constant of

Electric potential: — The electric potential or voltage at any point in an electric field is equal to the work done in moving a unit positive charge from infinity to that point against the electric field. The unit of electric potential is volt (V).

Potential difference: — The potential difference betn two points in an electric field is equal to the work done in moving a unit positive charge from the point of lower potential to the point of higher potential. The unit of potential difference is volt.

Electromotive force (emf): — The difference of potential produced by sources of electric energy which can be used to drive currents through external circuits.

Current: — An electric current is said to flow through a conductor when there is an

The unit of current is ampere.

Source: — An active pair of terminals that can deliver power to a load.

Load: — The rate at which energy is fed into a process or removed from it. The examples of electrical loads are T.V., cooler, bulb, fan, freeze, etc.

Resistance: — The resistance is the property of a material by virtue of which it opposes the flow of current through it. The unit of resistance is ohm (Ω).

The resistance of a conducting wire is directly proportional to its length (l). It is inversely proportional to its area of cross-section (a). It depends upon the nature of the conducting material. Also, it depends upon temperature. Mathematically,

$$R \propto \frac{l}{a}$$

... where ρ (rho) is a constant of material called specific resistance or resistivity. If $l = 1m$ and $a = 1m^2$, then $\rho = R$. So, the resistivity of a material is the resistance offered by 1m of its length & having a cross-section of $1m^2$. The SI unit of specific resistance is ohm.metre. The reciprocal of resistance is called conductance (G). Mathematically,

$$G = \frac{1}{R}$$

The unit of conductance is ohm^{-1} or mho.

OHM'S LAW: — The ohm's law is defined as follows.

The current passing through a conductor is directly proportional to the potential difference across the ends of the conductor, provided the physical condition of the conductor remains the same. Mathematically,

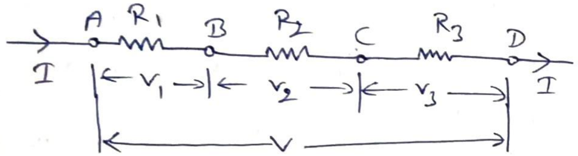
$$I \propto V$$

$$\Rightarrow \frac{V}{I} = \text{Constant} = R$$

$\therefore R = \frac{V}{I}$

where, the constant 'R' is the resistance of the conductor.

Conductors in series :-



conductors in series

If the conductors are connected end to end, ~~and~~ same current flows through all conductors and p.d. across each one is different depending upon their resistances, then the conductors are said to be connected in series. In the above fig, A and D are the free ends of three conductors AB, BC & CD connected in series. Let R_1, R_2 & R_3 be the respective resistance.

R = resistance of combination

V = total p.d. across the resistors

I = current

Then,

$V = IR \quad \ldots (1)$

But V = sum of the individual p.d. across R_1, R_2 & R_3.

$V = V_1 + V_2 + V_3$

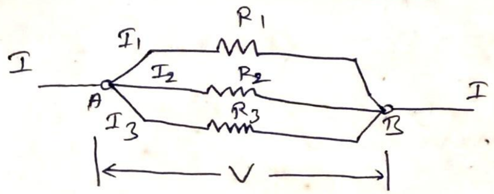
$= IR_1 + IR_2 + IR_3 \quad \ldots (2)$

By putting the value of 'V' from eqn (1) in eqn (2), we get

$IR = IR_1 + IR_2 + IR_3$

$\Rightarrow R = R_1 + R_2 + R_3 \quad \ldots (3)$

Conductors in parallel :-



If the conductors are connected across two common points, they are said to be connected in parallel. In the above fig. three conductors of resistance R_1, R_2 & R_3 are connected betn the common points A and B. So, same p.d. (V) exists betn the ends of each conductor. The current passing through each is different depending upon their resistances. Let the main current I is divided into I_1, I_2 & I_3 through the resistors R_1, R_2 & R_3 respectively. If R is the combined resistance betn A & B, then

$I = \frac{V}{R} \quad \ldots (1)$

Again $I = I_1 + I_2 + I_3$

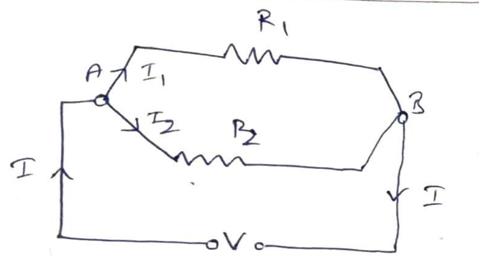
$\Rightarrow I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \ldots (2)$

On putting the value of I from eqⁿ (1) in eqⁿ (2), we get

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

$$\Rightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Division of current in parallel circuits:-



(Two resistors in parallel across a voltage V)

Let's consider two resistors joined in parallel across a voltage V. So, current in branches $I_1 = \frac{V}{R_1}$ & $I_2 = \frac{V}{R_2}$.

$$\frac{I_1}{I_2} = \frac{V}{R_1} \div \frac{V}{R_2}$$

$$= \frac{V}{R_1} \times \frac{R_2}{V}$$

$$= \frac{R_2}{R_1}.$$

So, the division of current in the branches of a parallel ckt is inversely proportional to their resistance.

Again, $I_1 + I_2 = I$

$$\Rightarrow I_2 = I - I_1$$

$$\therefore \frac{I_1}{I - I_1} = \frac{R_2}{R_1}$$

$$\Rightarrow I_1 R_1 = R_2 (I - I_1)$$

$$\Rightarrow I_1 R_1 = R_2 I - R_2 I_1$$

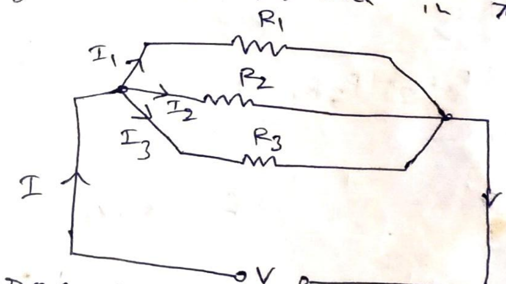
$$\Rightarrow I_1 R_1 + R_2 I_1 = R_2 I$$

$$\Rightarrow I_1 (R_1 + R_2) = R_2 I$$

$$\Rightarrow I_1 = I \times \frac{R_2}{(R_1 + R_2)}$$

And $I_2 = \frac{I R_1}{(R_1 + R_2)}$

Let's consider three resistors R_1, R_2 & R_3 joined in parallel across a voltage 'V' as shown in the fig below.



(Three resistors in parallel across a voltage V).

