alternating Current)

VOLTAGE (OR) POTENTIAL DIFFERENCE:-

- To move the electron in a conductor in a particular direction requires some work or energy transfer. This work is performed by an external electromotive force (emf), typically represented by the battery in Fig 1.3(a). This emf is also known as voltage or potential difference. The voltage V_{ab} between two points a and b in an electric circuit is the energy (or work) needed to move a unit charge from a to b.

Battery

(a)

(b)
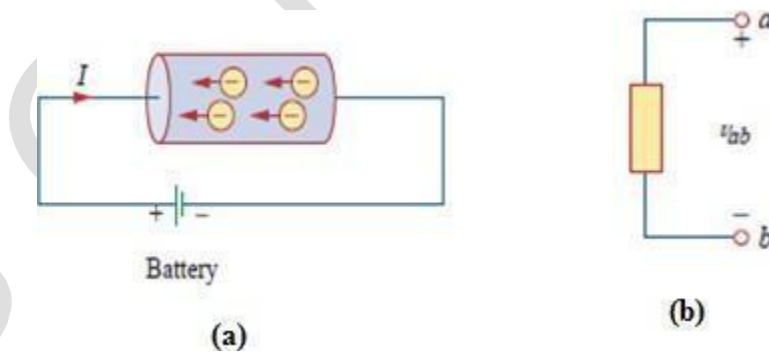
(**Fig. 1.3**.(a) Electric Current in a conductor, (b) Polarity of voltage V_{ab})

- Voltage (or potential difference) is the energy required to move charge from one point to the other, measured in volts (V). Voltage is denoted by the letter v or V.

  Mathematically,

$$V_{ab} = \frac{dw}{dt}$$

..........(1.4)

2

where w is energy in joules (J) and q is charge in coulombs (C). The voltage Vab or simply V is measured in volts (V).

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

Fig1.3(b). shows the voltage across an element (represented by a rectangular block) connected to points a and b. The plus (+) and minus (-) signs are used to define reference direction or voltage polarity.

● The V_{ab} can be interpreted in two ways: (1) point a is at a potential of V_{ab} volts higher than point b, or (2) the potential at point a with respect to point b is V_{ab}. It follows logically that in general

$$V_{ab} = -V_{ba}$$ ....(1.5)

● Voltage is always measured across a circuit element in Voltmeter as shown in Fig.1.4
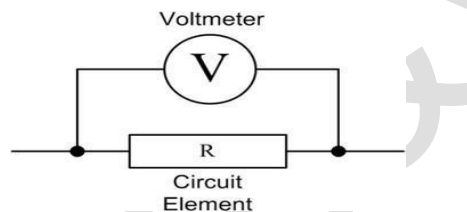
(**Fig.1.4.** Measurement of voltage through voltmeter across circuit element)

POWER:-

● Power is the time rate of expending or absorbing energy, measured in watts (W). Power, is denoted by the letter p or P.
Mathematically,

$$P = \frac{dw}{dt}$$ ....(1.6)

Where P is power in watts (W), w is energy in joules (J), and t is time in seconds (s). From voltage and current equations, it follows that;

$$P = \frac{dw}{dt} = \frac{dw}{dq} \times \frac{dq}{dt} = V \times I$$ ....(1.7)

Thus, if the magnitude of current I and voltage are given, then power can be evaluated as the product of the two quantities and is measured in watts (W).
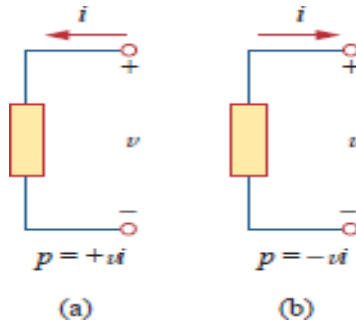
● **Sign of power:**

Plus sign: Power is absorbed by the element. (Resistor, Inductor)
Minus sign: Power is supplied by the element. (Battery, Generator)

- **Passive sign convention:**
  If the current enters through the positive polarity of the voltage, P = +VI
  If the current enters through the negative polarity of the voltage, P = - VI

$$p = +vi \qquad\qquad p = -vi$$
$$(a) \qquad\qquad\qquad (b)$$

(**Fig.1.5.** Polarities for Power using passive sign convention
(a) Absorbing Power (b) Supplying Power)

ENERGY:-

- Energy is the capacity to do work, and is measured in joules (J).
- The energy absorbed or supplied by an element from time 0 to t is given by,

$$W = \int_0^t P \, dt = \int_0^t VI \, dt$$

...........(1.8)

- The electric power utility companies measure energy in watt-hours (WH) or Kilo watt-hours (KWH).

$$1 \text{ WH} = 3600 \text{ J}...(1.9)$$

ENERGY SOURCES:-

- The energy sources which are having the capacity of generating the energy. The most important energy sources are voltage or current sources that generally deliver power/energy to the circuit connected to them.

  There are two kinds of sources
  a) Independent sources
  b) Dependent sources

a) Independent Sources:

An ideal independent source is an active element that provides a specified voltage or current that is completely independent of other circuit elements.

Ideal Independent Voltage Source:

An ideal independent voltage source is an active element that gives a constant voltage across its terminals irrespective of the current drawn through its terminals.

Ideal Independent Current Source:

An ideal independent Current source is an active element that gives a constant current through its terminals irrespective of the voltage appearing across its terminals.

b) Dependent (Controlled) Sources:

- An ideal dependent (or controlled) source is an active element in which the source quantity is controlled by another voltage or current.
- Dependent sources are usually designated by diamond-shaped symbols, as shown in Fig.1.6 Since the control of the dependent source is achieved by a voltage or current of some other element in the circuit, and the source can be voltage or current, it follows that there are four possible types of dependent sources, namely:

  1. A voltage-controlled voltage source (VCVS)
  2. A current-controlled voltage source (CCVS)
  3. A voltage-controlled current source (VCCS)
  4. A current-controlled current source (CCCS)

(a) VCVS   (b)CCVS   (c) VCCS   (d)CCCS
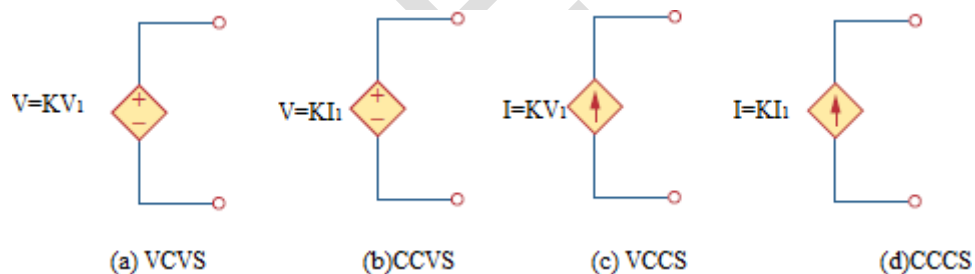
(**Fig.1.6.** (a) voltage-controlled voltage source (b) current-controlled voltage source (c) voltage-controlled current source (d) current-controlled current source)

ELECTRICAL LOAD:-

- The electrical load is a device that consumes electrical energy in the form of the current and transforms it into other forms like heat, light, work etc.
- The electrical load are (a) Resistive (b) Inductive (c) Capacitive
- **Resistive Load** – The resistive load obstructs the flow of electrical energy in the circuit and converts it into thermal energy.
  Ex- Lamp, Heater
- **Inductive Load-** The inductive load has a coil which stores magnetic energy when the current pass through it.
  Ex- Generator, motor, transformer
- **Capacitive Load-** The capacitive load include energy stored in materials and device.
 Ex- capacitor bank and synchronous condenser

OHM'S LAW:-

- Georg Simon Ohm (1787-1854), a German physicist, is credited with finding the relationship between current and voltage for a resistor. This relationship is known as Ohm"s law.
- Ohm"s law states that at constant temperature, the voltage (V) across a conducting material is directly proportional to the current (I) flowing through the material. Mathematically,

$$V \propto I$$
$$V = RI \qquad \qquad \text{.........(1.10)}$$

Where the constant of proportionality R is called the resistance of the material. The V-I relation for resistor according to Ohm"s law is depicted in Fig.1.7
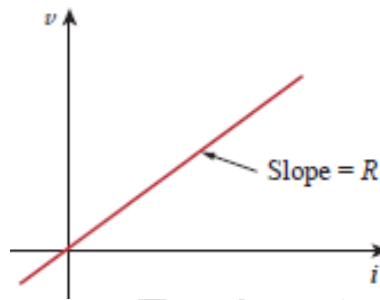
(**Fig.1.7.** V-I Characteristics for resistor)

Limitations of Ohm"s Law:
1. Ohm"s law is not applicable to non-linear elements like diode, transistor etc.
2. Ohm"s law is not applicable for non-metallic conductors like silicon carbide.

Example-1.1. An electrical iron carrying 2A at 120V. Find resistance of the device?

Solution:

$$R = \frac{V}{I} = \frac{120}{2} = 60\Omega$$

Example-1.2. The essential component of a toaster is an electrical element (a resistor) that converts electrical energy to heat energy. How much current is drawn by a toaster with resistance 12Ω at 110V?

Solution:

$$I = \frac{V}{R} = \frac{110}{12} = 9.167\,Amp$$

RESISTOR:-

Materials in general have a characteristic behavior of resisting the flow of electric charge. This physical property, or ability to resist the flow of current, is known as resistance and is represented by the symbol R. The Resistance is measured in ohms (Ω).

RELATION OF V,I &R IN SERIES CIRCUIT: -

Two or more resistors are said to be in series if the same current flows through all of them. The process of combining the resistors is facilitated by combining two of them at a time. With this in
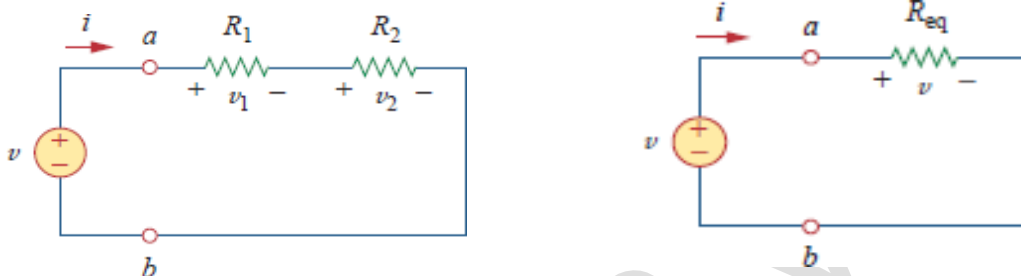
mind, consider the single-loop circuit of Fig.1.8

| (a) | (b) |

(**Fig.1.8.** (a) A single loop circuit with two resistors in series, (b) Equivalent Circuit of series resistors)

The two resistors are in series, since the same current i flow in both of them. Applying Ohm"s law to each of the resistors, we obtain

$$V_1 = iR_1, V_2 = iR_2$$

........(1.11)

If we apply KVL in the loop (moving in the clockwise direction), we have

$$V - V_1 - V_2 = 0$$

.........(1.12)

Combining equation (1.11) &(1.12), we get

$$V = V_1 + V_2 = iR_1 + iR_2 = i(R_1 + R_2)$$

..........(1.13)

Equation (1.13) can be written as $V = iR_{eq}$ ....(1.14)

Where $R_{eq} = R_1 + R_2$ i.e. the summation of two resistors.

From Eq.(1.13) we get,

$$i = \frac{V}{R_1 + R_2}$$

.........(1.15)

In general, the equivalent resistance of any number of resistors connected in series is the sum of the individual resistances.

For N resistors in series then,

$$R_{eq} = R_1 + R_2 + \ldots + R_N = \sum_{n=1}^{N} R_n$$

..........(1.16)

Voltage Division:

To determine the voltage across each resistor in Fig.1.8, we substitute Eq. (1.15) into Eq. (1.11) and obtain

$$V_1 = \frac{V}{R_1 + R_2} R_1, V_2 = \frac{V}{R_1 + R_2} R_2$$

.........(1.17)

Note that the source voltage is divided among the resistors in direct proportion to their resistances; the larger the resistance, the larger the voltage drop. This is called the principle of voltage division.

Example.1.3. Find the current I passing through and the voltage across each of the resistors in the circuit.
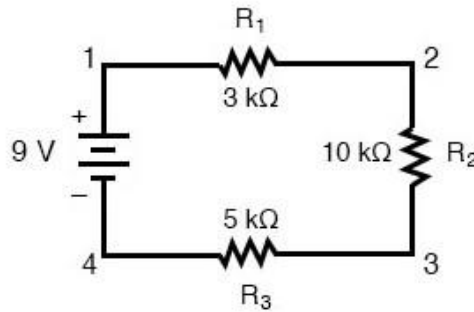
Solution: $R_{total} = R_1 + R_2 + R_3 = 3K\Omega + 10K\Omega + 5K\Omega = 18K\Omega$

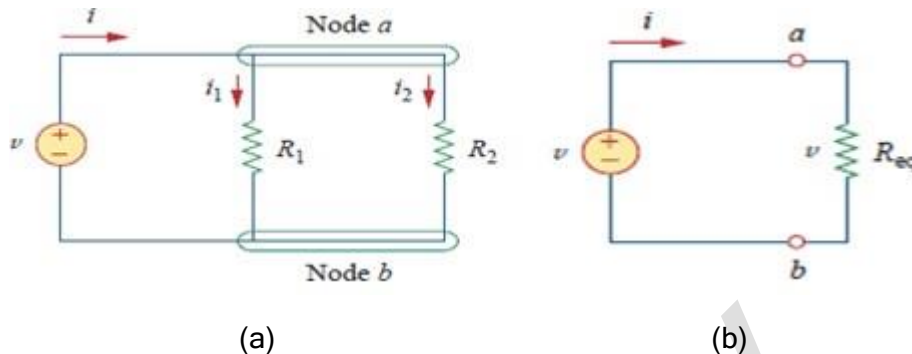$$I = \frac{V}{R_{total}} = \frac{9}{18 \times 10^3} = 0.5 \text{ mA}$$

$$V_{R1} = \frac{VR1}{R_1 + R_2 + R_3} = \frac{9}{18 \times 10^3} \times 3 \times 10^3 = 1.5V$$

$$V_{R2} = \frac{V}{R_1 + R_2 + R_3} R_2 = \frac{9}{18 \times 10^3} \times 10 \times 10^3 = 5V$$

$$V_{R3} = \frac{V}{R_1 + R_2 + R_3} R3 = = 2.5V$$

8

RELATION OF V,I &R IN PARALLEL CIRCUIT:-

Two or more resistors are said to be in parallel if the same voltage appears across each element. Consider the circuit in Fig.1.9(a) , where two resistors are connected in parallel and therefore have the same voltage across them.

(a)   (b)

(**Fig: 1.9.** (a) Two resistors in parallel (b) Equivalent circuit)

$$v = i_1 R_1 = i_2 R_2 \qquad\qquad\qquad ..... (1.18)$$

$$i_1 = \frac{v}{R_1}, i_2 = \frac{v}{R_2} \qquad\qquad\qquad ...... (1.19)$$

Applying KCL at node a gives the total current i is

$$i = i_1 + i_2 \qquad\qquad\qquad .....(1.20)$$

Substituting Equation 1.19 into 1.20, we get

$$i = \frac{v}{R_1} + \frac{v}{R_2} = v\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{v}{R_{eq}} \qquad\qquad ......(1.21)$$

Where R_{eq} is the equivalent resistance of the resistors in parallel.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad\qquad\qquad ......(1.22)$$

Thus, The equivalent Resistance of parallel-connected resistors is the reciprocal of the sum of the reciprocals of the individual resistances.

If a circuit with N resistors in parallel then the equivalent resistance is

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} +............ + \frac{1}{R_N} = \sum_{n=1}^{N} \frac{1}{R_n} \qquad ....(1.23)$$

DIVISION OF CURRENT IN PARALLEL CIRCUIT:-

We know that the equivalent resistor has the same voltage, or

$$v = iR_{eq} = \frac{iR_1R_2}{R_1 + R_2}$$

......(1.24)

Substituting eq (1.24) into (1.19)

$$i_1 = \frac{iR_2}{R_1 + R_2}$$

$$i_2 = \frac{iR_1}{R_1 + R_2}$$

.......(1.25)

This shows that the total current is shared by the resistors in inverse proportion to their resistances. This is known as the principle of current division, and the circuit is known as a current divider.

Example.1.4. Find the current I passing through and the current passing through each of the resistors in the circuit below.
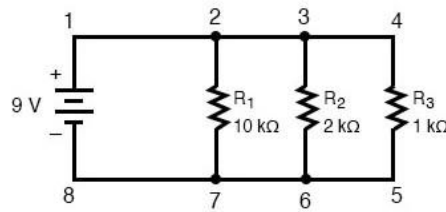
Solution:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{10 \times 10^3} + \frac{1}{2 \times 10^3} + \frac{1}{1 \times 10^3} = 0.0016$$

$$R_{total} = 625\Omega$$

$$I = \frac{V}{R_{total}} = \frac{9}{625} = 0.0144 Amp = 14.4mA$$

$$I_{R1} = \frac{V}{R_1} = \frac{9}{10 \times 10^3} = 0.9mA$$

$$I_{R2} = \frac{V}{R_2} = \frac{9}{2 \times 10^3} = 4.5mA$$

$$I_{R3} = \frac{V}{R_3} = \frac{9}{1 \times 10^3} = 9mA$$

POWER IN SERIES & PARALLEL CIRCUIT:-

(a) Series Combinations:- If the electrical appliances of power P_1 & P_2 are connected in series with main voltage V having resistance R_1 & R_2, then

$$R_1 = \frac{V^2}{F_1}; R_2 = \frac{V^2}{P_2} \qquad \left(\cdot\, P = \frac{V^2}{R} \right) \quad \text{.....(1.26)}$$

When connected in series, then their effective resistance is $R = R_1 + R_2$

$$\frac{V^2}{P} = \frac{V^2}{P_1} + \frac{V^2}{P_2} \Rightarrow \frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} \quad \text{......(1.27)}$$

(b) Parallel Combinations:- If the electrical appliances of power P_1 & P_2 are connected in parallel with main voltage V having resistance R_1 & R_2, then

$$R_1 = \frac{V^2}{F_1}; R_2 = \frac{V^2}{P_2} \qquad \left(\cdot\, P = \frac{V^2}{R} \right) \quad \text{........(1.28)}$$

When connected in parallel, then their effective resistance is

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{P}{V^2} = \frac{P_1}{V^2} + \frac{P_2}{V^2} \Rightarrow P = P_1 + P_2 \quad \text{..........(1.29)}$$

KIRCHHOFF'S LAWS:-

The most common and useful set of laws for solving electric circuits are the Kirchhoff"s voltage and current laws. Several other useful relationships can be derived based on these laws. These laws are formally known as Kirchhoff"s current law (KCL) and Kirchhoff"s voltage law (KVL).