Then, $I = I_1 + I_2 + I_3$

Let R = equivalent resistance of $R_1 \parallel R_2 \parallel R_3$.

$$\therefore V = IR = I_1 R_1 = I_2 R_2 = I_3 R_3$$

So, $\frac{I}{I_1} = \frac{R_1}{R}$

$$\Rightarrow I_1 = \frac{IR}{R_1}$$

Similarly, $I_2 = \frac{IR}{R_2}$ & $I_3 = \frac{IR}{R_3}$

But $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$= \frac{R_2R_3 + R_3R_1 + R_1R_2}{R_1R_2R_3}$

$\Rightarrow R = \frac{R_1R_2R_3}{R_2R_3 + R_3R_1 + R_1R_2}$

So,

$I_1 = I\left(\frac{R_2R_3}{R_1R_2 + R_2R_3 + R_3R_1}\right)$

$I_2 = I\left(\frac{R_3R_1}{R_1R_2 + R_2R_3 + R_3R_1}\right)$

$I_3 = I\left(\frac{R_1R_2}{R_1R_2 + R_2R_3 + R_3R_1}\right)$

Electric power:-

Electric power is the rate of doing work.

Mathematically, $P = VI$

where, P = power

V = voltage

I = current

(a) power in series ckt:-

(i) The reciprocal of total power supplied by the source in any series resistive ckt is equal to the sum of the reciprocal of power in each resistor in series i.e.,

$\frac{1}{P_S} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + \dots + \frac{1}{P_n}$

where, P_n = power in the last resistor in series

n = no. of resistors in series

$P_1, P_2, P_3 \dots$ = powers in the resistors of the series ckt

P_S = total power supplied by source.

(ii) The total power in the series ckt is the total voltage applied to a ckt multiplied by the total current.

Mathematically,

$P_S = V_S I = I^2 R_T = \frac{V_S^2}{R_T}$

where, V_S = total voltage applied

R_T = total resistance

I = total current

(b) Power in parallel ckt:-

The total power supplied by the source in any parallel resistive ckt is equal to the sum of the powers in each resistor in parallel, i.e.,

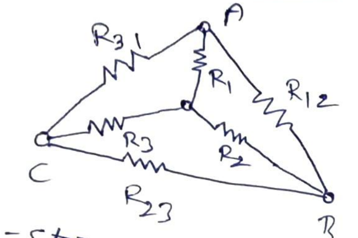
$P_S = P_1 + P_2 + P_3 + \dots + P_n$

n = no. of resistors in parallel

P_S = total power supplied by source.

$P_1, P_2, P_3 \dots P_n$ = powers in the resistors of the parallel ckt.

Delta-star transformation:-



(Delta-star or star-delta transformation)

Let's consider a delta ckt ABC made up of three resistors R_{12}, R_{23} & R_{31} as shown above. Let its equivalent star ckt is R_1, R_2 & R_3.

The resistance betn terminals A and B in delta connection

$$= \frac{R_{12} \times (R_{23}+R_{31})}{R_{12}+(R_{23}+R_{31})} \quad \ldots (1)$$

The resistance betn the same terminals A and B in the star connection

$$= R_1 + R_2 \quad \ldots (2)$$

Because the terminals are same, so

$$R_1 + R_2 = \frac{R_{12} \times (R_{23}+R_{31})}{R_{12}+(R_{23}+R_{31})} \quad \ldots (3)$$

In the same way, by solving the terminals B and C, C and A, we get

$$R_2 + R_3 = \frac{R_{23} \times (R_{31}+R_{12})}{R_{23}+(R_{31}+R_{12})} \quad \ldots (4)$$

$$\& \; R_3 + R_1 = \frac{R_{31} \times (R_{12}+R_{23})}{R_{31}+(R_{12}+R_{23})} \quad \ldots (5)$$

Now, by subtracting eqn (4) from eqn (3) and adding the result to eqn (5), we get

$$R_1 + R_2 - (R_2+R_3) + R_3 + R_1 = \frac{R_{12} \times (R_{23}+R_{31})}{R_{12}+(R_{23}+R_{31})} - \frac{R_{23} \times (R_{31}+R_{12})}{R_{23}+(R_{31}+R_{12})} + \frac{R_{31} \times (R_{12}+R_{23})}{R_{31}+(R_{12}+R_{23})}$$

$$\Rightarrow R_1 + R_2 - R_2 - R_3 + R_3 + R_1 = \frac{R_{12}R_{23} + R_{12}R_{31} - R_{23}R_{31} - R_{23}R_{12} + R_{31}R_{12} + R_{31}R_{23}}{R_{12}+R_{23}+R_{31}}$$

$$\Rightarrow 2R_1 = \frac{2R_{12}R_{31}}{R_{12}+R_{23}+R_{31}}$$

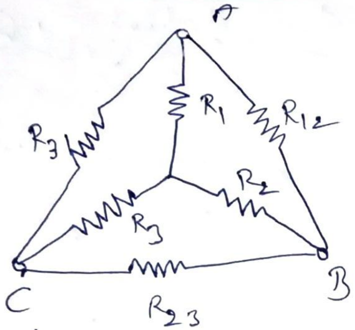
$$\Rightarrow R_1 = \frac{R_{12}R_{31}}{R_{12}+R_{23}+R_{31}}$$

In the same way, we get

$$R_2 = \frac{R_{12}R_{23}}{R_{12}+R_{23}+R_{31}}$$

$$R_3 = \frac{R_{31}R_{23}}{R_{12}+R_{23}+R_{31}}$$

Star - delta transformation: -



(Delta - star or star-delta transformation)

It is a method of obtaining equivalent delta of a star. The total resistance betn B and C must be same for both star and delta connections. So,

$$R_2 + R_3 = R_{23} \,||\, (R_{31} + R_{12})$$

$$= \frac{R_{23} \cdot R_{31} + R_{23} \cdot R_{12}}{R_{23} + R_{31} + R_{12}} \quad \ldots (1)$$

Similarly, we get

$$R_3 + R_1 = R_{31} \,||\, (R_{12} + R_{23}) = \frac{R_{31} \cdot R_{12} + R_{31} \cdot R_{23}}{R_{31} + R_{12} + R_{23}} \quad \ldots (2)$$

& $R_1 + R_2 = R_{12} \,||\, (R_{31} + R_{23})$

$$= \frac{R_{12} \cdot R_{31} + R_{12} \cdot R_{23}}{R_{12} + R_{31} + R_{23}} \quad \ldots (3)$$

By adding eqns (1), (2), (3), we get

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

$$\Rightarrow R_1 + R_2 + R_3 = \frac{R_{23}R_{31} + R_{31}R_{12} + R_{12} \cdot R_{23}}{R_{12} + R_{23} + R_{31}} \quad \ldots (4)$$

By subtracting eqn (1) from eqn (4), we get

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

$$\Rightarrow R_1 = \frac{R_{23}R_{31} + R_{31}R_{12} + R_{12}R_{23} - R_{23}R_{31} - R_{23}R_{12}}{R_{12} + R_{23} + R_{31}}$$

$$= \frac{R_{31}R_{12}}{R_{12} + R_{23} + R_{31}} \quad \ldots (5)$$

By subtracting eqns (2) & (3) from eqn (4), turn by turn, we get

$$R_2 = \frac{R_{12} \cdot R_{23}}{R_{12} + R_{23} + R_{31}} \quad \ldots (6)$$

$$R_3 = \frac{R_{23} \cdot R_{31}}{R_{12} + R_{23} + R_{31}} \quad \ldots (7)$$

By dividing eqn (5) by eqn (6), we get

$$\frac{R_1}{R_2} = \frac{R_{31}}{R_{23}}$$

$$\Rightarrow R_{31} = \frac{R_1 \times R_{23}}{R_2} \quad \ldots (8)$$

similarly, we get

$$\frac{R_3}{R_1} = \frac{R_{23}}{R_{12}} \quad \text{or} \quad R_{12} = \frac{R_1 \cdot R_{23}}{R_3} \quad \ldots (9)$$