KIRCHHOFF'S CURRENT LAW (KCL)

This is also called as Kirchhoff's first law or Kirchhoff"s nodal law. Kirchhoff"s first law is based on the law of conservation of charge, which requires that the algebraic sum of charges within a system cannot change.
Statement: Algebraic sum of the currents meeting at any junction or node is zero. The term „algebraic" means the value of the quantity along with its sign, positive or negative.

Mathematically, KCL implies that

$$\sum_{n=1}^{N} i_n = 0 \quad \text{........(1.30)}$$

Where N is the number of branches connected to the node and is the nth current entering (or leaving) the node. By this law, currents entering a node may be regarded as positive, while

currents leaving the node may be taken as negative or vice versa.
Alternate Statement: Sum of the currents flowing towards a junction is equal to the sum of the currents flowing away from the junction
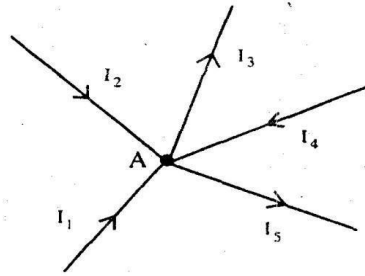
(**Fig.1.10.** Currents meeting in a junction)

Explanation:-

Consider Fig.1.10. where five branches of a circuit are connected together at the junction or node A. Currents I_1, I_2 and I_4 are flowing towards the junction whereas currents I_3 and I_5 are flowing away from junction A. If a positive sign is assigned to the currents I_2 and I_4 that are flowing into the junction then the currents I_3 and I_4 flowing away from the junction should be assigned with the opposite sign i.e. the negative sign.
Applying Kirchhoff"s current law to the junction A

$$I_1 + I_2 - I_3 + I_4 - I_5 = 0 \text{ (algebraic sum is zero)}$$

The above equation can be modified as $I_1 + I_2 + I_4 = I_3 + I_5$ (sum of currents towards the junction = sum of currents flowing away from the junction).

KIRCHHOFF'S VOLTAGE LAW (KVL):-

This is also called as Kirchhoff's second law or Kirchhoff's loop or mesh law. Kirchhoff"s second law is based on the principle of conservation of energy.
**Statement:** Algebraic sum of all the voltages around a closed path or closed loop at any instant is zero. Algebraic sum of the voltages means the magnitude and direction of the voltages; care should be taken in assigning proper signs or polarities for voltages in different sections of the circuit.
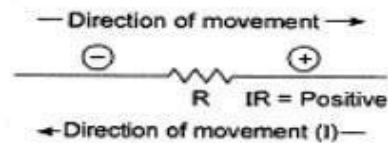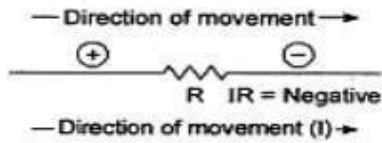
Mathematically, KVL implies that

$$\sum_{n=1}^{N} V_n = 0$$

.............(1.31)

Where N is the number of voltages in the loop (or the number of branches in the loop) and is the n voltage in a loop.
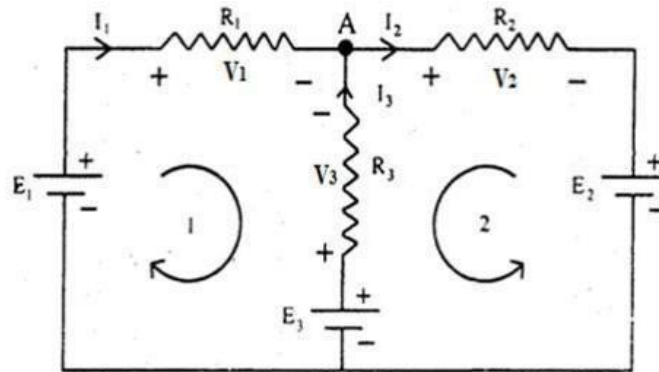Sign Rules of KVL : If we give positive sign to all rise in potential then we must give Negative sign for all fall in potential and vice versa.
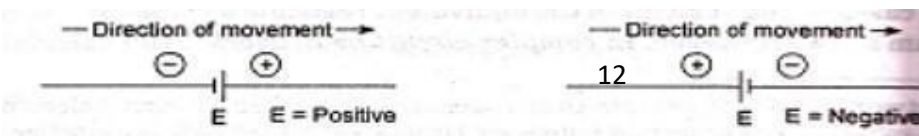
Explanation:-

The circuit has three active elements with voltages E_1, E_2 and E_3. The polarity of each of them is fixed. R_1, R_2, R_3 are three passive elements present in the circuit. Currents I_1 and I_3 are marked flowing into the junction A and current I_2 marked away from the junction A with known information or assumed directions. With reference to the direction of these currents, the polarity of voltage drops V_1, V_2 and V_3 are marked.

For loop1 it is considered around clockwise

+ E_1 - V_1 + V_3 - E_3 = 0

+ E_1 - $I_1 R_1$ + $I_3 R_3$ - E_3 = 0

$E_1 - E_3 = I_1 R_1 - I_3 R_3$

For loop2 it is considered anticlockwise

+ E_2 + V_2 + V_3 − E_3 = 0

+ E_2 + $I_2 R_2$ + $I_3 R_3$ − E_3 = 0

$E_2 - E_3 = - I_2 R_2 - I_3 R_3$

Two equations are obtained following Kirchhoff's voltage law. The third equation can be written based on Kirchhoff"s current law as

$I_1 - I_2 + I_3 = 0$

With the three equations, one can solve for the three currents I_1, I_2, and I_3.

If the results obtained for I_1, I_2, and I_3 are all positive, then the assumed direction of the currents are said to be along the actual directions. A negative result for one or more currents will indicate that the assumed direction of the respective current is opposite to the actual direction.

Example.1.5. Calculate the current supplied by two batteries in the circuit given below
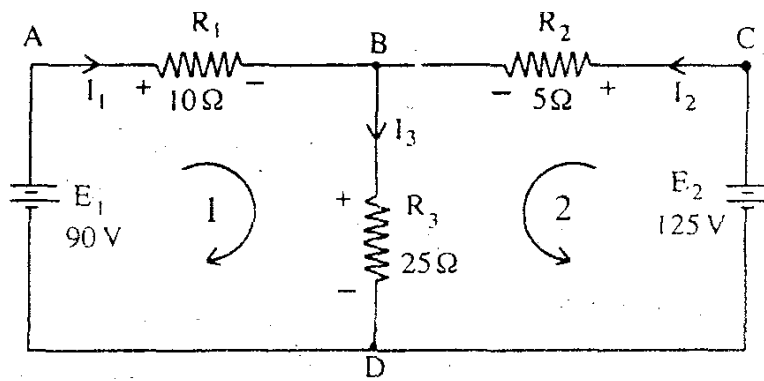
Solution:

The four junctions are marked as A, B, C and D. The current through R_1 is assumed to flow from A to B and through R_2, from C to B and finally through R_3 from B to D. With reference to current directions, polarities of the voltage drop in R_1, R_2 and R_3 are then marked as shown in the figure. Applying KCL to junction B

$$I_3 = I_1 + I_2 \quad .....(1)$$

Applying KVL to loop 1

$$E_1 - I_1 R_1 - I_3 R_3 = 0 \Rightarrow E_1 = I_1 R_1 + I_3 R_3$$
$$\Rightarrow 90 = 10I_1 + 25I_3 \qquad .....(2)$$

Substituting Eq. (1) in Eq. (2)

$$90 = 10I_1 + 25(I_1 + I_2) \Rightarrow 90 = 35I_1 + 25I_2 \qquad --------(3)$$

Applying KVL to loop 2

$$E_2 - I_2 R_2 - I_3 R_3 = 0 \Rightarrow E_2 = I_2 R_2 + I_3 R_3$$
$$\Rightarrow 125 = 5I_2 + 25I_3 \qquad ....(4)$$

Substituting Eq. (1) in Eq. (4)

$$125 = 5I_2 + 25(I_1 + I_2)$$
$$\Rightarrow 125 = 25I_1 + 30I_2 \qquad ....(5)$$

After solving Eq. (3) & (5) we get

$$I_1 = -1A$$

$$I_2 = 5A$$

As the sign of the current I_1 is found to be negative from the solution, the actual direction of I_1 is from B to A to D i.e. 90 V battery gets a charging current of 1 A.

QUESTIONS FOR PRACTICE

Short Answer Questions

1. Define electric current.
2. State and explain Ohm's Law.
3. Define One Ohm.
4. What is meant by source in electricity?
5. State and explain Kirchoff's Voltage Law.

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6. State and explain Kirchoff's Current Law.
7. Derive the expression of resistance in (i) series circuit (ii) Parallel circuit

Long Answer Questions

1. A 10v battery is connected to parallel combination of two resistors 10Ω and 5Ω. Calculate the current through in each resistor and power consumed by them.

2. The resistance of two wires is 15Ω when connected in series and 7Ω when connected in parallel, find the resistances of each one.
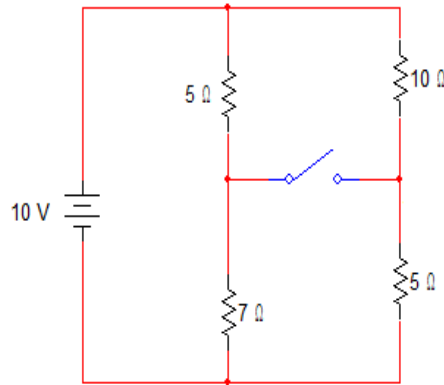
3. A resistance R is connected in series with a parallel circuit comprising of resistances of 4Ω and 6Ω respectively. When the applied voltage is 15V, the power dissipated in 4Ω resistor is 36W, Calculate R.

4. Determine the electric current that flows in the circuit as shown in the figure below.
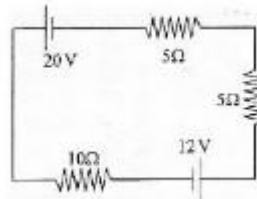
5. Determine the equivalent resistance and electric current that flows in circuit as shown in figure below.


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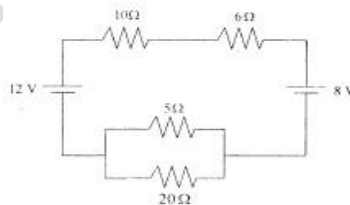
CHAPTER- 2

A.C. THEORY

An electrical quantity is said to be "alternating" if it changes in magnitude & direction continuously with time. The term AC is nothing but the alternating current & the circuit that carries the AC is called as AC circuit. This alternating quantity may be periodic and non-periodic. Periodic quantity is one whose value will be repeated for every specified interval. Generally to represent alternating voltage or current we prefer sinusoidal wave form

GENERATION OF ALTERNATING EMF:-

AC generator generates A.C. voltage based on the faraday"s law of electromagnetic induction.
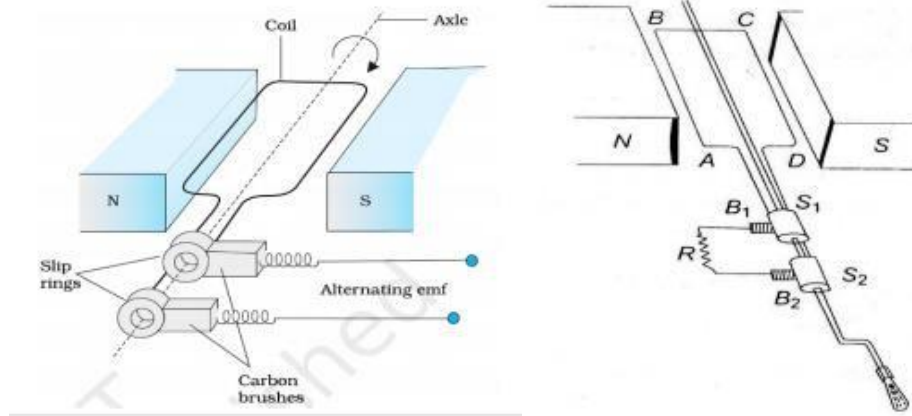
(**Fig.2.1.** Schematic Diagram of AC generator)

- The armature coil is rotated as shown in the fig.2.1, about an axis perpendicular to the magnetic field lines. As the angle between the area vector of the coil and the magnetic field changes, the magnetic flux linked with the coil changes and an e.m.f. is induced in the coil.
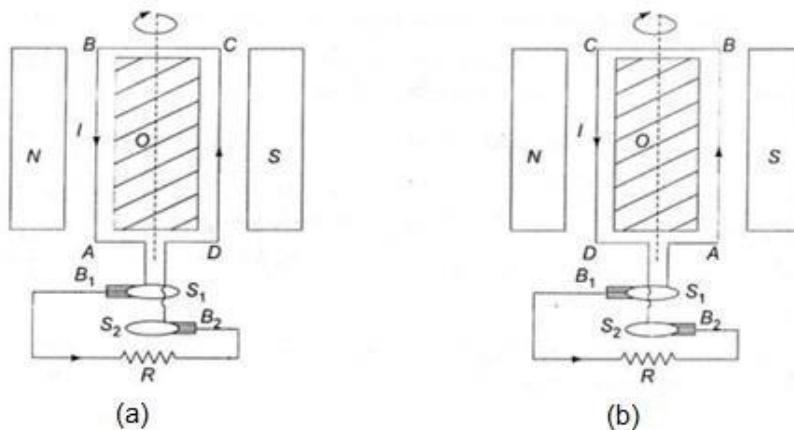
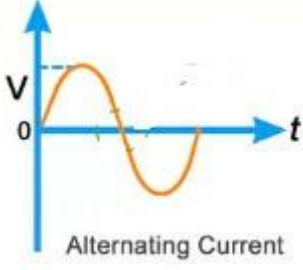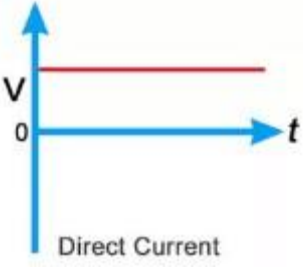(**Fig.2.2.** Rotation of armature in AC generator)

- When the plane of the coil is parallel to the plane of the paper, the flux linked with the coil is zero. As the coil is rotated as shown in fig. 2.2(a), AB moves in and CD moves out of the screen, causing current I to be induced in the coil in the direction DCBAD, through the resistance R in the external circuit as shown.
- After half a rotation of the coil. AB moves out and CD moves into the plane of the screen, causing current I to be induced in the coil in the direction ABCDA, through resistance R in the external circuit in the opposite direction as in fig.2.2 (b).
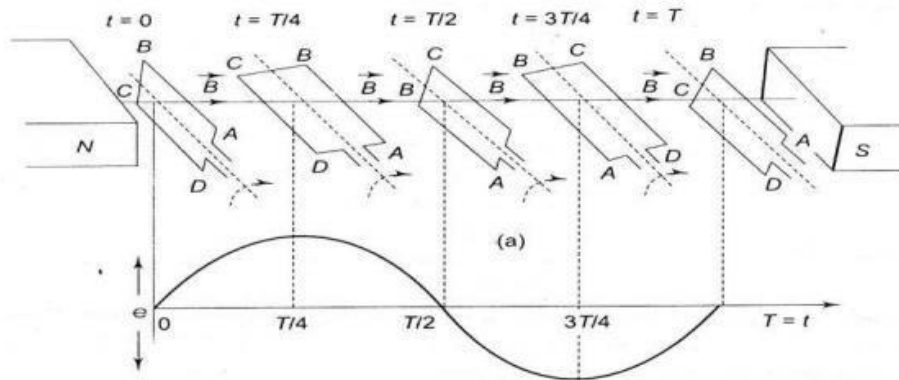
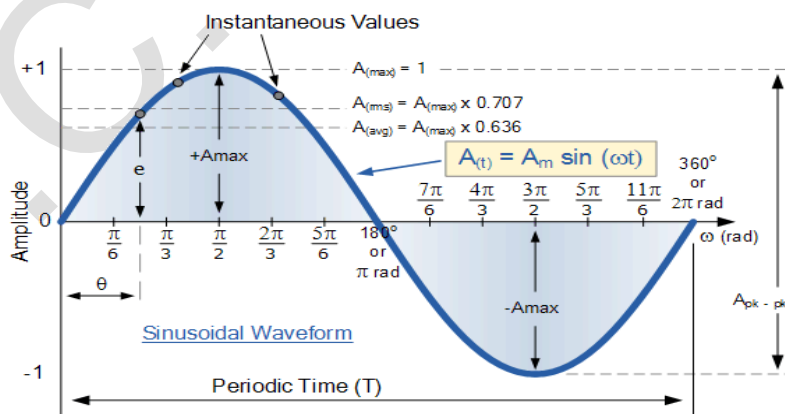(**Fig.2.3.** Rotation of armature in different instant of time & induced emf in AC generator)

- In five different position of the armature coil ABCD at time t = 0, T/4, T/2, 3T/4 t =T, the induced emf will change w.r.t time.
- The coil is rotated in uniform magnetic field B with constant angular velocity ω .*where m* = $2\pi T$. T is the periodic time or time for one complete rotation of the coil.
- The change in direction of induced current due to induced emf. The graph of emf vs time shows the variation in voltage as a consequence of rotation of the coil.
- When we get maximum emf and when its value becomes zero. For one complete rotation there are two instants when emf is max at T/4 and at 3T/4. The same would be repeated for the next rotation.

DIFFERENCE BETWEEN AC & DC:-

AC	DC
Alternating Current	Direct Current
1. The current which change its	1. The current which does not change its

magnitude & direction periodically (or at regular interval) is called alternating current.	magnitude & direction periodically is called alternating current. i.e the direction of current remains same.
2. The direction of flow of electron is bidirectional	2. The direction of flow of electron is unidirectional
3. It has frequency, like Indian standard frequency is 50Hz.	3. It has zero frequency.
4. It"s power factor lies between 0 & 1.	4. It"s power factor is always 1
5. It"s passive parameter is impedance Combination of Reactance and Resistance.	5. It"s passive parameter is resistance.
6. AC generate from AC generator.	6. DC generate from DC generator, battery, solar cell etc.
7. It is represented by sine wave, square wave, triangular wave etc.	7. It is represented by straight line i.e it may be 2 types Pure DC and Pulsating DC
8. Can be transmitted over long distance with some losses.	8. It can be transmitted over very long distance with negligible losses.
9. Their load is resistive, inductive or capacitive.	9. Their load is usually resistive in nature.
10. Dangerous	10. Very Dangerous
11. Easily convert into direct current by rectifier.	11. Easily convert into alternating current by inverter.
12. Application- Factories, Industries and for the domestic purposes.	12. Application- Electroplating, Electrolysis, Electronic Equipment etc.

DEFINITIONS RELATED TO AN ALTERNATING VOLTAGE OR CURRENT: -

(**Fig.2.4.** An alternating sin wave)

1) Periodic waveform

If the same set of variations is repeated indefinitely after a certain interval of time then the waveform is known as periodic waveform.

2) Peak Amplitude

It is the maximum value reached by the alternating quantity in a cycle either in positive or negative half cycle. It. is also known as crest value. It is denoted by A_m

3) Cycle

The interval of time during which a complete set of non-repeating waveform variation occurs is called cycle. It may be positive or negative cycle.

4) Frequency

It is defined as the number of cycles completed by an alternating quantity in one second. Its SI unit is Hertz (Hz). 1 Hz = 1 cycle/second

5) Angular frequency

It is the angular distance (angle) covered by alternating quantity in one second. It is also known as angular velocity. ω = 2πf

6) Time Period

It is defined as the time required for an alternating quantity to complete one cycle. It is denoted by T.

7) Phase

Phase of an alternating quantity is the angular displacement of the phasor representing that alternating quantity up to the instance of consideration measured from a mean or reference value.
In other word it is the angular measurement of alternating quantity which specifies the position of wave. Phase of the sine indicates staring phase of the sine wave.
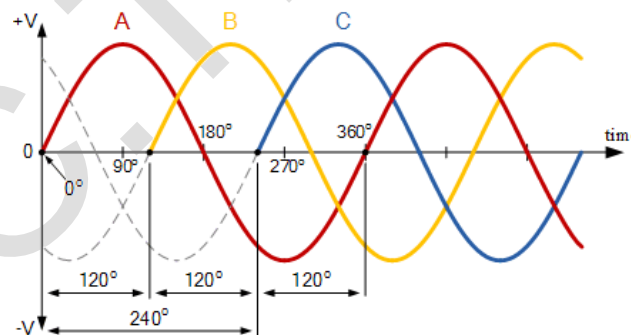
(**Fig.2.5.** Phasor Representation of Alternating emf)

In the above figure,**A** waveform being a reference wave at $\emptyset = 0°$,**B** waveform being 120° time delayed or lag behind A,**C** waveform being 120° time advanced or lead behind A.

8) Phase difference

The difference between the phases of the two alternating quantities is called as phase difference.

Let, V(t) = Vm sin wt, here we can say that phase is zero as function starts from origin.

V(t)= Vm sin(wt-θ), here we can say that phase of function is θ degrees to right shift.

V(t)= Vm sin(wt+θ), here we can say that phase of the function is θ degrees to the left shift.

In the above fig the phase difference between A &B is120°.

DIFFERENT TYPES OF VALUES OF ALTERNATING VOLTAGE & CURRENT:-

1. **Instantaneous Value:-**

   It is defined as the value of alternating quantity at any instant of time. It is represented by i(t) or v(t).

   Ex: v(t)= $V_m$sin(ωt +Θ)

2. **Average value:-**

   For an alternating current, the average value is defined as that value of DC current which transfers across any circuit the same charge as is transferred by the alternating current during the same time under the same conditions. It is represented by V_{avg} or I_{avg}.
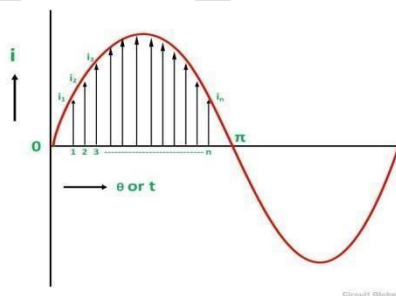
   - There are two methods to calculate average value
     i. **Mid ordinate method/ graphical method**

        The average value is defined as the arithmetic average or mean value of all the values of an alternating quantity over one cycle
        Let i_1, i_2, i_3 ....i_n be the mid ordinates
        The Average value of current I_{av} = mean of the mid ordinates

(**Fig.2.6.** Average Value of a positive half-cycle)

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

        If we consider symmetrical waves like sinusoidal current or voltage waveform, the positive half cycle will be exactly equal to the negative half cycle. Therefore, the average value over a complete cycle will be **zero**.

        So the average value is taken for only the positive half cycle.

     ii. **Analytical method**

Consider a sinusoidal waveform, the average value of alternating current is

$$I_{avg} = \frac{Area\ under\ the\ half\ cycle}{Length\ of\ base\ of\ half\ cycle}$$

$$Iavg = \frac{\int_0^\pi i\,d\theta}{\pi}$$

$$Iavg = \frac{\int_0^\pi I_m\ Sin\theta\,d\theta}{\pi}$$

$$Iavg = \frac{Im}{\pi}\int_0^\pi \sin\theta\,d\theta$$

$$Iavg = \frac{Im}{\pi}[-\cos\theta]_0^\pi$$

$$Iavg = \frac{2Im}{\pi}$$

Hence average value of current = 0.637× maximum value of current (for half cycle)

3. RMS value (root-mean-square)/ effective value:-

The RMS value of an alternating current is given by that value of DC current which when flowing through a given circuit for a given time, produces the same amount of heat as produced by the alternating current, which when flowing through the same circuit for the same time.

 In other words, the R.M.S value is defined as the square root of means of squares of instantaneous values. It is represented by V_{rms} or I_{rms}.

There are two methods calculate RMS value.

i.   Mid ordinate method/ graphical method

Let I be the alternating current flowing through a resistor R for time t seconds, which produces the same amount of heat as produced by the direct current (I_{eff}). The base of one alteration is divided into n equal parts so that each interval is of t/n seconds as shown in the figure below

Let i_1, i_2, i_3, ... i_n be the mid ordinates. Then the heat produced in

First interval = $\dfrac{i_1^2 Rt}{Jn}$ calories

$$\text{Second interval} = \frac{i_2^2 Rt}{Jn} \text{ calories}$$

$$n^{th} \text{ interval} = \frac{i_n^2 Rt}{Jn} \text{ calories}$$

$$\text{Total Heat produced} = \frac{Rt}{J}\left(\frac{i_1^2 + i_2^2 + \dots + i_n^2}{n}\right) calories \dots(2.1)$$

Since I_{eff} is considered as the effective value of this current, then the total heat produced by this current will be

$$\frac{I_{eff}^2 Rt}{J} calories \dots (2.2)$$

Now, equating equation (2.1) and (2.2) we will get

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

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

ii. Analytical method

RMS value of sinusoidal current $i = i_m \sin \omega t$

$$i_{rms} = \sqrt{\frac{1}{2\Pi} \int_0^{2\Pi} i^2 \, d(\omega t)}$$

$$i_{rms} = \sqrt{\frac{1}{2\Pi} \int_0^{2\Pi} i_m^2 \sin^2 \omega t \, d(\omega t)}$$

$$i_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

4. Form Factor
The form factor is the ratio of RMS value of an alternating quantity to the average value of the same quantity

$$form\ factor = \frac{RMS\ Value}{Average\ Value} = \frac{0.707 \times maximum\ Value}{0.637 \times maximum\ Value} = 1.11$$

F.F=1.11 for sinusoidal alternating quantity only

5. Peak factor/ crest/ amplitude factor

Hence RMS value of current =0.707×maximum value of current

Peak factor or crest factor of an alternating quantity is the ratio of maximum value (peak value) to RMS value

$$\text{Peak factor} = \frac{maximum\ Value}{RMS\ Value} = \frac{maximum\ Value}{0.707 \times maximum\ Value} = 1.414$$

Example 2.1:- Write down the equation for a sinusoidal voltage of 50 Hz and its peak value is 20 V. Draw the corresponding voltage versus time graph.
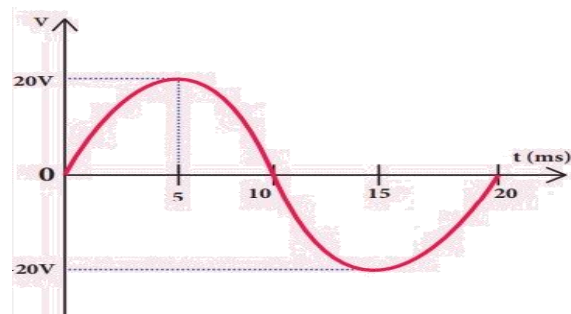
Solution

$$f = 50Hz \quad ; \quad V_m = 20V$$

Instantaneous Voltage =

$$v = V_m \sin \omega t$$
$$= V_m \sin 2\Pi\, ft$$
$$= 20 \sin(2\,\Pi \times 50)t$$
$$= 20 \sin(2 \times 3.141 \times 50)t$$
$$= 20 \sin 314t$$

Time for one cycle = $T = \dfrac{1}{f} = \dfrac{1}{50} = 0.02 \text{sec}$

The waveform is:

Example 2.2:-

The equation for an alternating current is given by $i = 77 \sin 314t$. Find the peak value, frequency, time period and instantaneous value at t = 2 ms.

Solution

i = 77 sin 314t ; t = 2 ms = 2×10⁻³ s
The general equation of an alternating current is i = I$_m$ sin ωt . On comparison,
(i) Peak value, I$_m$ = 77 A
(ii) Frequency, f = ω/2π = 314 / 2 ×3.14 = 50 Hz

Time period, T = 1/f = 150 = 0 .02 s
(iv) At t = 2 m s,
Instantaneous value,
i = 77 sin(314×2×10^{-3})
 i = 45.24 A

REPRESENT AC VALUES IN PHASOR DIAGRAMS:-

An alternating quantity can be represented using
i) Waveform
ii) Equations
iii) Phasor

A sinusoidal alternating quantity can be represented by a rotating line called a **Phasor.** A phasor is a line of definite length rotating in anticlockwise direction at a constant angular velocity

The waveform and equation representation of an alternating current is as shown. This Sinusoidal quantity can also be represented using phasors.

$$i = I_m \sin \omega t$$
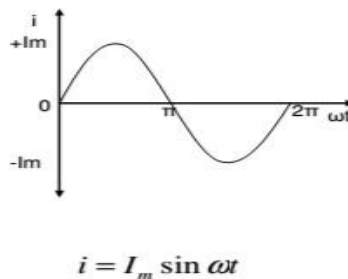
(**Fig.2.7.** Waveform of alternating quantity)

In phasor form the above wave is written as $\overline{I} = I_m \angle 0°$

Draw a line OP of length equal to I_m. This line OP rotates in the anticlockwise direction with a uniform angular velocity ω rad/sec and follows the circular trajectory shown in figure. At any instant, the projection of OP on the y-axis is given by OM=OPsinθ = $I_m$sinωt. Hence the line OP is the phasor representation of the sinusoidal current.
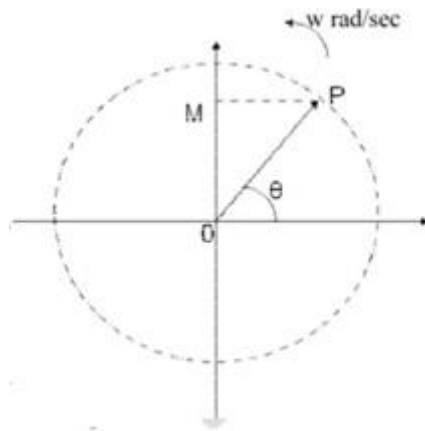
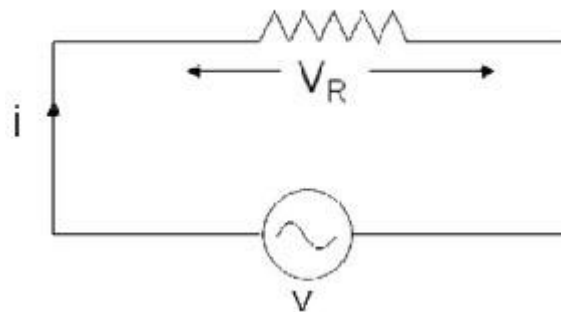(**Fig.2.8.** Phasor representation of alternating wave)

AC THROUGH PURE RESISTANCE, INDUCTANCE & CAPACITANCE:-

AC Circuit with A Pure Resistance

(**Fig.2.9.** AC circuit with a pure resistance R)

Consider an AC circuit with a pure resistance R as shown in the figure 2.9.
The alternating voltage v is given by

$$v = Vm \sin(\omega t) \qquad ....(2.3)$$

The current flowing in the circuit is i. The voltage across the resistor is given as V_R which is the same as v.
Using ohm's law, we can write the following relations

$$i = \frac{v}{R} = \frac{Vm \sin(\omega t)}{R}$$
$$i = Im \sin(\omega t)$$

Where, $\qquad\qquad\qquad\qquad\qquad\qquad\qquad Im = \frac{Vm}{R} \qquad ....(2.4)$

From equation (2.3) and (2.4) we conclude that in a pure resistive circuit, the voltage and current are in phase. Hence the voltage and current waveforms and phasors can be drawn as below.
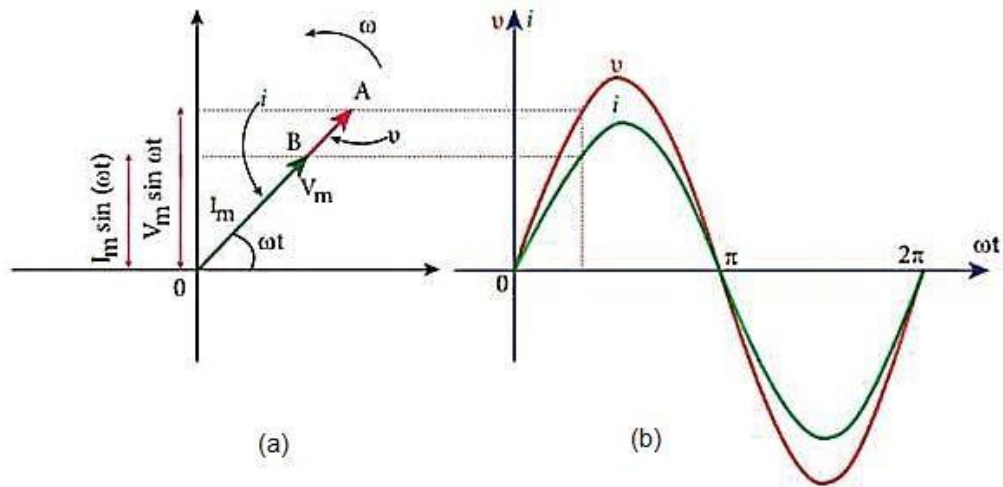
(Fig.2.10.(a) Phasor representation of voltage and current in pure resistive circuit (b) Wave representation of voltage and current in pure resistive circuit)

AC Circuit with A Pure Inductance
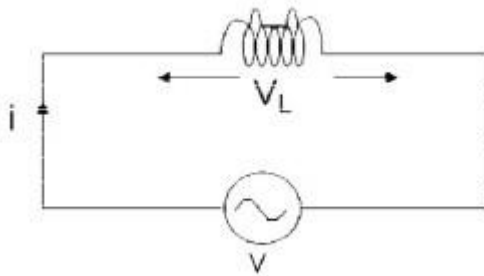
(Fig.2.11. AC circuit containing pure inductor)

Consider an AC circuit with a pure inductance L as shown in the figure 2.11. The alternating voltage V is given by

$$v = V_m \sin (\omega t) ....(2.5)$$

The current flowing in the circuit is i. The voltage across the inductor is given as V_L which is the same as v.