By substituting the values of R_{31} & R_{12} from eqn (8) and eqn (9) respectively in eqn (1), we get

$$R_2 + R_3 = \frac{R_{23}\left(R_1 \cdot \frac{R_{23}}{R_2}\right) + R_{23}\left(R_1 \cdot \frac{R_{23}}{R_3}\right)}{R_{23} + \left(R_1 \cdot \frac{R_{23}}{R_2}\right) + \left(R_1 \cdot \frac{R_{23}}{R_3}\right)}$$

$$\Rightarrow R_2 + R_3 = \frac{\left(R_1 \cdot \frac{R_{23}}{R_2}\right) + \left(R_1 \cdot \frac{R_{23}}{R_3}\right)}{1 + (R_1/R_2) + (R_1/R_3)}$$

$$= \left(\frac{R_1 \cdot R_{23}}{R_2} + \frac{R_1 \cdot R_{23}}{R_3}\right) \div \left(\frac{R_2R_3 + R_1R_3 + R_1R_2}{R_2R_3}\right)$$

$$= \frac{(R_1 \cdot R_{23} \cdot R_3 + R_1 \cdot R_2 \cdot R_{23})}{R_2R_3} \times \frac{R_2R_3}{(R_2R_3 + R_1R_3 + R_1R_2)}$$

$$= \frac{R_1 \cdot R_3R_{23} + R_1R_2R_{23}}{R_2R_3 + R_1R_3 + R_1R_2}$$

$$= \frac{R_1 \cdot R_{23}(R_3 + R_2)}{R_2R_3 + R_1R_3 + R_1R_2}$$

$$\Rightarrow R_1 \cdot R_{23} = R_2R_3 + R_1R_3 + R_1R_2$$

$$\Rightarrow R_{23} = R_2 + R_3 + \frac{R_2R_3}{R_1}$$

similarly, we get

$$R_{31} = R_3 + R_1 + \frac{R_3R_1}{R_2}$$

$$R_{12} = R_1 + R_2 + \frac{R_1R_2}{R_3}$$

Superposition Theorem:—

This Theorem is defined as follows.

In a network of linear resistors containing more than one source, the resultant current or emf flowing in an element is found by considering one source at a time, ~~And~~ and all other sources replaced temporarily by their internal resistances, followed by adding the currents or emfs due to the individual sources.

Thevenin's Theorem:—

The Thevenin's theorem is defined as the current flowing through a resistance R_L connected across any two terminals of a network containing one or more sources of current or voltage given by

$$I = \frac{V_{Th}}{R_L + R_{Th}}$$

where V_{Th} = open circuit voltage with R_L disconnected.

R_{Th} = equivalent resistance of the network with R_L removed and the sources replaced by their respective internal resistances.

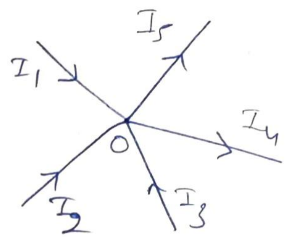
Maximum Power Transfer Theorem :—

It states that maximum power output from a network is obtained when the load resistance is equal to Thevenin's equivalent resistance of the network as seen from the load terminals.

Kirchoff's first law or Kirchoff's current law (KCL) :—

This law states that in any network of conductors in any electrical circuit, the algebraic sum of the current in all the conductors meeting at any point is zero.

Illustration :—



Let there be a no. of conducting elements meeting a junction 'O' as shown above. Let the incoming currents I_1, I_2 & I_3 are taken as positive. T...

outgoing currents I_4 & I_5 will be negative. According to KCL,

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

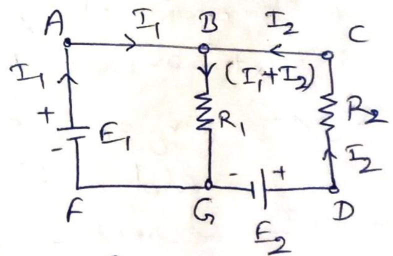
$\Rightarrow I_1 + I_2 + I_3 = I_4 + I_5$

Kirchoff's second law or Kirchoff's mesh or voltage law (KVL) :—

This law states that the algebraic sum of the products of current and resistance of each conductor in any closed path in a network plus the algebraic sum of the voltages in that path is zero. mathematically,

$\Sigma IR + \Sigma V = 0$

Illustration :—



Let's consider the network as shown above. Let's consider the loop FABGF. By applying KVL to it, we get

$E_1 + (-)(I_1 + I_2) R_1 = 0$

$\Rightarrow E_1 = (I_1 + I_2) R_1$

By applying KVL to loop BCDGB, we get

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

$\Rightarrow E_2 = I_2 R_2 + (I_1 + I_2) R_1$

Faraday's first law of electromagnetic induction: — It states that whenever the number of magnetic lines of force passing through a circuit changes, an induced emf is set up in the circuit.

Faraday's second law of electromagnetic induction: — It states that the magnitude of the induced emf is proportional to the rate of change of magnetic lines of force. Mathematically,

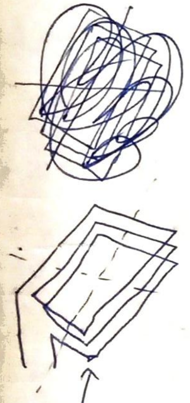
$$e = -N \frac{d\phi}{dt} \text{ volt.}$$

Fleming's left-hand rule: — Hold the thumb, the first finger and the middle finger of the left hand at right angles to each other. If the first finger points to the direction of field the middle finger to the direction of the current, then thumb points to the direction of motion of force.

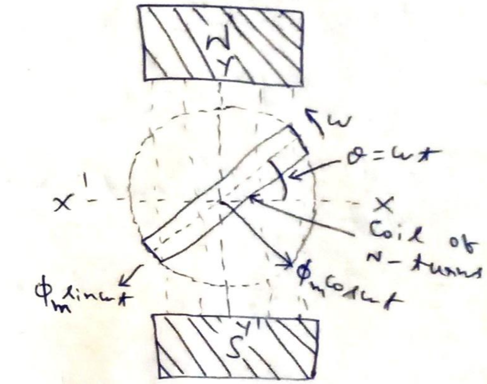
Fleming's right hand rule: — Hold the thumb, the first and the middle fingers of the right hand at right angles to each other. If the thumb points to the direction of motion, the first finger to the direction of the field, then the middle finger points to the direction of the induced emf.

A.C THEORY: —

Generation of alternating emf: —



(Rectangular coil of N-turns and area of cross section Am^2)



(Generation of alternating emf)

Let's consider a rectangular coil of N turns and area A m^2 rotating in a uniform magnetic field with an angular velocity ω radians/sec about X-axis in its own plane. Suppose ϕ_m is the max^m flux density perpendicular to the axis of rotation when the plane of the coil coincides with the X-axis. Let in 't' seconds the coil rotates through an angle θ = ωt. In this position the flux component ... perpendicular to the plane of the coil,

$\phi = \phi_m \cos\omega t$

so, the flux linkages of the coil in this position is

$N\phi = N\phi_m \cos\omega t$

The instantaneous induced emf 'e' at time when $\theta = \omega t$ is

$e = -\frac{d}{dt}(N\phi)$ volt

$= -\frac{d}{dt}(N\phi_m \cos\omega t)$ volt

$= -N\phi_m\left(\frac{d}{dt}\cos\omega t\right)$ volt

$= -N\phi_m \times \left\{-\sin\omega t \times \frac{d}{dt}(\omega t)\right\}$ volt

$= \omega N\phi_m \sin\omega t$ volt ... (1)

The induced emf 'e' has a max^m value of E_m when $\sin\theta = \sin 90° = 1$.

So, $E_m = \omega N\phi_m$ volt $= \omega N B_m A$ volt

$= 2\pi f N B_m A$ volt ... (2)

where, f = the no. of revolutions/sec in hertz

B_m = max^m flux density in Wb/m^2

From eq^ns (1) & (2), we get

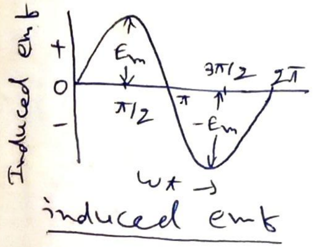
$e = E_m \sin\theta = E_m \sin\omega t$ volt ... (3)

The current 'i' at any time in the coil is proportional to the induced emf 'e' in the coil.

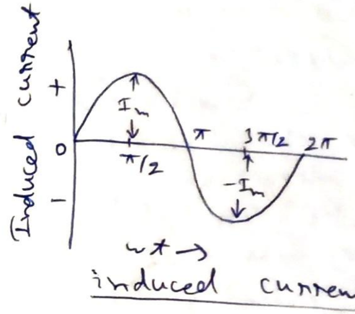
So, the induced alternating current 'i' is

$i = I_m \sin\omega t$ ampere ... (4)

where I_m = max^m value of the current



induced emf



induced current

Difference bet^n D.C. & A.C. :-

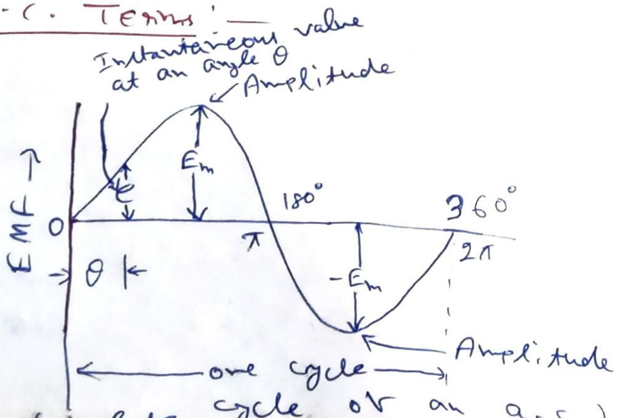
Alternating current	Direct current
(1) Both voltage and current reverses periodically.	(1) Both voltage and current remain constant.
(2) Low cost of production.	(2) Higher cost of production.
(3) An a.c. generator is almost free from dissipation of energy.	(3) A D.C. generator undergoes dissipation of energy.
(4) The cost of transmitting a.c. power can be reduced by using step-up transformers.	(4) No such provision can be made.
(5) By using transformer a.c. voltages can be lowered or raised as desired.	(5) No such provision can be made.
(6) A.C. ckt current can be decreased by using choke or capacitor without any appreciable power loss.	(6) For decreasing D.C. ckt current a resistance has to be used alone. Power dissipation factor (I^2R) is large.
(7) A.C. can be converted into D.C. by using a device called convertor.	(7) D.C. can be converted to a.c. by using inverter.

(8) A.C. can't be used directly for electroplating, electrotyping, etc.	(8) D.C. can be used directly for carrying out such operations.
(9) A.C. motors and other appliances are more robust and durable.	(9) D.C. motors and appliances are less durable.
(10) A.C. attracts a person. So, faulty insulations of a.c. are more dangerous. Because peak of a.c. is $\sqrt{2}$ times its effective value.	(10) D.C. gives a repelling shock to a person. So, faulty insulations of D.C. are less dangerous.

Direct Current:— A current which maintains a constant direction, i.e., current which flows in one direction only. Although, it may have appreciable pulsations in its magnitude.

Alternating current:— An alternating current is one that reverses periodically in direction and whose magnitude undergoes a definite cycle of changes in definite intervals of time.

A.C. Terms:—



Cycle:— The cycle is one complete set of positive, zero and negative values of an alternating quantity spread over 360° or 2π radians.

Amplitude or peak value:— It is the maximum value, positive or negative, of an alternating quantity.

Instantaneous value:— The instantaneous value of an alternating quantity is its value at any instant.

Time period(T):— It is the duration of time required for an a.c. quantity to complete one cycle.

Frequency(f):— It is the number of cycles that occurs in one second. The unit of frequency is the Hertz (Hz) or cycles/sec. Mathematically

$$f = \frac{1}{T}$$

$$\text{or, } T = \frac{1}{f}$$

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

Phase angle(φ):— The phase angle φ is equivalent of phase in radians or degrees.

Phase difference:— It is the angular quantities.

Average or mean value: – It is the arithmetic sum of all the values divided by the total numbers of value used to obtain the sum. The average value of any cycle of wave form is area under the wave form divided by time period.

The average value of current (I_{av}) of an a.c. sinusoidal wave is

$$I_{av} = \frac{2I_m}{\pi} = 0.637 I_m$$

where, I_m = Maximum value of current

Root mean square (rms) or effective value:

It is the square root of average values of square of alternating quantity over a time period. The rms value of a.c. current is equivalent direct current which when allowed to flow through a given circuit for a given time produces the same amount of heat as produced by the alternating current when allowed to flow through the same circuit for the same time.

The rms value of a.c. sinus... current (I_{rms})

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

where I_m = Maximum value of current

Form factor (K_f): – It is the ratio of rms value to the average value of an alternating quantity.

For sinusoidal wave, form factor

$$K_f = \frac{0.707 I_m}{0.637 I_m} = 1.11$$

Crest or Peak or Amplitude factor (K_a): –

It is the ratio of the maximum value to the rms value of an alternating quantity. For a sine wave

$$K_a = \frac{I_m}{I_{rms}} = \frac{I_m}{0.707 I_m} = 1.414$$

Q) The equation of an alternating current is: $i = 62.35 \sin 323t$ A. Determine its: (i) Maximum value; (ii) Frequency; (iii) rms value; (iv) average value, & (v) form factor.