The voltage $v = L \dfrac{di}{dt}$

$$V_m \sin (\omega t) = L \dfrac{di}{dt}$$

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$$\Rightarrow di = \frac{V_m}{L}\sin \omega t$$

$$\Rightarrow i = \frac{V_m}{L}\int \sin(\omega t)dt$$
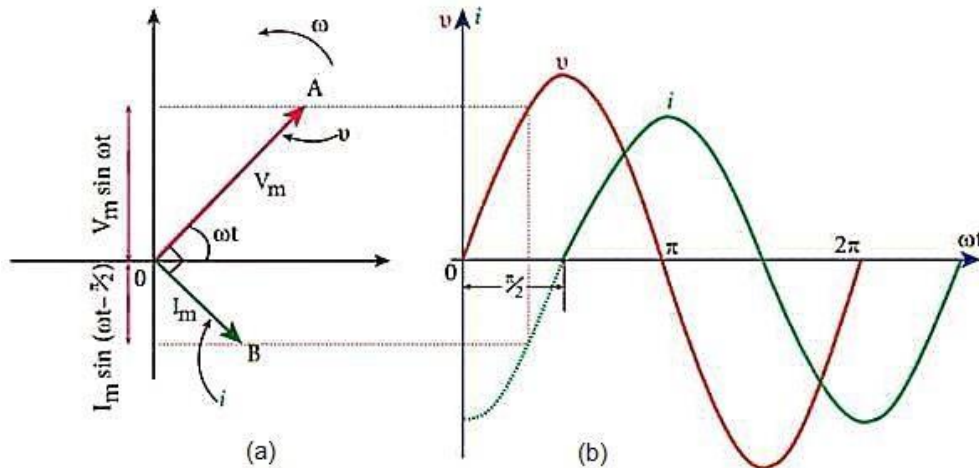
$$\Rightarrow i = \frac{V_m}{\omega L}(-)\cos(\omega t)$$

$$\Rightarrow i = \frac{V_m}{\omega L}\sin\left(\omega t - \frac{\Pi}{2}\right)$$

$$\Rightarrow i = I_m \sin\left(\omega t - \frac{\Pi}{2}\right)$$

Where $I_m = \frac{V_m}{\omega L}$ .... (2.6)

From equation (2.5) and (2.6) we observe that in a pure inductive circuit, the current lags behind the voltage by 90°. Hence the voltage and current waveforms and phasors can be drawn as below.
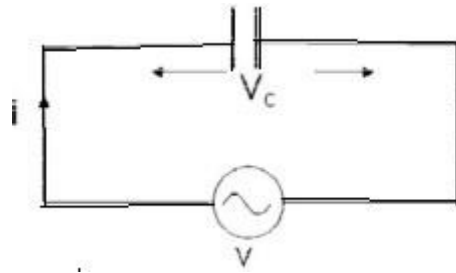

(Fig.2.12.(a) Phasor representation of voltage and current in pure inductive circuit (b) Wave representation of voltage and current in pure inductive circuit)

<u>Inductive reactance:-</u>

The inductive reactance X_L is given as $X_L = 2\pi fL$
It is equivalent to resistance in a resistive circuit. The unit is ohms (Ω).

<u>AC Circuit with A Pure Capacitance</u>

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(Fig.2.13. AC circuit containing pure inductor)

Consider an AC circuit with a pure capacitance C as shown in the figure 2.13. The alternating voltage v is given by

$$v = V_m \sin(\omega t) \text{.......}(2.7)$$

The current flowing in the circuit is i. The voltage across the capacitor is given as V_C which is the same as V .

Current through the capacitor is $v = \dfrac{1}{c}\int i \, dt$

$$i = c\frac{dv}{dt}$$

$$= c\frac{d(V_m Sin\omega t)}{dt}$$

$$= cV_m(\omega Cos\omega t)$$

$$= \omega CV_m Cos\omega t$$

$$= \omega CV_m Sin(\omega t + \frac{\Pi}{2})$$

$$= i_m Sin(\omega t + \frac{\Pi}{2}) \text{...... } (2.8)$$

Where $i_m = \omega CV_m = X_c V_m$

From equation (2.7) and (2.8) we observe that in a pure capacitive circuit, the current leads the voltage by 90°. Hence the voltage and current waveforms and phasors can be drawn as below.
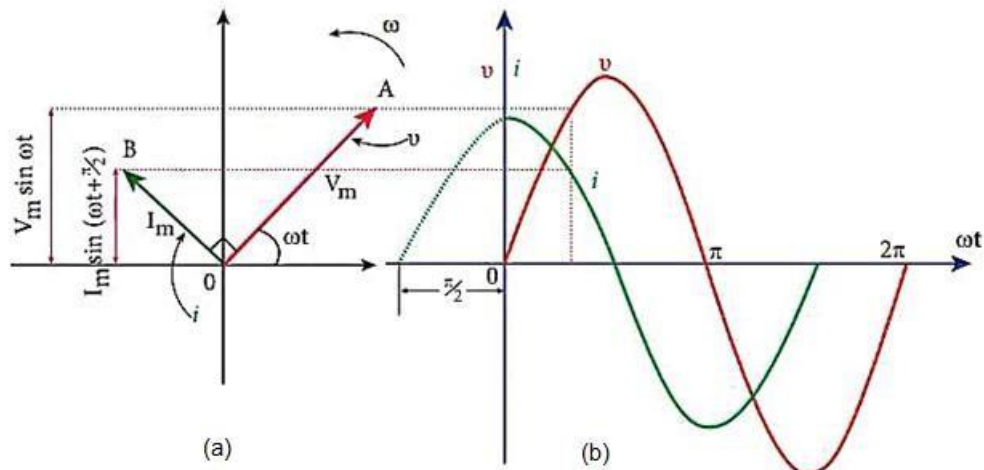
(Fig.2.14.(a) Phasor representation of voltage and current in pure capacitive circuit (b) Wave representation of voltage and current in pure capacitive circuit)

 Capacitive reactance:-

The capacitive reactance X_c is given as

$$X_c = \frac{1}{2\pi f C}$$

$$Im = \frac{V_m}{X_c}$$

It is equivalent to resistance in a resistive circuit. The unit is ohms (Ω)

AC THROUGH RL, RC, RLC SERIES CIRCUITS

In actual practice, AC circuits contain two or more than two components connected in series. In a series circuit, each component carries the same current. An AC series circuit may be classified as under:

- R-L series circuit
- R-C series circuit
- R-L-C series circuit

RL Series Circuit

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(Fig.2.15.(a) Circuit diagram of RL series circuit (b) Phasor diagram of RL series circuit)

In right angle triangle OAB $\qquad$ $V_R = IR,$ $\qquad$ $V_L = IX_L$
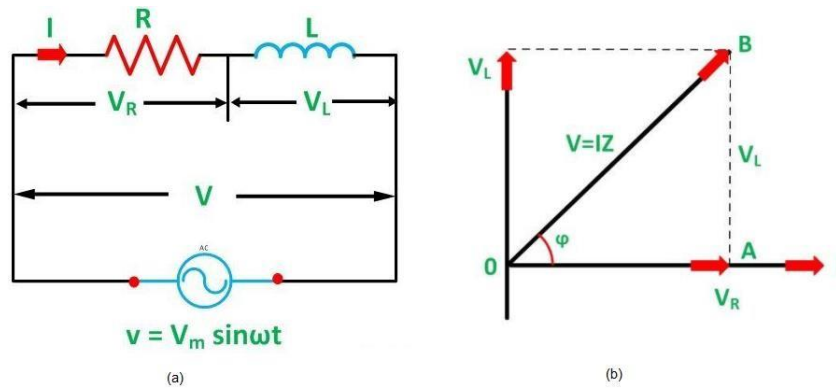
So supply voltage V = $\sqrt{(IR)^2 + (IX_L)^2}$

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

$$= IZ \quad .....(2.9)$$

Where Z = Impedance = $\sqrt{(R)^2 + (X_l)^2}$

So $I = \dfrac{V}{Z}$

Where Z in ohm(Ω).

Phase angle: - In RL Series circuit the current lags the voltage by 90 degrees angle known as phase angle. It is given by the equation:

$$\tan\phi = \frac{V_L}{V_R} = \frac{IX_L}{IR} = \frac{X_L}{R}$$

$$\phi = \tan^{-1}\left(\frac{X_L}{R}\right)$$

Voltage drop V_R is in phase with current vector, whereas, the voltage drop in inductive reactance V_L leads the current vector by 90° since current lags behind the voltage by 90° in the purely inductive circuit. The vector sum of these two voltage drops is equal to the applied voltage V (RMS value).

The power waveform for RL series circuit is shown in the figure. In this figure, voltage wave is considered as a reference. The points for the power waveform are obtained from the product of the corresponding instantaneous values of voltage and current.

It is clear from the power waveform that power is negative between 0 and φ and between 180° and (180° + φ). The power is positive during rest of the cycle. Since the area under the positive loops is greater than that under the negative loops, the net power over a complete cycle is positive. Hence a definite quantity of power is consumed by the RL series circuit. But power is consumed in resistance only; inductance does not consume any power.

(**Fig.2.16.** waveform representation of R-L circuit)

RC Series Circuit
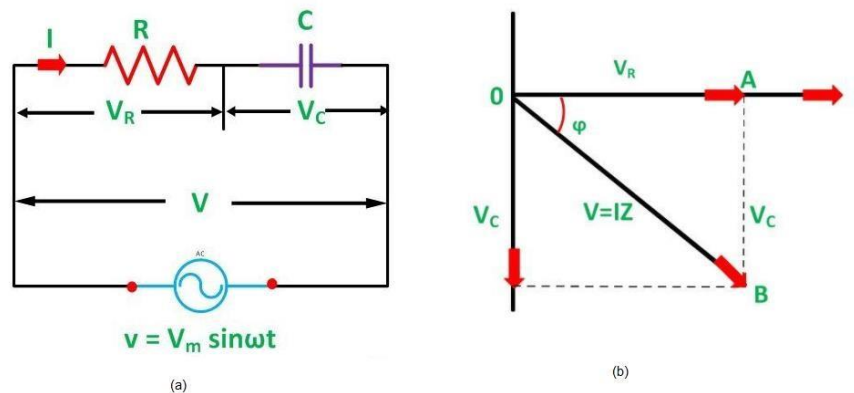
(Fig.2.17.(a) Circuit diagram of RC series circuit (b) Phasor diagram of RC series circuit)

In right angle triangle OAB $V_R = IR$, $V_C = IX_C$

So supply voltage $V = \sqrt{(IR)^2 + (IX_C)^2}$

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

$$= IZ \quad .....(2.10)$$

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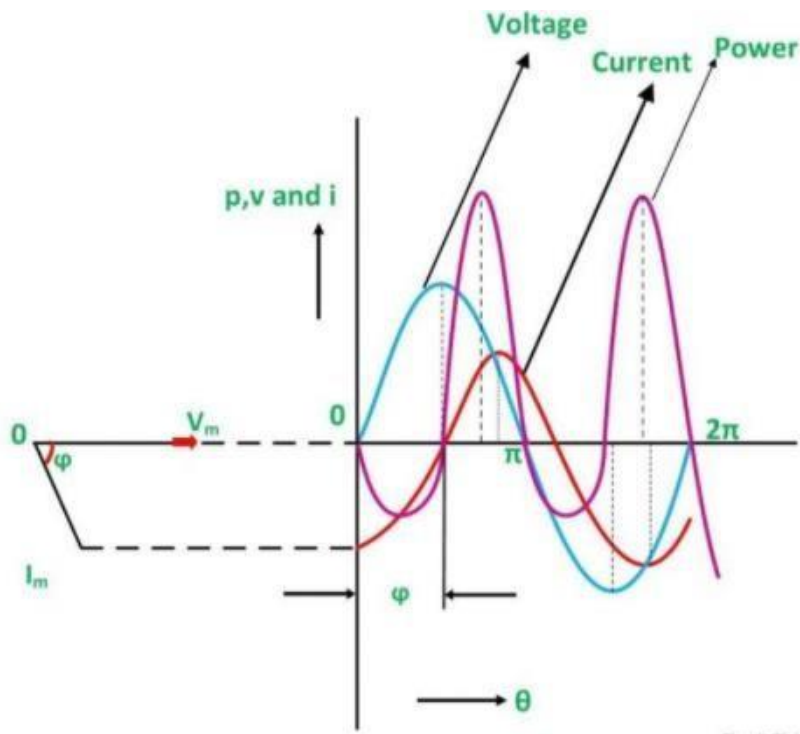Where Z = Impedance = $\sqrt{(R)^2 + (X_C)^2}$

So $I = \dfrac{V}{Z}$

Phase angle: - In RC Series circuit the current leads the voltage by 90 degrees angle known as phase angle. It is given by the equation:

$$\tan\phi = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{X_C}{R}$$

$$\phi = \tan^{-1}\left(\frac{X_C}{R}\right)$$

Voltage drop V_R is in phase with current vector, whereas, the voltage drop in capacitive reactance V_C lags behind the current vector by 90°, since current leads the voltage by 90° in the pure capacitive circuit. The vector sum of these two voltage drops is equal to the applied voltage V (RMS value).
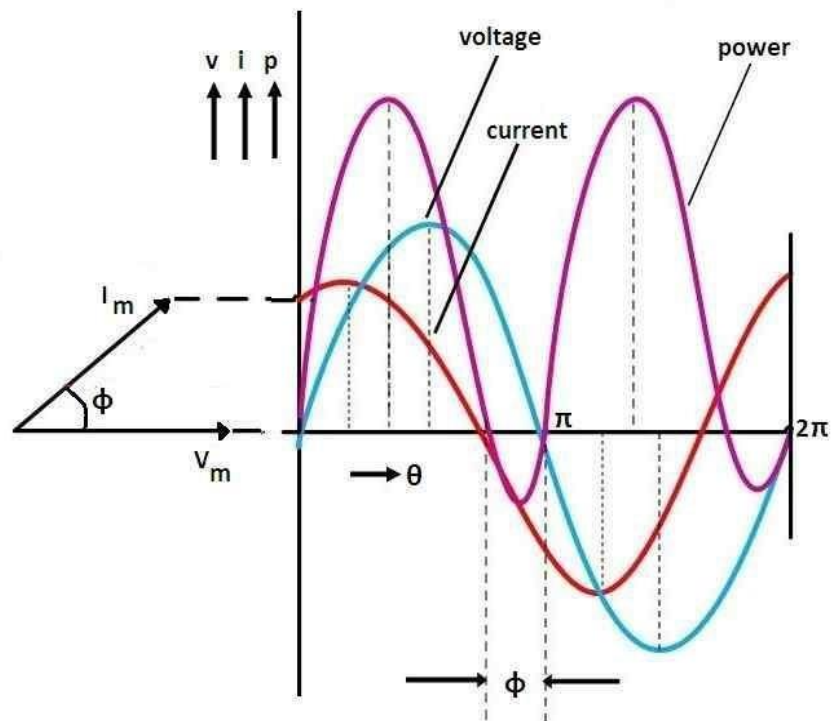
(**Fig.2.18.** Waveform representation of R-C circuit)

The power waveform for RC series circuit is shown in the figure. In this figure, voltage wave is considered as a reference. The points for the power waveform are obtained from the product of the corresponding instantaneous values of voltage and current. It is clear from the power waveform that power is negative between (180° – φ) and 180° and between (360° – φ) and 360°. The power is positive during rest of the cycle.

Since the area under the positive loops is greater than that under the negative loops, the net power over a complete cycle is positive. Hence a definite quantity of power is consumed by the

RC series circuit. But power is consumed in resistance only; capacitor does not consume any power.

RLC Series Circuit
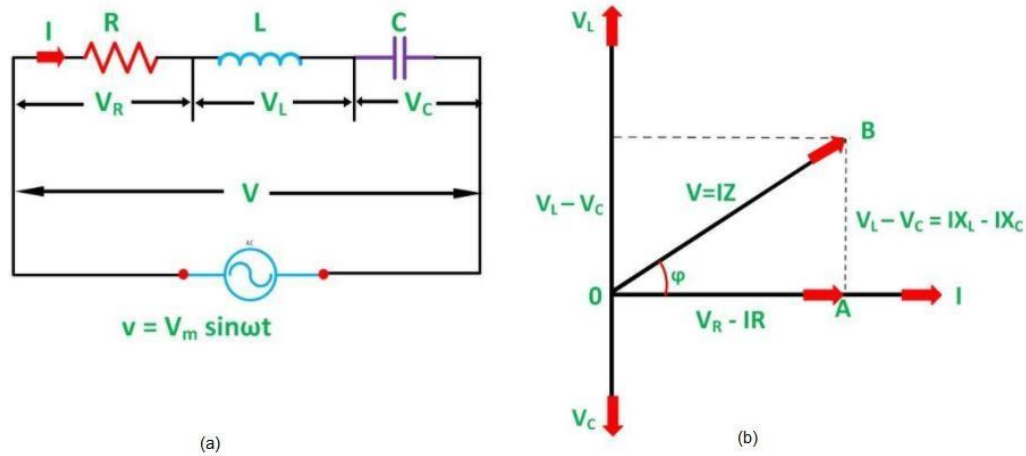
(Fig.2.19.(a) Circuit diagram of RLC series circuit (b) Phasor diagram of RLC series circuit)

In right angle triangle OAB $V_R = IR,$ $V_L - V_C = IX_L - IX_C$

So supply voltage $V = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$

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

$$= IZ \quad \dots\dots(2.11)$$

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

So $I = \dfrac{V}{Z}$

Phase angle: -

$$\tan\phi = \frac{V_L - V_C}{V_R} = \frac{IX_L - IX_c}{IR} = \frac{X_L - X_C}{R}$$
$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

The voltage drop V_L is in phase opposition to V_C. It shows that the circuit can either be effectively inductive or capacitive. There can be three cases of RLC series circuit.