Sol^n: – (i) $I_m = 62.35A$

(ii) $\omega = 323$

$\Rightarrow 2\pi f = 323$

$\Rightarrow f = \frac{323}{2\pi} = \frac{323}{(2\times 3.14)} = 51.4 HZ$

(iii) ~~rms value~~ RMS value,

$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{62.35}{\sqrt{2}} = 44.1A$

(iv) Average value, $I_{av} = \frac{2I_m}{\pi} = \frac{2\times 62.35}{3.14} = 39.7$

(v) Form factor,

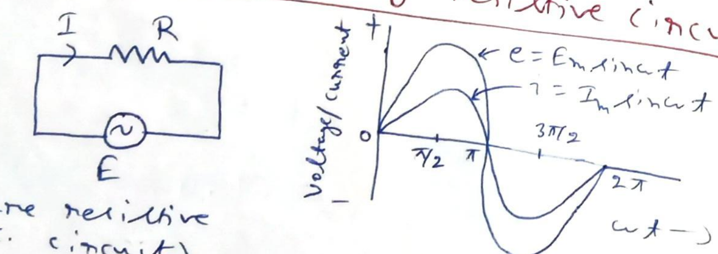
$$k_f = \frac{I_{rms}}{I_{av}} = \frac{44.1}{39.7} = 1.11$$

Phasor or vector Representation of An Alternating Quantity:—

The alternating quantities are vector quantities, i.e., having magnitude as well as direction. However, their instantaneous values are continuously changing. So, they are represented by a rotating vector or phasor. A phasor is a vector rotating at a constant angular velocity.

The phasor diagram is one in which different alternating quantities of the same frequency are represented by phasors with their correct phase relationship. A phasor diagram represents a still position of the phasors in one particular position.

A.C. through Purely resistive circuit:—



(Pure resistive A.C. circuit)

In a the ckt containing pure ohmic resistor only, the potential difference across the resistor is

$e = iR$ ... (1)

where, e = applied voltage to overcome the ohmic voltage drop only

R = ohmic resistance

i = instantaneous current

For a.c. ckt,

$e = E_m \sin\omega t$ ... (2)

From eqns (1) & (2), we get

$iR = E_m \sin\omega t$

$\Rightarrow i = \left(\frac{E_m}{R}\right)\sin\omega t$ ... (3)

For $\sin\omega t = 1$, the value of current 'i' is max, i.e.,

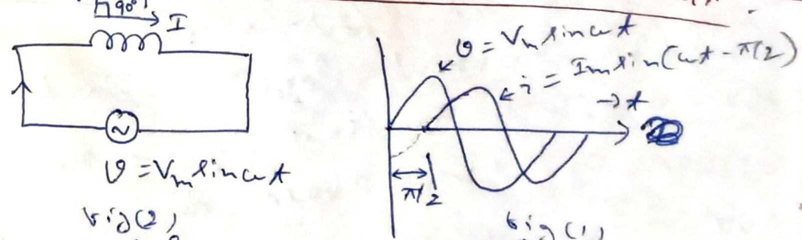
$I_m = \frac{E_m}{R}$ ... (4)

From eqns (3) & (4), we get

$i = I_m \sin\omega t$ ... (5)

From eqns (2) & (5), we see that alternating voltage (e) and alternating current (i) are in phase with each other.

A.C. through Purely inductive circuit:—



When an alternating voltage is applied to a pure inductive coil a back e.m.f. is produced due to the self inductance of the coil. The back e.m.f. at every step opposes the rise or fall of current through the coil. Here, the applied voltage has to overcome the self-induced emf only.

So, at every step,

$$v = L\frac{di}{dt}$$

Now, $v = V_m \sin \omega t$

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

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

By integrating both sides, we get

$i = \frac{V_m}{L}\int \sin \omega t \, dt = \frac{V_m}{\omega L}(-\cos \omega t)$ (const. of integration = 0)

$= -\frac{V_m}{\omega L}\cos \omega t$

$\therefore i = \frac{V_m}{\omega L}\sin(\omega t - \pi/2)$

The max^m value of 'i' is $I_m = \frac{V_m}{\omega L}$ when $\sin(\omega t - \pi/2)$ is unity. So, eq^n of the current becomes

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

So, the current lags behind the applied voltage by a quarter cycle or the phase difference bet^n the two is $\pi/2$ with voltage leading. It is as shown in fig (1). The vectors are shown in fig (2).

A.C. Through Capacitance Alone :—

If an alternating voltage is applied to the plates of a capacitor, it is charged first in one direction and then in the opposite direction.

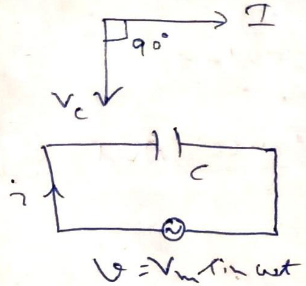


fig (1)

In the ckt diagram given above, let
v = p.d. bet^n plates at any instant
q = charge on plates at that instant

Then, $q = Cv$

$= CV_m \sin \omega t$

The current 'i' is given by the rate of flow of charge.

$\therefore i = \frac{dq}{dt} = \frac{d}{dt}(CV_m \sin \omega t)$

$= \omega C V_m \cos \omega t$

$\Rightarrow i = \frac{V_m}{1/\omega C}\cos \omega t = \frac{V_m}{1/\omega C}\sin(\omega t + \pi/2)$

So, $I_m = \frac{V_m}{1/\omega C} = \omega C V_m$ . . . (1)

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

Here, $X_C = \frac{1}{\omega C}$ & it is said to be capacitive reactance. The current in a pure capacitor leads its voltage by a quarter cycle as shown below in fig (2).

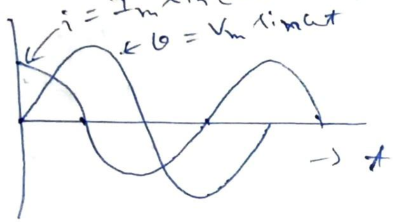


fig (2)

The vector representation is shown in fig (1).

A.C. Through Resistance And Inductance In series: —

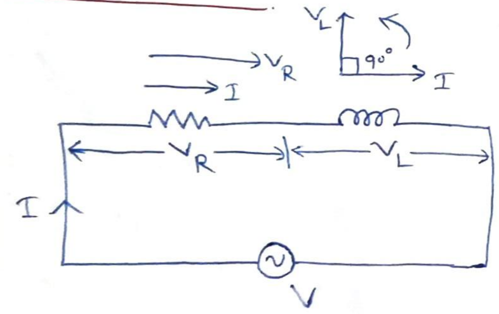


fig (1)

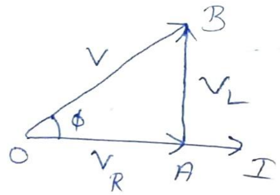


fig (2)

Here, a pure resistance of R ohms and a pure inductive coil of inductance L henry are connected in series as shown in fig (1).