- When $X_L > X_C$, the phase angle φ is positive. In this case, RLC series circuit behaves as an RL series circuit. The circuit current lags behind the applied voltage and power factor is lagging. In this case, if the applied voltage is represented by the equation; v= V_m Sinωt
  then, the circuit current will be represented by the equation; i = I_m Sin (ωt - φ).

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- When $X_L < X_C$, the phase angle φ is negative. In this case, the RLC series circuit behaves as an RC series circuit. The circuit current leads the applied voltage and power factor is leading. In this case, the circuit current will be represented by the equation: $i = I_m \sin (\omega t + \varphi)$.
- When $X_L = X_C$, the phase angle φ is zero. In this case, the RLC series circuit behaves like a purely resistive circuit. The circuit current is in phase with the applied voltage and power factor is unity. In this case, the circuit current will be represented by the equation: $i = I_m \sin (\omega t)$.

CONCEPT OF POWER AND POWER FACTOR:-

An understanding of load characteristics in electrical power systems involves the concept of power and power factor. The power consumed by a load will be comprised of several individual power components. These components are apparent power, reactive power, and active or real power. Power factor (PF) is the ratio of working power, measured in kilowatts (kW), to apparent power, measured in kilovolt amperes (kVA).It is also defined as cosω and ω is the angle between voltage and current.

Power Components

1. Apparent power (S) :- It is the product of voltage and current only.

$$\textbf{S=VI}$$ - unit is volt ampere (VA or KVA)

2. Active Power (P or W) :- It is the power which is actually dissipated in the circuit resistance

$$\textbf{P= VI Cos } \varphi \quad \text{or} \quad I^2R$$ -Unit is watts or kw

3. Reactive power (Q) :-It is the power developed in the inductive reactance of the circuit
$$\textbf{Q= VI Sin } \varphi \text{ or } I^2X$$ - Unit is VAR or KVAR

IMPEDANCE TRIANGLE AND POWER TRIANGLE:-

Power triangle:-

$$(\text{Apparent Power})^2 = (\text{active power})^2 + (\text{Reactive power})^2$$

$$S^2 = P^2 + Q^2$$
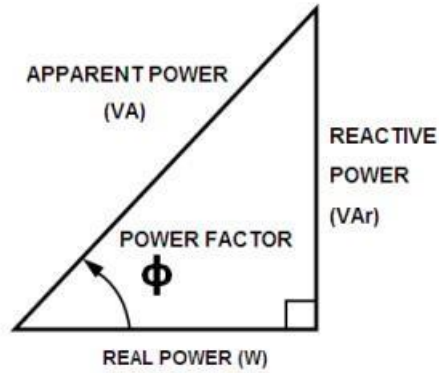
(**Fig.2.20.**Power Triangle)

VA = $\sqrt{W^2 + VAR^2}$;

W = VA $cos\,\emptyset$; and

VAR = VA $sin\,\emptyset$

(i) R-L Series Circuit
Active Power P= VI Cos φ = I^2R
Reactive Power Q= VI Sin φ = I^2X_L
Apparent Power S=VI = I^2Z

(ii) R-C Series Circuit
Active Power P= VI Cos φ = I^2R
Reactive Power Q= VI Sin φ = I^2X_C
Apparent Power S=VI = I^2Z

(iii)R-L-C Series Circuit
Active Power P= VI Cos φ = I^2R
Reactive Power Q= VI Sin φ = $I^2(X_L-X_c)$
Apparent Power S=VI = I^2Z

Impedance triangle

(i) Impedance triangle R-L circuit
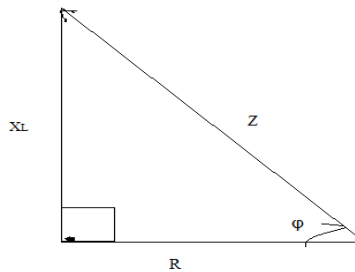
(**Fig.2.21.**Impedance Triangle of RL Series Circuit)

Impedance, $Z = \sqrt{R^2 + X_L^2}$

$tan\ \emptyset = \frac{X_L}{R}$

$sin\ \emptyset = \frac{X_L}{Z}$

Power factor= $cos\ \emptyset = \frac{R}{Z}$

(ii) Impedance triangle R-C circuit
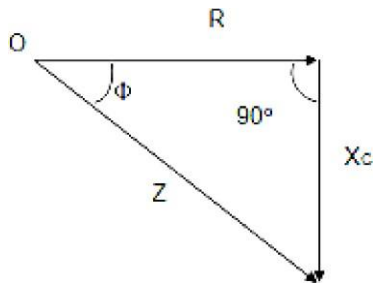
(**Fig.2.22.**Impedance Triangle of RC Series Circuit)

Impedance, $Z = \sqrt{R^2 + X_c^2}$

$tan\ \emptyset = \frac{X_c}{R}$

$sin\ \emptyset = \frac{X_c}{Z}$

Power factor= $cos\ \emptyset = \frac{R}{Z}$

(iii)Impedance triangle R-L-C circuit
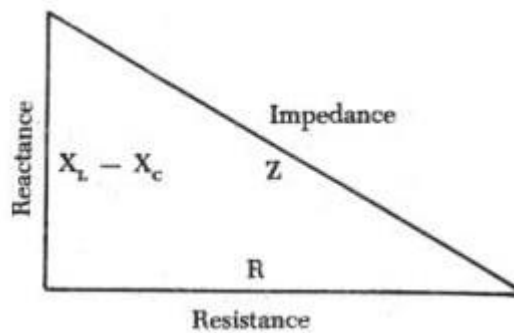
(**Fig.2.23.**Impedance Triangle of RLC Series Circuit)

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

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$$tan\ \emptyset = \frac{X_L - X_C}{R}$$

$$sin\ \emptyset = \frac{X_L - X_C}{Z}$$

Power factor= $cos\ \emptyset = \frac{R}{Z}$

Example 2.3:- A Capacitor of capacitance 79.5µF is connected in series with a non-inductive resistance of 30 ohm across a 100V, 50Hz supply. Find (i) impedance (ii) current (iii) phase angle.

Solution:

$$X_c = \frac{1}{2\pi f C} = \frac{1}{2*3.14*50*79.5*10^{-6}} = 40\Omega$$

i) $Z = \sqrt{R^2 + X_c^2} = \sqrt{30^2 + 40^2} = 50\Omega$

ii) $I = \frac{V}{Z} = \frac{100}{50} = 2A$

iii) Phase angle = $tan^{-1}(\frac{X_c}{R}) = tan^{-1}(\frac{40}{30}) = 53°$

Example 2.4:- A resistance of 20 Ω and inductance of 0.2H and a capacitance of 100µF are connected in series with 220 volt, 50 Hz mains. Determine (a) impedance (b) current (c) voltage across R, L, C (d) power in watts and VA (e) p.f. and angle of lag.

Solution

R= 20Ω;   L=0.2 H;   C=10⁻⁴F

$X_l = 2\pi f L$ =0.2×314 = 62.8 Ω ≈ 63 Ω

$X_c = \frac{1}{2\pi f C} = \frac{1}{314*10^{-4}}$ =31.847 ≈ 32Ω; $X_L - X_c$ = 63-32 = 31Ω (inductive)

(a) Z=$\sqrt{20^2 + 31^2}$ = 37Ω   (b) I = 220/37= 6A

(c) V_R = I × R = 6 × 20 = 120 v; V_L = 6 × 63 = 278 V; V_c = 6 × 32 = 192 V

(d) Power in VA = 6×220 = 1320 VA

Power in watts = 6×220×0.54= 713 W

(e) p.f. = $cos\ \emptyset = \frac{R}{Z} = \frac{20}{37} = 0.54$; $\emptyset = cos^{-1}(0.54) = 57°18'$

Example 2.5:- A 230 V, 50 Hz ac supply is applied to a coil of 0.06 H inductance and 2.5 Ω resistance connected in series with a 6.8 µF capacitor. Calculate (i) Impedance (ii) Current (iii)Phase angle between current and voltage (iv) power factor

Solution

$X_L = 2\pi f L = 2 \times 3.141 \times 50 \times 0.06 = 18.84 ohm$

$X_C = \dfrac{1}{2\pi f c} = \dfrac{1}{2 \times 3.141 \times 50 \times 6.8 \times 10^{-6}} = 468 ohm$
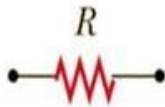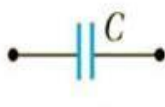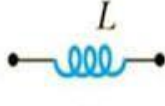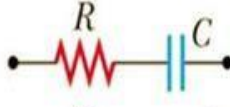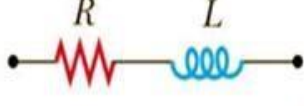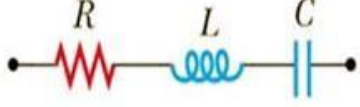
(i) $Z = \sqrt{(R)^2 + (X_L - X_C)^2} = \sqrt{(2.5)^2 + (18.84 - 468)^2} = 449.2$ ohm

(ii) $I = \dfrac{V}{Z} = \dfrac{230}{449.2} = 0.512 A$

(iii) $\emptyset = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right) = \tan^{-1}\left(\dfrac{18.84 - 468}{30}\right) = -89.7°$

(iv) $power\ factor = \cos\emptyset = \cos(-89.7°) = 0.0056 lead$

SUMMARY OF CIRCUIT ELEMENT, IMPEDANCE AND PHASE ANGLE

Circuit Elements	Impedance Z	Phase Angle ϕ
R (resistor)	R	$0°$
C (capacitor)	$X_C = 1/\omega C$	$-90°$
L (inductor)	$X_L = \omega L$	$+90°$
R, C	$\sqrt{R^2 + X_C^2}$	Negative, between $-90°$ and $0°$
R, L	$\sqrt{R^2 + X_L^2}$	Positive, between $0°$ and $90°$
R, L, C	$\sqrt{R^2 + (X_L - X_C)^2}$	Negative if $X_C > X_L$ Positive if $X_C < X_L$

QUESTIONS FOR PRACTICE

Short Answer Questions

1. Define average value, RMS value.
2. What is Time period and frequency?
3. Define amplitude of a sinusoidal wave.
4. Define instantaneous value of a wave.
5. What is a phasor?
6. Define a series RL circuit:
7. Define impedance
8. What is the unit of measurement for impedance?
9. What is the formula for impedance in an RL Series circuit?
10. With a 5 ohm resistor and a 10 ohm inductive reactance, what is the total impedance?
11. Define True Power.
12. What is reactive power?
13. What is apparent power?
14. What are the formulas for Power Factor (PF)?
15. Define a series RC circuit.
16. Draw the impedance triangle and mention its sides.
17. With a 7 ohm resistor and a 10 ohm capacitance reactance, what is the total impedance?
18. What is the formula for total impedance in a RLC circuit?

Long Answer Questions:-
1. If the voltage in an ac circuit is represented by the equation, $v = 220\sqrt{2} \sin(314t – \varphi)$ V . Calculate (a) peak and rms value of the voltage (b) average voltage (c) frequency of AC.
2. A 400 mH coil of negligible resistance is connected to an AC circuit in which an effective current of 6 mA is flowing. Find out the voltage across the coil if the frequency is 1000 Hz.
3. A capacitor of capacitance $102/\pi$ µF is connected across a 220 V, 50 Hz A.C. mains. Calculate the capacitive reactance, RMS value of current and write down the equations of voltage and current.
4. The inductance of a choke-coil is 0.2 henry and its resistance is 0.50 Ω . If a current of 2.0 ampere (rms value) and frequency 50Hz be passed through it, what will be the potential difference across its ends ?
5. A 10µF capacitor, an inductor and a resistor of 100 Ω are connected to an alternating source of emf 200 as shown in the figure. What is the r.m.s current in the circuit and the value of the inductance if the current and the source voltage attain their maxima simultaneously? What is the average power consumed in this case?
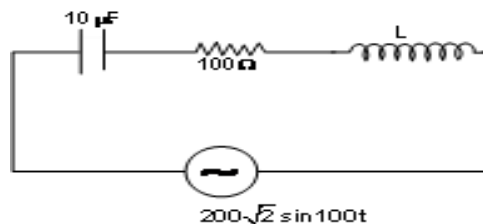
CHAPTER-3

GENERATION OF ELECTRICAL POWER

THERMAL POWER PLANT:-

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

The heat produced for burning of coal & with the help of water steam is produced. This produced steam flow towards turbine i.e. kinetic energy is converted into mechanical energy. The input steam drives the prime mover or turbine, simultaneously the generator also start to rotate. At that time mechanical energy is converted into electrical energy.

Selection of Site for Thermal Power Plant:

1. Supply of Fuel: The Steam power station should be located near the coal mine so that transportation cost of fuel is minimum.

2. Available of Water: A huge amount of water is required in boiler & condenser, so that the plant should be located near the river, lake etc.

3. Transportation Facility: For steam power station provide better transportation facility for the transportation of man, machinery etc.

4. Cost & Type of Land: The Steam Power Station should be located where the cost of land is cheap & also future extension is possible.

5. Near to Load Centre: In order to reduce transmission & distribution losses the plant should be located near to load centre.

6. Distance from Populated Area: As the thermal power plant produces flue gases, these gases will effect to live human being, so that the plant should be located away from thickly populated area.

7. Disposal Facility Provided: As the thermal power plant produces ash, while burning of coal. So that disposal of ash facility provided.

8. Availability of labour: Skilled and unskilled labour should be available nearly.

Schematic arrangement of Thermal Power Plant:
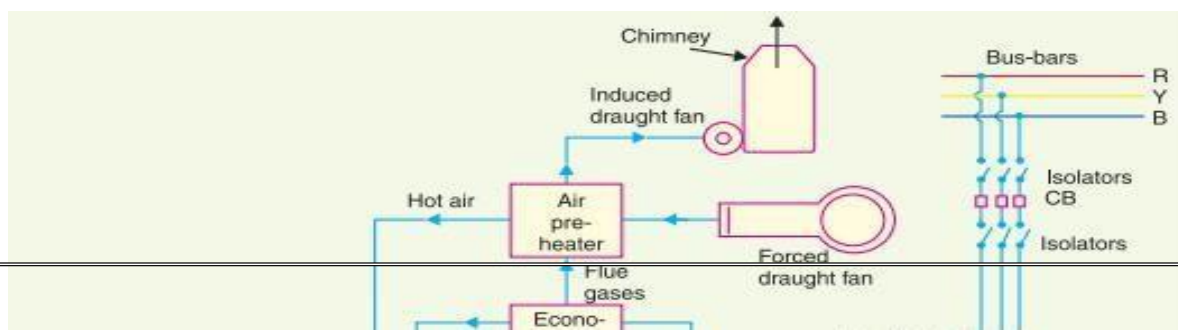
(**Fig.3.1.** Block Diagram of Thermal Power Plant)

1. Coal Storage & Coal Handling Plant:

The coal is transported to the power station by road or rail and is stored in the coal storage plant. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverised (i.e., crushed into small pieces).The pulverised coal is fed to the boiler by belt conveyors.

2. Ash handling Plant & Ash Storage:

The coal is burnt in the boiler and the ash produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal.

3. Boiler: (Steam Generating Plant):

A boiler is a closed vessel in which water is converted into steam by utilizing the heat of coal combustion. The heat of combustion of coal in the boiler is utilised to convert water into steam at high temperature and pressure. The flue gases from the boiler make their journey through super heater economiser, air pre-heater and are finally exhausted to atmosphere through the chimney.

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4. Super-Heater:

The steam produced in the boiler is wet and is passed through a super heater where it is dried and superheated (i.e. steam temperature increased above that of boiling point of water) by the flue gases on their way to chimney.

5. Economiser:

An economiser is essentially a feed water heater and derives heat from the flue gases for this purpose. The feed water is fed to the economiser before supplying to the boiler. The economiser extracts a part of heat of flue gases to increase the feed water temperature.

6. Feed water Arrangement:

The condensate from the condenser is used as feed water to the boiler. Some water may be lost in the cycle which is suitably made up from external source. The feed water on its way to the boiler is heated by water heaters and economiser.

7. Air Pre-heater:

An air pre-heater increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air pre-heater before supplying to the boiler furnace.

8. Condenser:

A condenser is a device which condenses the steam at the exhaust of the turbine. This helps in converting heat energy of steam into mechanical energy in the prime mover. The condensed steam can be used as feed water to the boiler.

9. Cooling arrangement:

During the scarcity of water in the river, hot water from the condenser is passed on to the cooling towers where it is cooled. The cold water from the cooling tower is reused in the condenser.

10. Steam Turbine:

The dry and superheated steam from the super heater is fed to the steam turbine through main valve. The heat energy of steam when passing over the blades of turbine is converted into mechanical energy.

11. Induced Draught fan (IDF):

Its (IDF) function is to remove rapidly flue gases (smoke) from the furnace chamber produced during combustion.

12. Forced Draught fan (FDF):

Its **(FDF)** function is to provide forced air (oxygen) for combustion process in furnace.

13. Cooling Tower:

The cooling tower is used to reduce the temperature of water coming from condensers & reused the same.

14. Chimney:

To reduce air pollution flue gas should be passed in air as high as possible with the help of Chimney.

15. Alternator:

The steam turbine is coupled to an alternator. The alternator converts mechanical energy of turbine into electrical energy.

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 POWER PLANT:-

A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as a hydro-electric power station.

Water is stored in dam by using rain water. This stored water contains Potential energy, due to height or head of dam. When this water is flow towards turbine, at that time the Kinetic Energy is converted into Mechanical Energy. The turbine or prime mover is mechanically coupled with generator. Whenever turbine starts to rotate with the help of high pressure water, automatically generator starts to rotate & it produced an electrical energy.

Selection of Site for Hydro-Electric Power Plant:

1. Quantity of Water Required: As we know that, the hydro-electric power plant totally runs on water, so that ample quantity of water is continuously available throughout the year.

2. Hilly Area Required: For storage of ample quantity of water, both side of dam hilly area or strong mountains required for storage of water.

3. Civil Work: It should have strong foundation or the cost of foundation should be as low as possible.

4. **Large Catchment Area:** Large catchment area required, so that the water in it should never fall below the minimum level.

5. **Transportation Facility:** For Workers & Civil Material required better transportation facility.

6. **Near to Load Centre:** To reduce cost of Transmission & Distribution the plant should be located near to load centre.

7. **Availability of Material:** At the time of erecting the dam & power house a huge amount of civil material is easily available without any shortage.

8. Future Expansion: For increasing per MW Capacity of plant the space is available for future expansion.

Schematic arrangement of Hydro-Electric Power Plant:
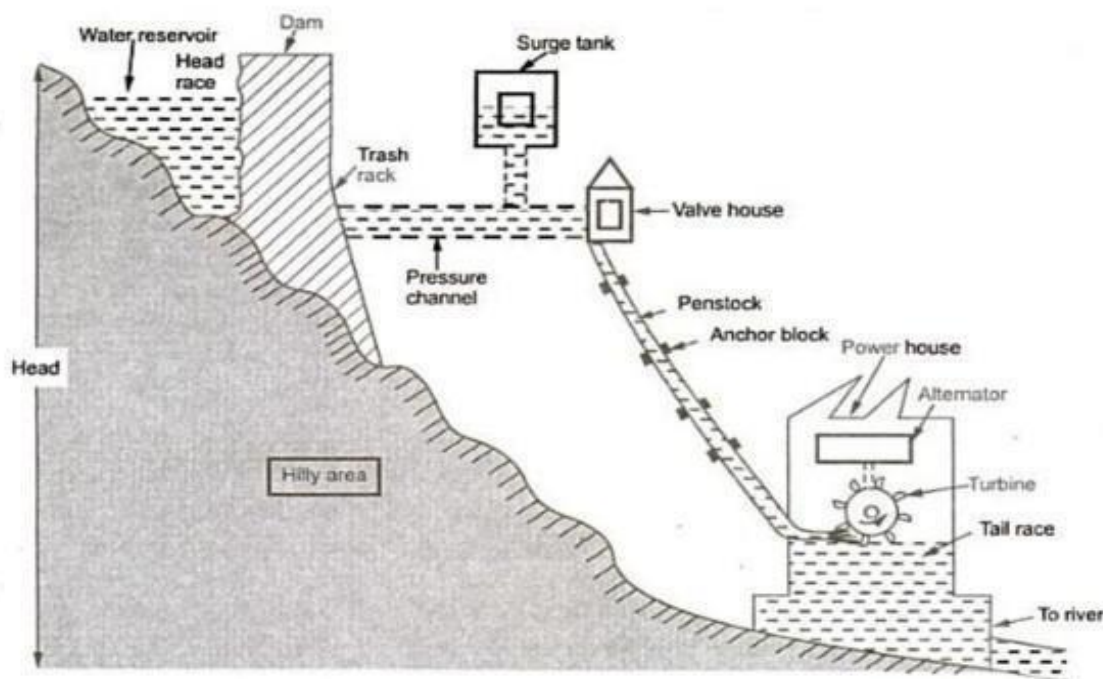
(**Fig.3.2.** Block Diagram of Hydro Power Plant)

1. Catchment Area:

In hydro-electric power plant collect the rain water through surrounding hilly area, the surrounding all water collect & stored area to those place is known as catchment area.

2. Reservoir:

The function of reservoir is to store the water near dam; this water is useful to drive the water turbines. The reservoir is useful to provide a head of stored water.

3. Head-Race Level:

The water surface in the reservoir up to the dam is known as head-race level.

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4. Dam:

The dam is used in hydro-electric power plant to store the water. Whenever the dam stored the water, it provides suitable head to this stored water. This stored water is useful throughout the year to run the hydro-electric power plant. Dam is made up of cement, concrete & sand materials..

5. Spill Way:

The excess water from dam is discharges through spillway at a permissible level.

6. Penstock:

It is the device which is used in hydro-electric power plant for the purpose of flow of water. The water flow of from dam towards turbine with the help of penstock.

7. Surge tank:

It is a device which is connected in between dam & power house. It is of vertical type. When load on power plant or alternator decreases then Governor (valve) reduces discharge of water. Due to sudden reduction in water discharge causes increase in pressure of the water in the penstock. Due to high pressure penstock may damage. At that time surge tank helps by storing this rejected water immediately.

8. Generator:

It is used to convert the mechanical energy into electrical energy. For that purpose the turbine & generator are mechanically coupled.

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 quality as compared to Thermal Power Station.

vi) In addition to generation of Electrical Energy these plants are also helpful in irrigation & control of floods.

DISADVANTAGES

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

ii) Generation depends on average rainfall round the year.

iii) High cost of transmission as these plants are located in hilly areas quite for off from localities.

NUCLEAR POWER PLANT:-

The Power Plant which uses nuclear energy of radioactive material (Uranium or Thorium) converted into Electrical Energy is known as Nuclear Power Plant.

As we know that, the freely moving neutrons bombarded with radioactive material (U^{235} or Th^{232}) the heat energy produced, with the help of this heat energy water a steam produced at high pressure & temperature. High pressure steam passes towards turbine where KE is converted to ME. We know that, turbine & generator are mechanically coupled through this combination an Electrical Energy is produced in Nuclear Power Plant.

Selection of Site for Nuclear Power Plant:

1. Availability of water: Sufficient supply of water is obvious for generating steam & cooling purposes in nuclear power station.

2. Disposal of Waste: The wastes of nuclear power station are radioactive and may cause severe health hazards. Because of this, special care to be taken during disposal of wastes of nuclear power plant.

3. Distance from Populated Area: As there is always a probability of radioactivity, it is always preferable to locate a nuclear station sufficiently away from populated area.

4. Transportation Facilities: During commissioning period, heavy equipment to be erected, which to be transported from manufacturer site. So good railways and road ways availabilities are required.

Schematic Arrangement of Nuclear Power Plant:
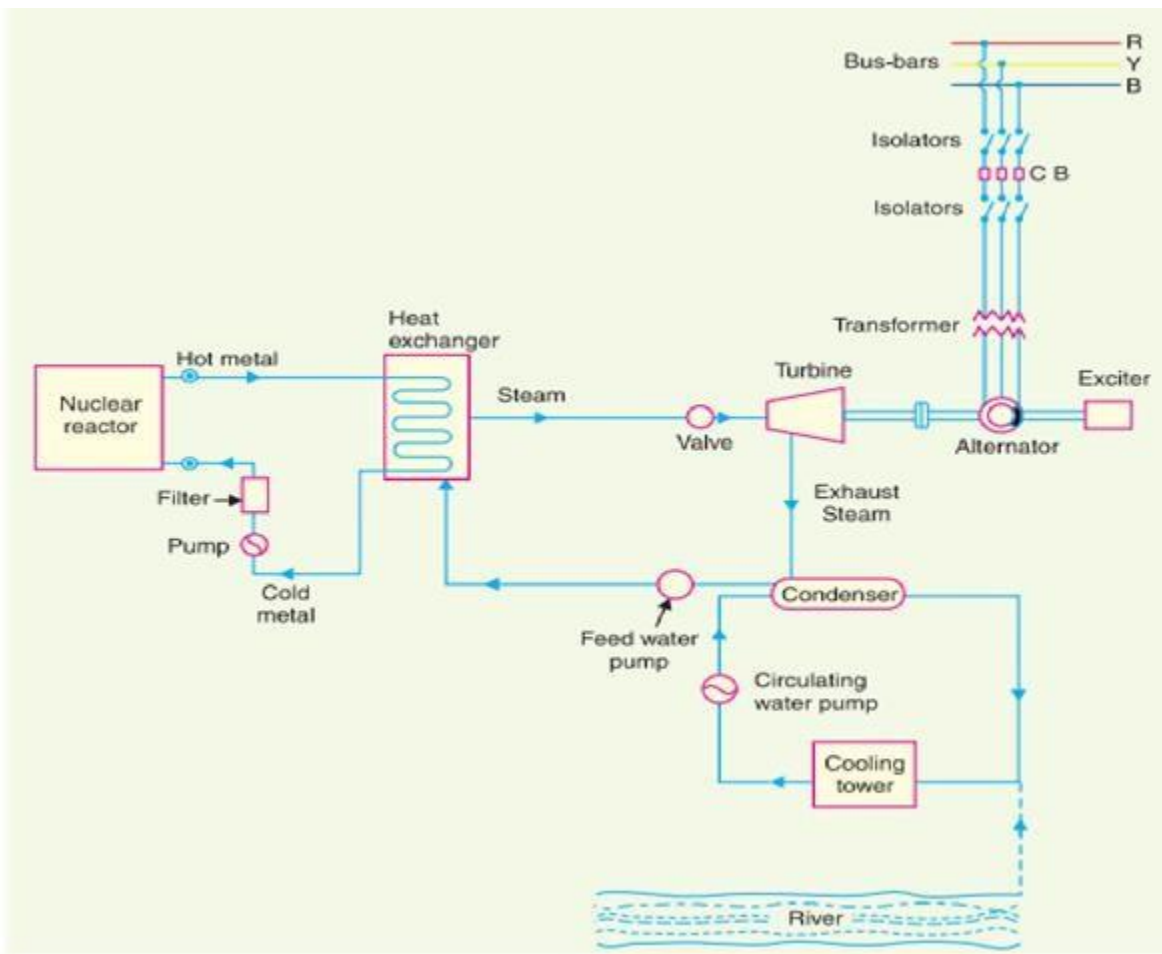
(**Fig.3.3.** Block Diagram of Nuclear Power Plant)

1. Nuclear Fuel:

In Nuclear Power Plant the fuels used are U^{235} or Pu^{239} or Th^{232}. Out of the three fuel any one of the fuel used in nuclear power plant. The fuel is required in nuclear power plant to produce a huge amount of heat energy. The fuel are inserted in fuel rod, these fuel rods are bombarded with slow moving neutrons. Separate provision provided for bombarded or hits the neutron to the fuel rod, this device is known as neutron bombardment device.

2. Moderator:

In nuclear power plant, moderator is a device, of rod shaped. Moderator is placed near the nuclear fuel rod. The main function of moderator in nuclear power plant is reduce the speed of neutrons (neutron at slower speed is required to produce fission) & increases the fission processes. Moderator rod is made up of graphite or heavy water or beryllium material.

3. Control Rods:

In nuclear power plant, the control rods are placed in between nuclear fuel rod, moderator and then control rod. In nuclear power plant the main function of control rod is to control the chain reaction. If the control rod is inserted then it absorbs the freely moving neutrons & stop the chain reaction, if it is no inserted chain reaction is in process, means chain

reaction continued. The steady rate or to stop the chain reaction is maintained through control rods. The control rods are made up of cadmium, boron (alloyed with steel or aluminium).

4. Nuclear Reactor:

It is an apparatus in which the nuclear fuel(U^{235}) is subjected to nuclear fission.

5. Heat Exchanger:

The main function of heat exchanger in nuclear power plant is the boiled the cold water and produces steam at high temperature & pressure.

6. Turbine:

Turbine receives steam from heat exchange at high pressure, and it rotates at high speed then alternator also rotates, this way electrical power produced. The exhaust steam from turbine passes to condenser for further use.

ADVANTAGES

i) There is saving in fuel transportation as amount of fuel required is less.

ii) A Nuclear Power Plant requires less space as compared to other plants.

iii) This type of plant is economical for producing bulk Electrical Energy.

DISADVANTAGES

i) Fuel is expensive and difficult to recover.

ii) Capital lost is higher than other plants.

iii) Experienced workman ship is required for plant erection & commissioning.

iv) The Fission by-products are radioactive & can cause dangerous radio-active pollution.

QUESTIONS FOR PRACTICE

Short Answer Questions

1. What are the function of following elements in Hydro Power Plant?
   (a) Surge Tank (b) Penstock (c) Generator (d) Dam (e) Spillway
2. Write down the function of following elements in Thermal Power Plant?
   (a) Boiler (b) Super-heater (c) Economiser (d) Feed-water Heater (e) Air Pre Heater
   (f) Condenser (g) Induced Draught Fan (h) Forced Draught Fan (i) Chimney (j) Cooling tower (k) Alternator
3. Describe the function of following elements in Nuclear Power Plant?
   (a) Moderator (b) Control Rod (c) Nuclear Reactor (d) Heat Exchanger (e) Turbine

Long Answer Questions

1. Write down the advantages & disadvantages of Hydro Power Plant, Thermal Power Plant & Nuclear Power Plant

2. Draw the block diagram of Hydro Power Plant and explain the function of each elements of it.

3. Draw the block diagram of Nuclear Power Plant and explain the function of each elements of it.

4. Draw the block diagram of Thermal Power Plant and explain the function of each elements of it.

CHAPTER - 4

CONVERSION OF ELECTRICAL ENERGY

INTRODUCTION:-

A DC 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.

PARTS OF DC MACHINE:-
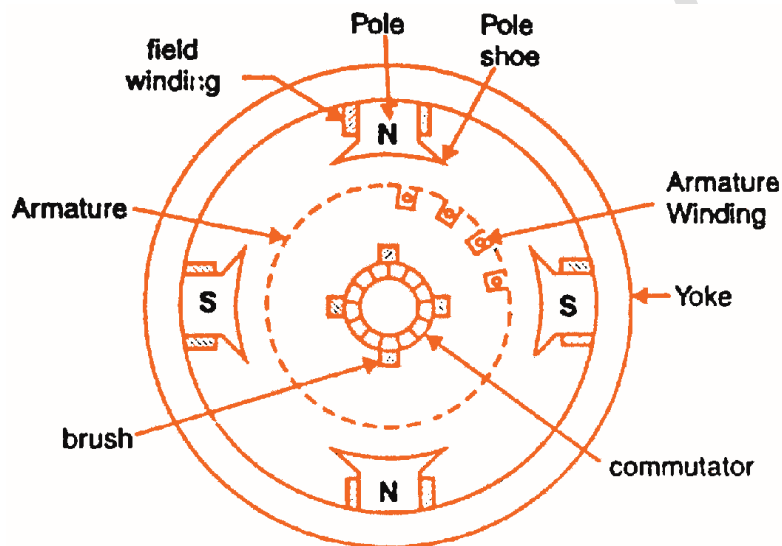
(**Fig.4.1.** Different Parts of DC Machine)

The DC machine consists of the following essential parts:

Magnetic frame or Yoke: - Purpose of Yoke is:
  (a) It act as a protecting cover for whole machine.
  (b) It also provides mechanical support for poles.
  (c) It carries the magnetic flux produced by poles

Pole Cores and Pole Shoes: - The field magnets consist of pole cores and pole shoes. The Pole shoes serve two purposes:
(a) They spread out the flux in the air gap
(b) They support the exciting coils

Field winding: - The field winding is wound on the pole core with a definite direction. Function of field winding is to carry current due to which pole core on which the winding is placed behaves as an electromagnet, producing necessary flux.

Armature Core: - Armature core is cylindrical in shape mounted on the shaft. It is made up of laminated construction to keep eddy current loss as low as possible. Function of armature core is:

1. Armature core provides house for armature winding i.e., armature conductors.

2. To provide a path of low reluctance path to the flux it is made up of magnetic material like cast iron or cast steel.

Armature Windings or Conductors: - Armature winding is the inter connection of the armature conductors, placed in the slots provided on the armature core. Function of armature conductor is:

1. Generation of emf takes place in the armature winding in case of generators.

2. To carry the current supplied in case of dc motors.

3. To do the useful work it the external circuit.

Commutator: - The function of Commutator is to facilitate collection of current from the armature conductors and converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit. The commutator is made up of insulated copper segments.

Brushes and Bearings: - Brushes are normally made up of soft material like carbon. Brushes are used to collect current from commutator and make it available to the stationary external circuit. Bearings are used for smooth running of the machine.

CLASSIFICATION OF DC GENERATOR/MOTOR:-

DC generators/motors are usually classified according to the way in which their fields are excited.

DC generators/motors may be divided into

(a) Separately excited DC generators/motors

(b) Self-excited DC generators/motors

a) Separately excited DC generators/motors: - Separately excited generators/motors are those whose field magnets are energized from an independent external source of dc current.

b) Self-excited DC generators/motors: - Self excited generators/motors are those whose field magnets are energized by the current produced by the generators/motors themselves.

There are three types of self-excited dc generators/motors named according to the manner in which their field coils (or windings) are connected to the armature.

(i) Shunt wound DC generator/motor: - In shunt the two windings, field and armature are in parallel.

(ii) Series wound DC generator/motor: - In series type both field and armature winding are in series.

(iii) Compound wound DC generator/motor: - There are two types of compound wound DC generator/motor.

(a) Long shunt compound DC generator/motor: - The shunt field winding is parallel with both armature and series field winding.