Let V = r.m.s. value of applied voltage

I = r.m.s. value of resultant current

$V_R = IR$ = voltage drop across R.

$V_L = IX_L$ = Voltage drop over coil

The voltage drops are shown in the voltage triangle OAB as shown in fig (2).

The vector OA represents ohmic drop V_R. The vector AB represents inductive drop V_L. The applied voltage V is the vector sum of OA and AB. So, the applied voltage is OB.

$$\therefore V = \sqrt{V_R^2 + V_L^2} = \sqrt{(IR)^2 + (IX_L)^2}$$
$$= I\sqrt{R^2 + X_L^2}$$
$$\Rightarrow I = \frac{V}{\sqrt{R^2 + X_L^2}}$$

Here, the quantity $\sqrt{R^2 + X_L^2}$ is said to be the impedance Z of the ckt. The impedance triangle PQM is as shown in fig (3).

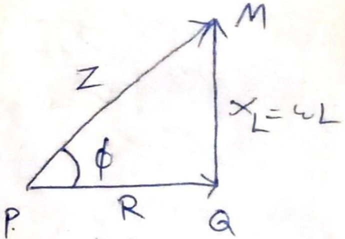


fig (3)

Here, $Z^2 = R^2 + X_L^2$

& $\tan\phi = \frac{X_L}{R}$

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

The instantaneous values of voltage and current are as shown below in fig (4).

If the applied voltage is $v = V_m \sin\omega t$, then the current eqn is

$i = I_m \sin(\omega t - \phi)$

where $I_m = V_m / Z$.

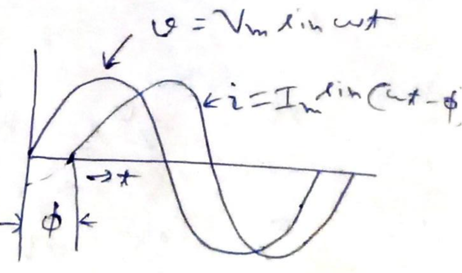
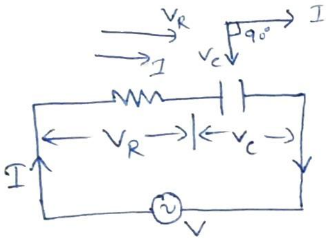
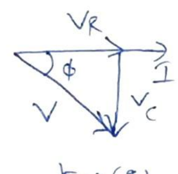


fig (4)

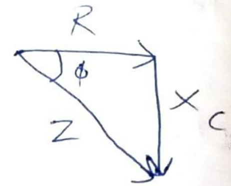
In series: —



fig(1)



fig(2)



fig(3)

The ckt diagram is shown in fig(1).

Here, $V_R = IR$ = drop across R

$V_C = I X_C$ = drop across Capacitor

Since Capacitive reactance X_C is taken negative, V_C is along negative direction of Y-axis. It is as shown in fig (2).

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

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

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

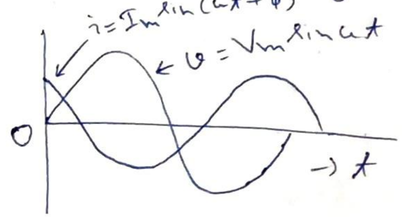
The impedance triangle is shown in fig (3).

$\tan\phi = \dfrac{X_C}{R}$

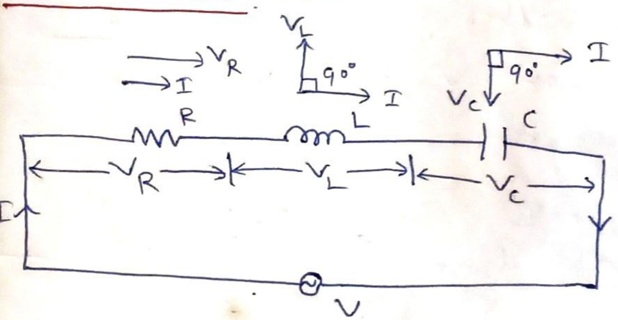
If the eqn of the applied alternating voltage is $v = V_m \sin\omega t$, the eqn of the current in the ckt is

$i = I_m \sin(\omega t + \phi)$

Here, the current leads the applied voltage by an angle ϕ. The instantaneous values of voltage and current are shown below in fig (4).



Resistance, Inductance and Capacitance in series: —



fig(1)

In the above ckt diagram, a.c. supply of r.m.s. voltage 'V' is applied across resistor, inductor & capacitor connected in series.

Let $V_R = IR$ = voltage drop across R.

$V_L = I X_L$ = voltage drop across L

$V_C = I X_C$ = voltage drop across C.

The voltage triangle is shown in fig.(2) & the impedance triangle is shown in fig(3) below.

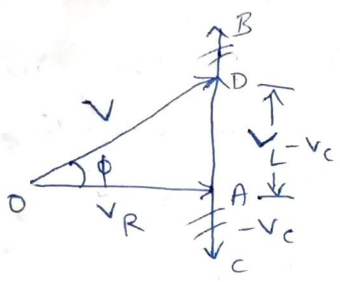


fig (2)

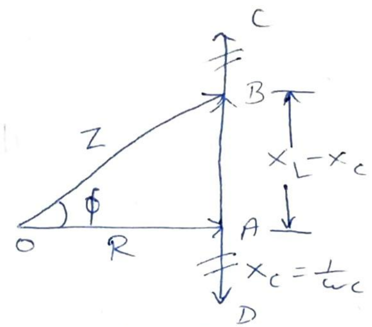


fig (3)

In voltage triangle, OA represents V_R, AB is inductive drop and AC is capacitive drop. Here, V_L & V_c are 180° out of phase with each other. V_L is taken greater than V_c in magnitude in this case. By subtracting BD from AB, we get the net reactive drop

$AD = V_L - V_c = I(X_L - X_c)$

The applied voltage V is OD and is the vector sum of OA and AD.

$$OD = \sqrt{OA^2 + AD^2}$$

$$\Rightarrow V = \sqrt{(IR)^2 + (IX_L - IX_c)^2}$$

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

$$\Rightarrow I = \frac{V}{\sqrt{R^2 + (X_L - X_c)^2}} = \frac{V}{Z}$$

In the impedance triangle

$$Z^2 = R^2 + (X_L - X_c)^2 = R^2 + X^2$$

where, X = net reactance

The phase angle ϕ is

$$\tan\phi = \frac{X_L - X_c}{R} = \frac{X}{R}$$

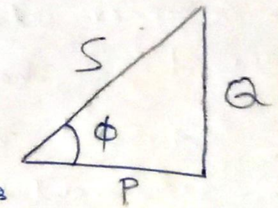
If the eqn of the applied voltage is $v = V_m \sin \omega t$, the eqn of the resulting current is

$i = I_m \sin(\omega t \pm \phi)$

The '+ve' sign is taken when current leads, i.e., when $X_c > X_L$. The '-ve' sign is taken when current lags, i.e., when $X_L > X_c$.

Power Factor: — It is defined as cosine of the angle of lead or lag betn the r.m.s. value of supply voltage and the r.m.s. value of resultant current. It is also defined as the ratio $\frac{R}{Z} = \frac{\text{Resistance}}{\text{Impedance}}$ or the ratio $\frac{W}{VA} = \frac{\text{watts}}{\text{volt . amperes}} = \frac{\text{true power}}{\text{apparent power}}$

Power Triangle: —



Suppose a series R-L ckt draw a current of I when an alternating voltage of r.m.s. value V is applied to it. So, current lags behind the applied voltage by ϕ. Then, the three powers drawn by the ckt is as follows.

① **Apparent Power(S)** :– It is the Product of r.m.s. value of applied voltage and ckt current.

$\therefore S = VI = (IZ)I = I^2 Z$ volt.amperes

② **Active power (P or W)** :– It is the power which is actually dissipated in the ckt resistance.

$P = I^2 R = VI\cos\phi$ watts.

③ **Reactive power (Q)** :– It is the power developed in the inductive reactance of the ckt.

$Q = I^2 X_L = VI\sin\phi$ volt.amperes reactive

The three powers are shown in the power triangle in the fig. above.

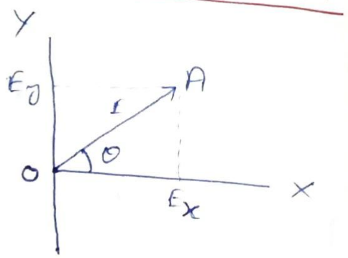
In the power triangle,

$S^2 = P^2 + Q^2$

$\Rightarrow S = \sqrt{P^2 + Q^2}$

Complex Notation Applied To A.C circuits :–

In complex algebra method, a phasor is resolved into two components at right angle to each other.



(Complex notation of a Phasor)

Let's consider the phasor E, represented in magnitude, and direction by OA. Then,

$E^2 = E_x^2 + E_y^2$.

The Phasor E can be represented in Cartesian form as

$E = E_x + jE_y = E(\cos\theta + j\sin\theta)$

The symbol $j(=\sqrt{-1})$ represents an operator indicating the anticlockwise rotation of phasor through $90°$. In polar method of representation, the phasor E can be written symbolically as

$\vec{E} = |\vec{E}|\angle\theta°$

where $\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right)$

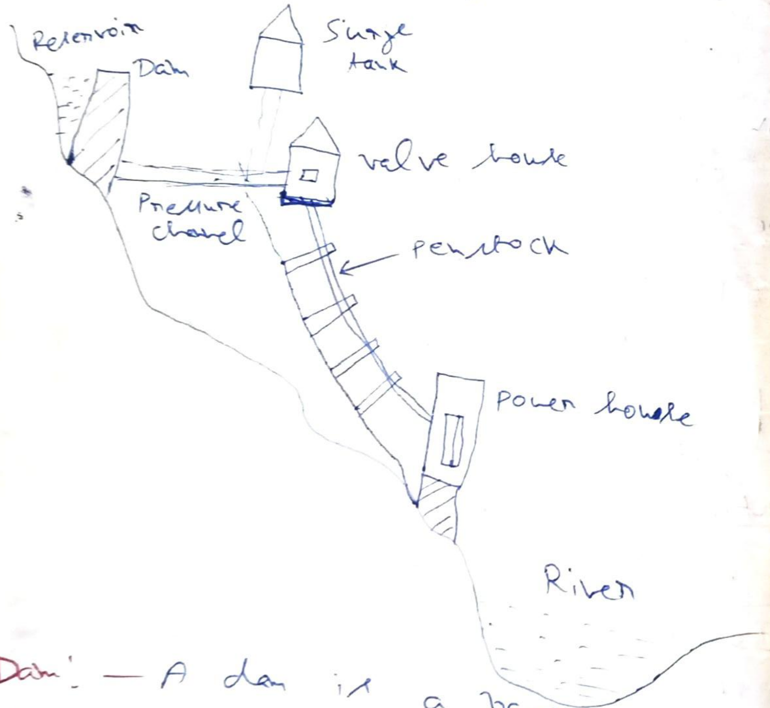
& $|\vec{E}| = \sqrt{E_x^2 + E_y^2}$

Generation of Electrical power

Hydro electric power station :–

In the hydroelectric power station, the potential energy of water head is used to generate electrical energy. The water head is created by constructing a dam across a river. The water from the dam is taken to the water turbine through valve house with the help of steel pipe known as penstock. The surge tank protects the penstock from the bursting, in case of turbine gates suddenly gets closed.

The turbine converts hydraulic energy into mechanical energy. The alternator connected to the turbine converts the mechanical energy into electrical energy.



Dam: — A dam is a barrier which stores water and creates water head. Dams are built of concrete or stone or rock fill.

Surge tank: — When the closed conduits are used then there is always provided with a surge tank. A surge tank is a small reservoir or tank in which water level rises or falls to reduce the pressure swings in the conduit.

Valve house: — The valve house contains main sluice valves and automatic isolating valves. The former controls the water flow to the power house and the auto isolating valves cuts off the supply of water when the penstock bursts.

Advantages: — ① It requires no fuel as water is used for the generation of electrical energy.

② It is quite neat and clean as no smoke or ash is produced.

③ It requires less maintainance.

④ It is robust and longer life.

⑤ In addition to the generation of electric energy, they also help in irrigation and controlling floods.

Disadvantages: — ① It involves high capital cost due to the construction of dam.

② There is uncertainty about the availability of huge amount of water.

Nuclear power station

A generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station.

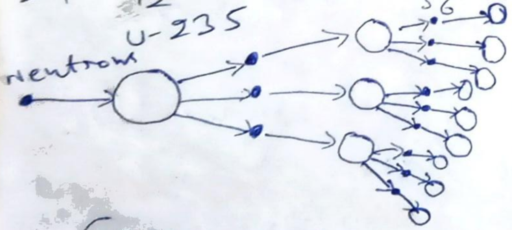
In nuclear power station, heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}), Plutonium (Pu^{239}) are subjected to nuclear fission in a special apparatus known as a reactor.

Nuclear fission: —

The splitting of heavy nucleus into two or more smaller nuclei with release of huge amount of energy is known as nuclear fission.

In the nuclear fission process, the heavy nucleus is split when it is bombarded by the slow neutrons.