(b) Short shunt compound DC generator/motor: - The shunt field winding is in parallel with armature winding only.
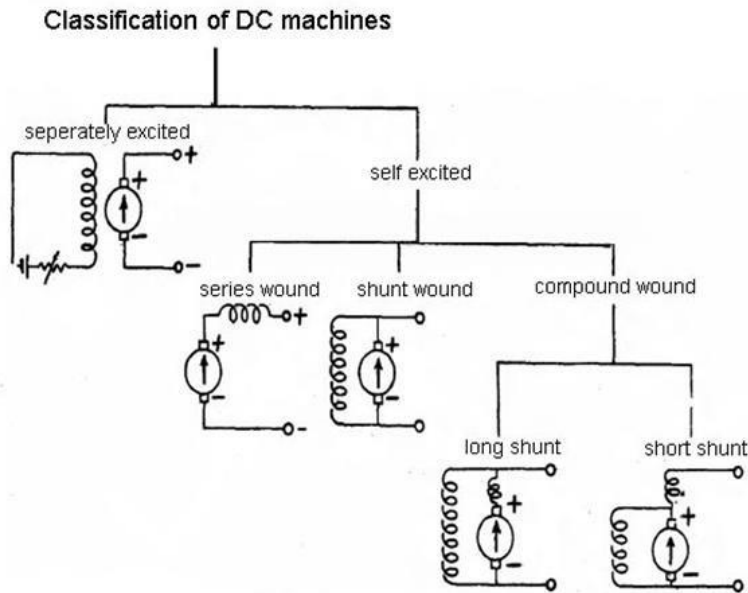
(**Fig.4.2.** Classification of DC machine)

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

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

CONCEPT OF LUMEN:-

It is the unit of luminous flux. It is defined as the luminous flux emitted by a source of one candle power per unit solid angle in all directions.

Lumen = candle power of source × solid angle.

Lumen = CP × ω

Total flux emitted by a source of one candle power is 4π lumens.

DIFFERENT TYPES OF LAMPS:-

(a) Filament Lamp:-

Construction
- It consists of an evacuated glass bulb and an aluminum or brass cap is provided with two pins to insert the bulb into the socket.
- The inner side of the bulb consists of a tungsten filament and the support wires are made of molybdenum to hold the filament in proper position.
- A glass button is provided in which the support wires are inserted.
- A stem tube forms an air-tight seal around the filament whenever the glass is melted.
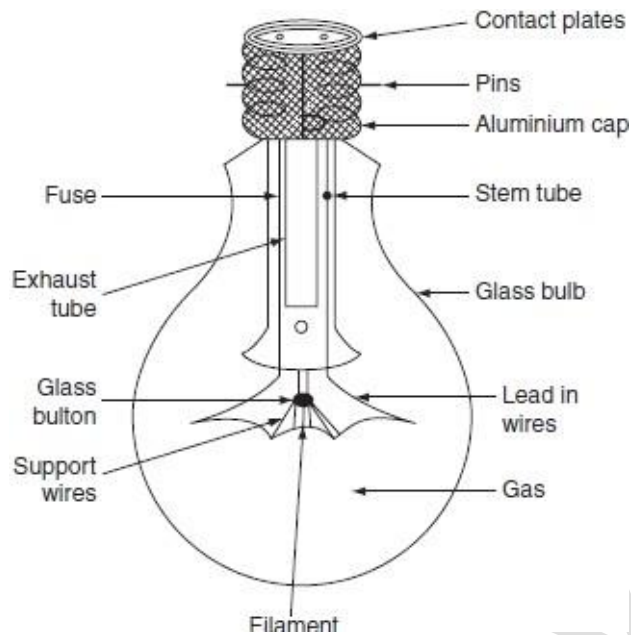
(**Fig.4.3.** Construction of Filament Lamp)

Principle

- When electric current is made to flow through the fine metallic tungsten filament, its temperature increases. At very high temperature, the filament emits both heat and light radiations, which fall in the visible region.
- The tungsten filament lamps can be operated efficiently beyond 2,000°C, it can be attained by inserting a small quantity of inert gas nitrogen with small quantity of argon.

(b) Fluorescent Lamp:-

Fluorescent lamp is a hot cathode low-pressure mercury vapor lamp.

Construction

- It consists of a long horizontal tube, due to low pressure maintained inside of the bulb; it is made in the form of a long tube.
- The tube consists of two spiral tungsten electrode coated with electron emissive material and are placed at the two edges of long tube.
- The tube contains small quantity of argon gas and certain amount of mercury, at a pressure of 2.5 mm of mercury.
- Normally, low-pressure mercury vapor lamps suffer from low efficiency and they produce an objectionable colored light. Such drawback is overcome by coating the inside of the tube with fluorescent powders. They are in the form of solids, which are usually knows as phosphors.
- A glow starter switch contains small quantity of argon gas, having a small cathode glow lamp with bimetallic strip is connected in series with the electrodes, which puts the electrodes directly across the supply at the time of starting.

- A choke is connected in series that acts as ballast when the lamp is running, and it provides a voltage impulse for starting. A capacitor of 4μF is connected across the starter in order to improve the power factor.
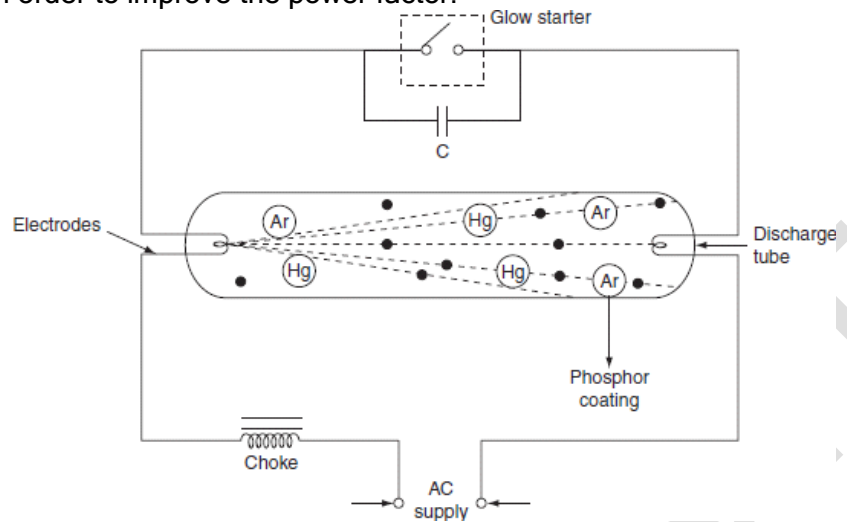
(**Fig.4.4.** Construction of Filament Lamp)

Principle

- At the time of starting, when both the lamp and the glow starters are cold, the mercury is in the form of globules.
- When supply is switched on, the glow starter terminals are open circuited and full supply voltage appeared across these terminals, due to low resistance of electrodes and choke coil.
- The small quantity of argon gas gets ionized, which establishes an arc with a starting glow.
- This glow warms up the bimetallic strip thus glow starts gets short circuited. Hence, the two electrodes come in series and are connected across the supply voltage.
- Now, the two electrodes get heated and start emitting electrons due to the flow of current through them.
- These electrons collide with the argon atoms present in the long tube discharge that takes place through the argon gas. So, in the beginning, the lamp starts conduction with argon gas as the temperature increases, the mercury changes into vapor form and takes over the conduction of current.
- In the meantime, the starter potential reaches to zero and the bimetallic strip gets cooling down. As a result, the starter terminals will open. This results breaking of the series circuit.
- A very high voltage around 1,000 V is induced, because of the sudden opening of starter terminals in the series circuit. But in the long tube, electrons are already present; this induced voltage is quite sufficient to break down the long gap. Thus, more number of electrons collide with argon and mercury vapor atoms.
- The excited atom of mercury gives UV radiation, which will not fall in the visible region. Meanwhile, these UV rays are made to strike phosphor material; it causes the re-emission of light of different wavelengths producing illumination. The phenomenon of the emission is called as luminescence.

(c) LED Lamp:-

- A Light emitting diode bulb consists of two semiconducting material i.e. p-type material and n-type material. A p-n junction is formed, by connecting these two types of materials.

- When the p-n junction is forward biased, the majority carriers; either electrons or holes; start moving across the junction.
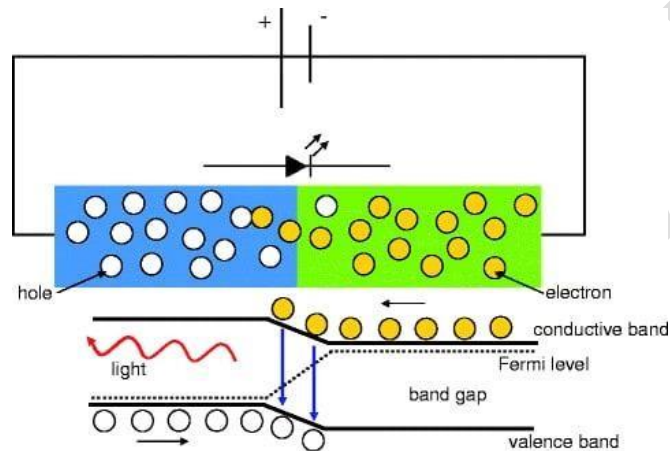
(**Fig.4.5.** Construction of LED Lamp)

- As shown in the figure above, electrons start moving from n-region and holes start moving from p-region. When they moved from their regions they start to recombine across the depletion region. Free electrons will remain in the conduction band of energy level while holes remain in the valence band of energy level.
- The Energy level of the electrons is high than holes because electrons are more mobile than holes i.e. current conduction due to electrons are more. During the recombination of electrons and holes, some portion of energy must be dissipated or emitted in the form of heat and light.
- The phenomenon into which light emits from the semiconductor under the influence of the electric field is known as electroluminescence.
- Always remember that the majority of light is produced from the junction nearer to the p-type region. So diode is designed in such a way that this area is kept close to the surface of the device to ensure that the minimum amount of light is absorbed.
- The electrons dissipate energy in different forms depending on the nature of the diode used. Like for silicon and germanium diodes, it dissipates energy in the form of heat while for gallium phosphide (GaP) and gallium arsenide phosphide (GaAsP) semiconductors, it dissipates energy by emitting photons.
- For the emission of different colors, different semiconductors are used. For example; phosphorus is used for a red light, gallium phosphide for the green light and aluminum indium gallium phosphide for yellow and orange light.

STAR RATING OF HOME APPLIANCES:-

- **Terminology**

  White goods > Home appliances (refrigerator, a/c etc)
  Brown goods > Portable appliances (television and wireless sets, microwave ovens, coffee makers)
  BEE > Bureau of Energy Efficiency
  EER > Energy Efficiency Ratio
  BTU > British thermal unit

- **Energy Efficiency**

  It is defined as energy service per unit of energy consumption.

- **Star Rating**
  - An energy efficiency rating scheme for Electrical appliances is known as Star labelling.
  - Star Rating is the average amount of electricity used by the equipment in a year i.e kWh/year or unit/year under standard test conditions.
  - Star ratings are provided to all the major kind of appliances in the form of labels. These star ratings are given out of 5 and they provide a basic sense of how energy efficient each product is.

(**Fig.4.6.** Star rating of appliance)

QUESTIONS FOR PRACTICE

Short Answer Questions

1. What is a motor?
2. Classify dc machine.
3. What is the function of (i) Yoke (ii) armature (iii) commutator (iv) brush
4. Define (i) BEE (ii) EER (iii) BTU
5. Define star rating.
6. What is Lumen?
7. State two uses of capacitor start motor and shaded pole motor.
8. What is the use of starter in fluorescent lamp?
9. Which materials are used in LED bulb?
10. What is the importance of using tungsten filament?
11. Which type of motor is used in Electric trains and cranes?
12. What is the function of Series Generator?
13. What is the unit of energy consumed?

Long Answer Questions
1. Draw the schematic diagram of a dc machine and label the parts. State the function of every part.
2. Describe the construction of filament lamp with a neat diagram.
3. Explain the working of fluorescent lamp.
4. Write short notes on
   (i) Types of single phase induction motor and their uses.
   (ii) LED Lamp, its construction and uses.
   (iii) Star rating of home appliances
   (iv)Uses of different types of dc motors

CHAPTER-5

WIRING AND POWER BILLING

ELECTRICAL WIRING:-

A network of cables connecting various electrical accessories for distribution of electrical energy from the supplier meter board to the various electrical energy consuming devices such as lamps, fans, radio, TV and other domestic appliances through controlling and safety devices is known as wiring system.

TYPES OF WIRING FOR DOMESTIC INSTALLATIONS:-

Electrical wiring system is classified into five categories:

- Cleat wiring
- Wooden casing and capping wiring
- CTS or TRS or PVC sheath wiring
- Lead sheathed or metal sheathed wiring
- Conduit wiring
  - Surface or open Conduit type
  - Concealed or underground type Conduit

- **Cleat Wiring**

  - In this system of wiring cables are supported and gripped between porcelain cleats above the wall or roof.
  - The porcelain cleats are made in two halves. The main part is base, which is grooved to accommodate the cables, the other part is the cap which is put over the base
  - The lower cleat (base) and upper cover (cap), after placing cables between them are then screwed on wooden gutties.
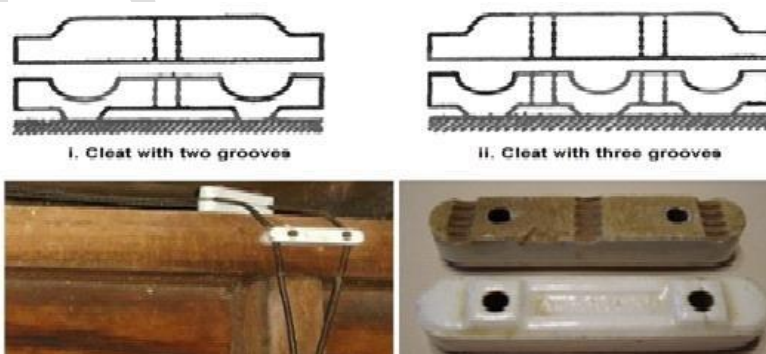
(**Fig.5.1.** Cleat Wiring)

Advantages:
- It is the cheapest system.
- Installation and dismantling is easy.
- Less skilled persons are required.

- Inspection is easy.
- Alterations and additions are easy.
- As the cables and wires of cleat wiring system is in open air, therefore fault in cables can be seen and repair easily
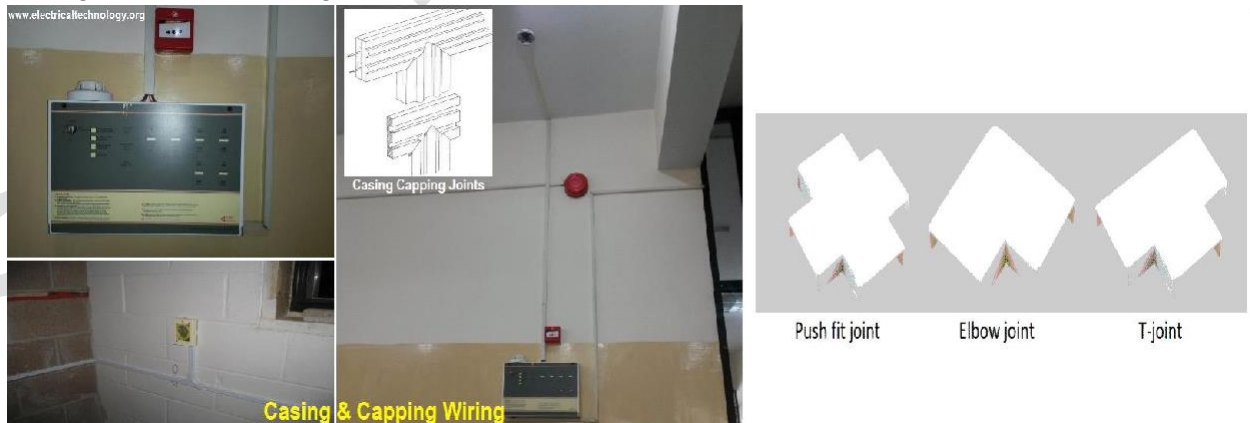
Disadvantages:
- It is purely temporary wiring system.
- Appearance is not good.
- Cables are exposed to atmosphere and there is a possibility of mechanical injury.
- This system should not be used in damp places otherwise insulation gets damaged.
- It is not lasting wire system because of the weather effect and wear & tear
- It can be only used on 250/440 Volts on low temperature.
- There is always a risk of fire and electric shock.
- It can"t be used in important and sensitive location and places.
- It is not reliable and sustainable wiring system.

Application:
- It is suitable for temporary installation in dry places i.e. under construction building or army camping

• **Casing and Capping wiring**

- It consists of rectangular blocks made from seasoned and knots free wood or PVC.
- The casing has usually two (or three) "U" shaped grooves, (two in number) into which the VIR or PVC cables are laid in such a way that the opposite polarity cables are laid in different grooves.
- The casing is covered by means of a rectangular strip of the same width as that of casing known as capping and is screwed to it.

(**Fig.5.2.** Casing & Capping Wiring)

Advantages:
- It provides good mechanical strength.
- Easy to inspect by opening the capping.
- It is cheap wiring system as compared to sheathed and conduit wiring systems.

- It is strong and long-lasting wiring system.
- If Phase and Neutral wire is installed in separate slots, then repairing is easy.
- Stay for long time in the field due to strong insulation of capping and casing..
- It stays safe from oil, Steam, smoke and rain.
- No risk of electric shock due to covered wires and cables in casing & capping
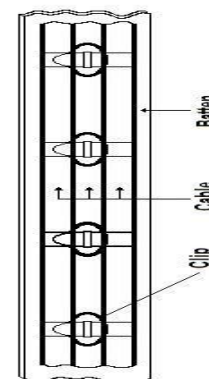
Disadvantages:
- Difficulty in finding any fault caused in the wire.
- There is a high risk of fire in casing & capping wiring system.
- Not suitable in the acidic, alkalies and humidity conditions
- Costly repairing and need more material.
- Material can"t be found easily in the contemporary
- White ants may damage the casing & capping of wood.
- This system cannot be used in damp places.

Application:
      Used in low voltage residential and office building.

-                        **<u>Batten Wiring (CTS or TRS)</u>**

- The cables are run or carried on well-seasoned, perfectly straight and well varnished (on all four sides) teak wood batten of thickness 10 mm. at least.
- The width of the batten depends upon the number and size of cables to be carried by it..
- The wooden battens are fixed to the walls or ceilings by means of PVC gutties or wooden plugs with flat head wooden screws, the wooden screws should be fixed on the batten at an interval not exceeding **75cm**.

(**Fig.5.3.** Batten Wiring)

Advantages:
- Wiring installation is simple and easy
- cheap as compared to other electrical wiring systems
- Repairing is easy
- Strong and long-lasting
- Appearance is better.

- Customization is easy
- Less chance of leakage current

Disadvantages:
- Not suitable for outdoor wiring
- Humidity, smoke, steam etc. directly affect on wires.
- Heavy wires are not recommended for this wiring scheme.
- Only suitable for below 250 V.
- High risk of fire.

Application:
- Used in domestic, commercial or industrial wiring except workshops
- Used for low voltage installation

- ## Lead Sheathed Wiring

- The type of wiring employs conductors that are insulated with VIR and covered with an outer sheath of lead aluminum alloy containing about 95% of lead.
- The metal sheath given protection to cables from mechanical damage, moisture and atmospheric corrosion.
- The whole lead covering is made electrically continuous and is connected to earth at the point of entry to protect against electrolytic action due to leaking current and to provide safety in case the sheath becomes alive.
- The cables are run on wooden batten and fixed by means of link clips just as in TRS wiring.

Advantages:
- Provides protection against mechanical injury better than TRS wiring.
- Easy to fix and looks nice
- Long life if proper earth continuity is maintained.
- Can be used in damp situation and in situation exposed to rain & sun.

Disadvantages:
- Costlier than TRS wiring
- Not suitable for chemical corrosion.
- In case of damage of insulation the metal sheath becomes alive & give shock.
- Skilled labour & proper supervision is required.

Application:
- Commonly used for laying sub mains from pole to electric meter

- ## Conduit Wiring

- There are two additional types of conduit wiring according to pipe installation
  - **Surface Conduit Wiring**

- **Concealed Conduit Wiring**

- **Surface Conduit Wiring**
- If conduits installed on roof or wall, It is known as surface conduit wiring. In this wiring method, they make holes on the surface of wall on equal distances and conduit is installed then with the help of rawal plugs.
- **Concealed Conduit wiring**
- If the conduits is hidden inside the wall slots with the help of plastering, it is called concealed conduit wiring. In other words, the electrical wiring system inside wall, roof or floor with the help of plastic or metallic piping is called concealed conduit wiring. obliviously,
- It is the most popular, beautiful, stronger and common electrical wiring system nowadays.
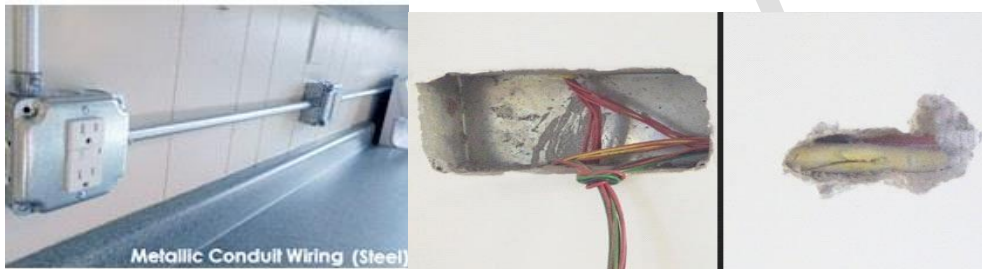
(**Fig.5.4.** Conduit Wiring)

Advantages:
- The safest wiring
- Appearance is better
- No risk of fire or mechanical wear and tear.
- No risk of damage of cable insulation
- Safe from humidity, smoke, steam etc.
- No risk of shock
- Long lasting
- Repairing and maintenance is easy.

Disadvantages:
- Very expensive
- Installation is not easy
- Not easy to customize for future
- Hard to detect the faults.
- Risk of Electric shock (In case of metallic pipes without proper earthing system)
- Experienced & highly skilled labour is required

Application:
- Places where dust is present such as in textile mills, sawmills, flour mills etc.
- Damp situation
- In workshop
- Residential, commercial and public building

LAYOUT OF HOUSEHOLD ELECTRICAL WIRING:-
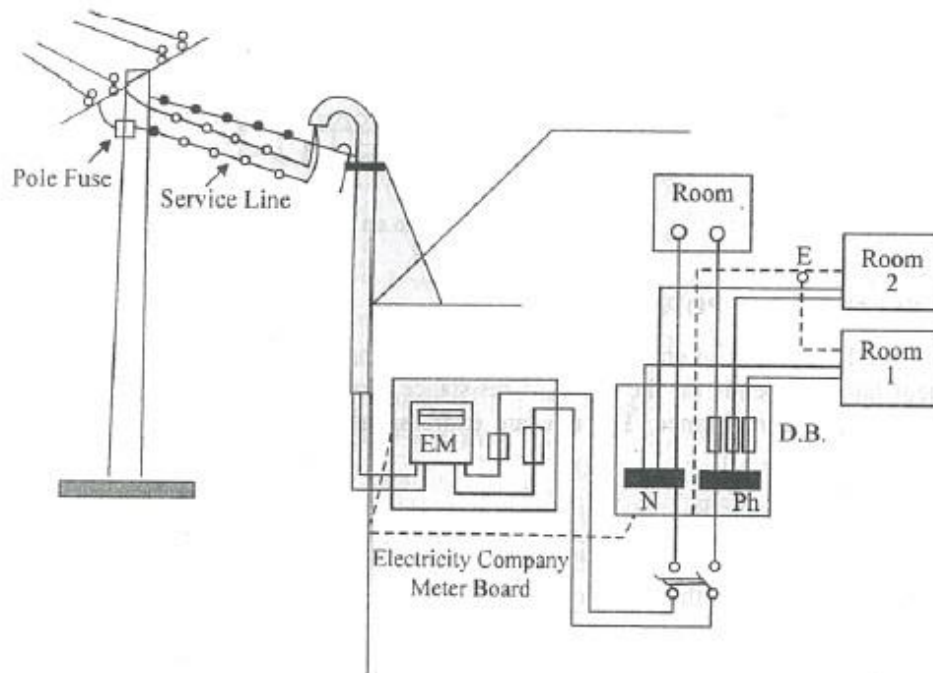
(**Fig.5.5.** Layout of Household Electrical Wiring)

BASIC PROTECTIVE DEVICES USED IN HOUSE HOLD WIRING:-

- Fuse
- MCB (Miniature Circuit Breaker)
- Lightening arrester
- Earthing Wire

ELECTRICAL ENERGY:-

- Energy is the capacity to do work, and is measured in joules (J).
- The electric power utility companies measure energy in watt-hours (WH) or Kilo watt-hours (KWH)

Example 5.1. 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:

Sl.No.	Name of Appliances	Quantity	Power Rating in KW	Working Hrs in a day	Energy consumed in KWH
01	Motor	1No.	1HP = 746W=0.746KW	5	1×0.746×5=3.73

02	Fans	3Nos	80W = 0.08KW	10	3×0.08×10=2.4
03	Tubelight	4Nos	40W = 0.04KW	15	4×0.04×15=2.4
				Total Energy consumed in KWH=	3.73+2.4+2.4=8.53

As we know 1KWH = 1unit
So, 8.53 KWH = 8.53 units.
In the month of November total Electrical Energy Consumed = 8.53 X 30 = 255.9 units.
Monthly bill = 255.9 X Rs.2.5 = Rs. 639.75P.

Example 5.2. A building has the following electrical appliances

(i) Two bulb each of 60 watt and one bulb of 100 watt.

(ii) Tube light 40 watt -2 nos.

(iii) Three Fans of 60 watt each

(iv) One Refrigerator of 150 watt.

All the lighting devices works for 6 hrs a day, fans work for 10 hrs and refrigerator works for 24 hrs. The electric tariff is as follows:- for first 100 units @ Rs. 1.40/-,next 100 units @ Rs. 2.30/- Rest @ Rs. 3.10/- .Calculate the bill for the month of 30 days.

Solution:

Sl.No.	Name of Appliances	Quantity	Power Rating in KW	Working Hrs in a day	Energy consumed in KWH
01	Bulb	2	0.060	6	2×0.06×6=0.72
02	Bulb	1	0.100	6	1×0.1×6=0.6
03	Tube light	2	0.040	6	2×0.04×6=0.48
04	Fan	3	0.060	10	3×0.06×10=1.8
05	Refrigerator	1	0.150	24	1×0.150×24=3.6
				Total energy consumed	7.2 KWH

As we know 1KWH = 1unit
So, 7.2KWH = 7.2units.
In the month of 30 days, total Electrical Energy Consumed = 7.2 X 30 = 216 units.
Monthly bill = 100 X Rs.1.40/- = Rs. 140/-

100 .X Rs 2.30/- = Rs. 230/-

16 X Rs 3.10/- = Rs. 49.6/-

Total = Rs. 419.6/-

QUESTIONS FOR PRACTICE

Short Answer Questions

1. Expand the abbreviations VIR, PVC, CTS, and TRS.

2. Name the different types protective devices used in house wiring.

3. Define one unit of electrical energy.

4. State the relation between

   (i) Kilowatt and joule

   (ii) H.P and Joule

   (iii) Energy and power

5. Which type of wiring is used for temporary installation?

Long Answer Questions

1. Writes on (i) CTS wiring (ii) Conduit wiring (iii) Batten wiring (iv) Casing and capping wiring (v) Lead sheathed wiring

2. Draw a layout of wiring of a domestic installation.

3. Find out the cost of electrical energy consumed in the month of September for the following electrical appliance @ Rs. 2.30/- per unit.

 (i) Four 60 watt lamp for 8 hours.

 (ii) Six 80 watt ceiling fans for 10 hrs.

 (iii) Two A.C of 1KW for 6 hrs.

 (iv) One 0.5 HP motor for 2 hrs.

CHAPTER-6
MEASURING INSTRUMENTS

INTRODUCTION TO MEASURING INSTRUMENTS:-

- The measurement of a given quantity is the result of comparison between the quantity to be measured and a definite standard. The instruments which are used for such measurements are called **measuring instruments**.
- The three basic quantities in the electrical measurement are current, voltage and power.
- The instrument which measures the current flowing in the circuit is called ammeter while the instrument which measures the voltage across any two points of a circuit is called voltmeter. The instruments which are used to measure the power are called wattmeter.

CLASSIFICATIONS OF ELECTRICAL INSTRUMENTS:-

Electrical instruments are broadly classified into two types
1) Absolute instruments
Absolute instruments are those which give the value of the quantity to be measured in terms of the constants of the instrument and their detection only. No previous calibration or comparison is necessary in their case.
Example: Tangent galvanometer, which gives the value of current, in terms of the tangent of deflection produced by the current, the radius and number of turns of wire used and the horizontal component of earth's field.
2) Secondary instruments
Secondary instruments are those, in which the value of electrical quantity to be measured can be determined from the deflection of the instruments, only when they have been pre-calibrated by comparison with an absolute instrument.
Example: Ammeter, Voltmeter etc.

- The secondary instruments are again divided into the following three types
a) Indicating instruments
b) Recording instruments
c) Integrating instruments
a) Indicating instruments:
Indicating instruments are those which indicate the instantaneous value of the electrical quantity being measured at the time at which it is being measured. Their indications are given by pointers moving over calibrated dials.
Example: Ordinary ammeters, voltmeters and wattmeter
b) Recording instruments:
These instruments give a continuous record of the given electrical quantity which is being measured over a specific period. The examples are various types of recorders. In such recording instruments, the readings are recorded by drawing the graph. The pointer of such instruments is provided with a marker i.e. pen or pencil, which moves on graph paper as per the reading.

Example: X-Y plotter, ECG.
c) Integrating instruments:
These instruments measure the total quantity of electricity delivered over period of time.

Example: a household energy meter.

TORQUES IN INSTRUMENT:-

In case of measuring instruments, the effect of unknown quantity is converted into a mechanical force which is transmitted to the pointer which moves over a calibrated scale. The moving system of such instrument is mounted on a pivoted spindle. For satisfactory operation of any indicating instrument, following torques must be present in an instrument.
1) Deflecting system producing deflecting torque (T_d)
2) Controlling system producing controlling torque (T_c)
3) Damping system producing damping torque

1) Deflecting Torque:
In most of the indicating instruments the mechanical force proportional to the quantity to be measured is generated. This force or torque deflects the pointer. The system which produces such a deflecting torque is called deflecting system and the torque is denoted as T_d.

2) Controlling Torque:
This system should provide a force so that current or any other electrical quantity will produce deflection of the pointer proportional to its magnitude. The important functions of this system are,
1) It produces a force equal and opposite to the deflecting force in order to make the deflection of pointer at a definite magnitude. If this system is absent, then the pointer will swing beyond its final steady position for the given magnitude and deflection will become indefinite.
2) It brings the moving system back to zero position when the force which causes the movement of the moving system is removed. It will never come back to its zero position in the absence of controlling system.

The controlling torque in indicating instruments may be provide by one of the following two methods.
a) By weighting of moving parts i.e., Gravity Control
b) By one or more springs i.e., Spring Control

3) Damping Torque:
The deflecting torque provides some deflection and controlling torque acts in the opposite direction to that of deflecting torque. So before coming to the rest, pointer always oscillates due to inertia, about the equilibrium position. Unless pointer rests, final reading cannot be obtained. So to bring the pointer to rest within short time, damping system is required. The system should provide a damping torque only when the moving system is in motion.

Damping torque is proportional to velocity of the moving system but it does not depend on operating current

The following methods are used to produce damping torque.
a) Air friction damping
b) Fluid friction damping
c) Eddy current damping.

DIFFERENT USES OF PMMC TYPES INSTRUMENT:-

(i)   Ammeter: - When PMMC used as an ammeter, except for a very small current range, the moving coil is connected across a suitable low resistance shunt, so that only small part of the main current flows through the coil.
(ii) Voltmeter: - When PMMC used as voltmeter, the coil is connected in series with high resistance. The same PMMC instrument can be used as voltmeter or ammeter
(iii) Galvanometer: - It is used to measure a small value of current along with its direction and strength.
(iv) Ohm meter: - It is used to measure the resistance of the electric circuit by applying a voltage to a resistance with the help of battery.

DIFFERENT USES OF MI TYPES INSTRUMENT:-

● They are suitable for measurement of current, voltage and power factor in electrical circuit.
● They are used for DC as well as low frequency AC in high power circuits.
● MI ammeter can be designed for full scale deflection current of 0.1Amp to 30Amp without use of shunt
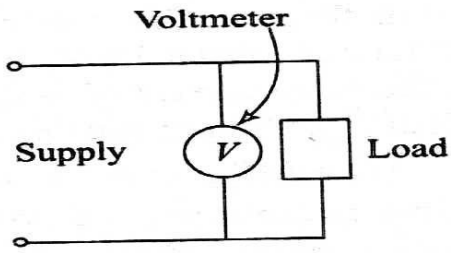● MI voltmeter of ranges over 50V without series resistance are in common use.

CONNECTION DIAGRAM:-

(i)   Ammeter:
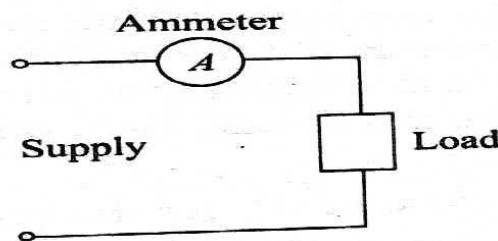
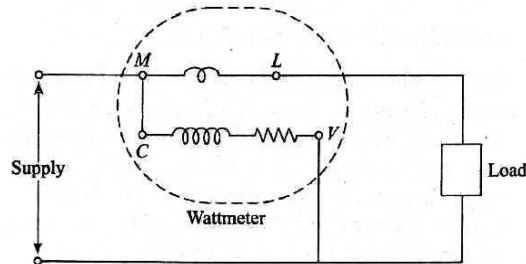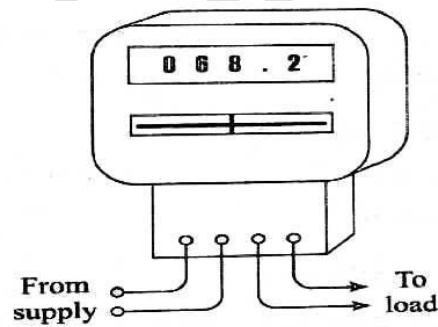(**Fig.6.1.** Connection Diagram of Ammeter)

(ii) Voltmeter:

(**Fig.6.2.** Connection Diagram of Voltmeter)

(iii) Wattmeter

(**Fig.6.3.** Connection Diagram of Wattmeter)

(iv) Energy meter

(**Fig.6.4.** Connection Diagram of Energy meter)

QUESTIONS FOR PRACTICE

Short Answer Questions

1. Which device is used for measuring current & voltage?
2. Draw layout diagram 1-phase energy meter used for domestic purpose.
3. Name three torques in measuring instruments.
4. Sketch connection diagram of :-
    (i) Ammeter
   (ii) Voltmeter
   (iii) Wattmeter

Long Answer Questions

1. Discuss the torques required in measuring instruments in detail.
2. Explain uses of PMMC type instruments.
3. Explain uses of MI type of instruments.

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