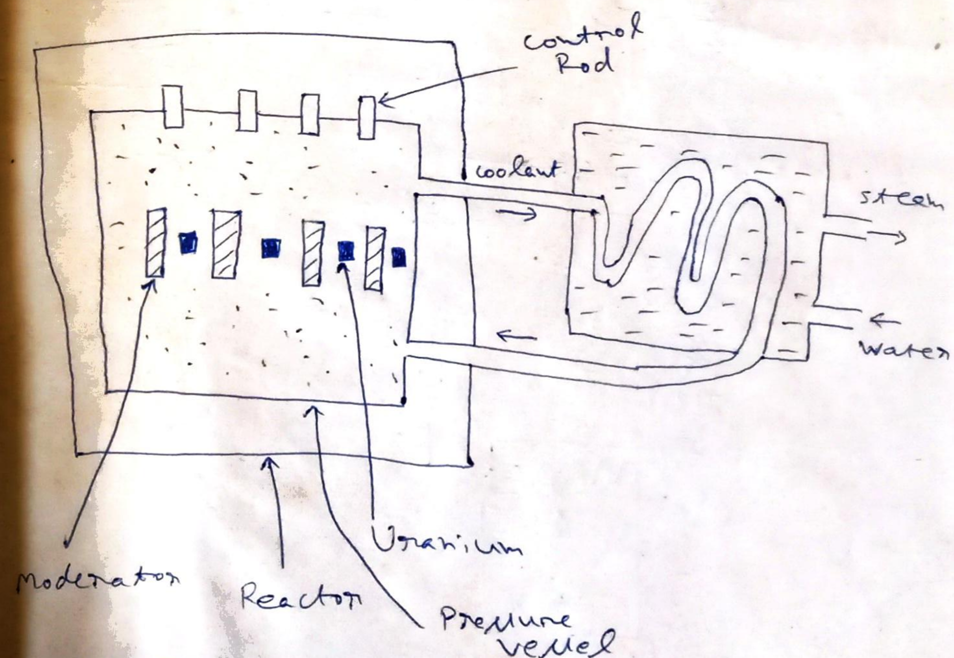
$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{139}_{56}Ba + {}^{94}_{36}Kr + 3\,{}^{1}_{0}n + energy$$



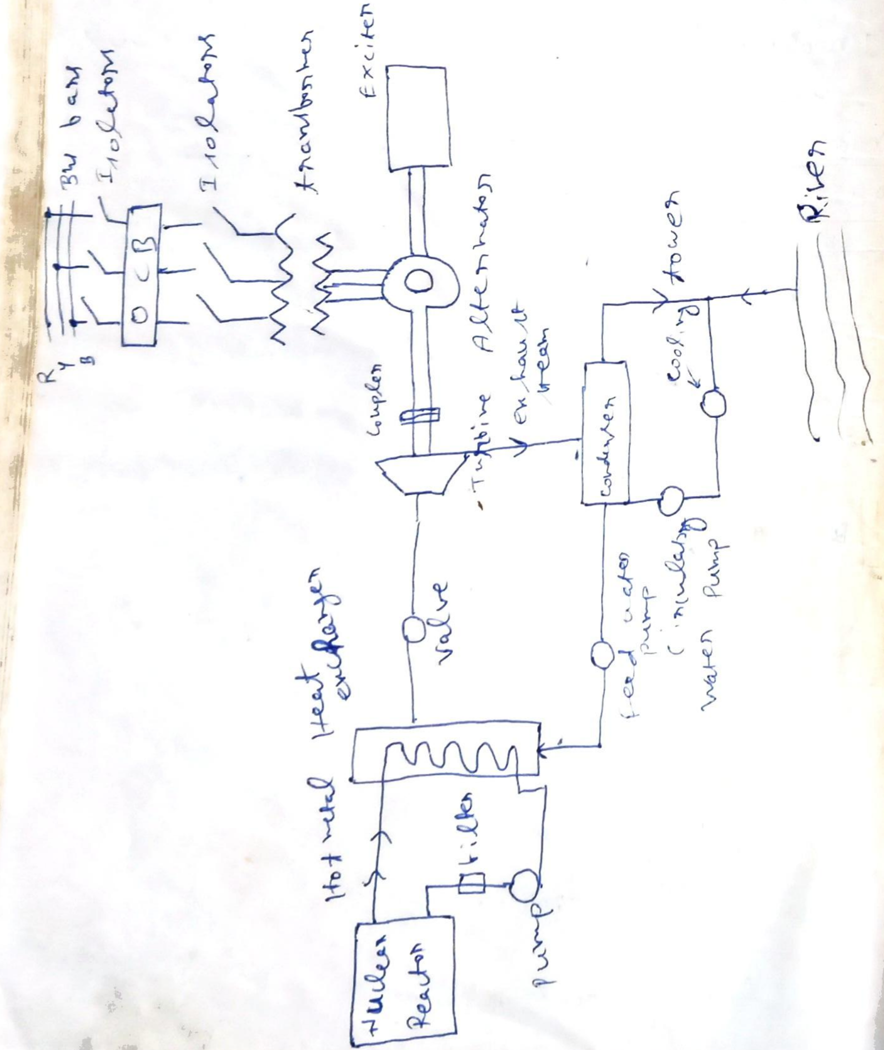
(Chain reaction)

The heat energy thus released is utilised in raising steam at high temp. & Pressure. The steam runs the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy. The most important feature of a nuclear power station is that huge amount of electrical energy can be produced from a small amount of nuclear fuel.

Schematic Arrangement of Nuclear Power station: —



(Nuclear Reactor)



A nuclear power plant consists of a nuclear reactor (for heat generation), heat exchanger (for converting water into steam by using the heat ~~generated~~ generated in nuclear reactor), ~~steam~~ steam turbine, alternator, condenser, etc.

The huge amount of heat energy produced in breaking of atoms of uranium or other similar metals of large atomic weight into lower atomic weight by fission process. The heated metal or gas is then allowed to exchange its heat to the heat exchanger by circulation. In the heat exchanger, the water is heated and steam is generated which is utilised to drive the turbine coupled to an alternator thereby generating electrical energy.

Main parts of Nuclear power plant:-

Nuclear Reactor:-

It is an apparatus in which the nuclear fuel (U^{235}) is subjected to nuclear fission. It controls the chain reaction. If the chain reaction is not controlled the result will be an explosion.

due to the vast increase in the energy released.

A nuclear reactor is a cylindrical pressure vessel and houses of fuel rods of uranium, moderator and control rods.

→ The fuel rods constitute the fission ~~material~~ and release huge amount of energy when bombarded with slow moving neutrons.

→ The moderator slows down the neutrons before they bombard the fuel rods. For moderator, Carbon, Heavy water, ordinary water is used.

→ Control rods are meant for controlling the rate of fission of U^{235}. These are made of boron-10, Cadmium or hafnium and are inserted into the reactor. It is used to absorb the neutrons & regulate the supply of neutrons to fission.

→ The heat produced in the reactor is removed by the coolant, generally a sodium metal (metal), Air, hydrogen, CO_2 (gases), light and heavy water (liquid). The coolant carries the heat to the heat exchanger.

(ii) Heat Exchanger:- The coolant gives up heat to the heat exchanger ~~a~~ which is utilised for producing the steam.

(iii) Steam turbine:— The steam produced in the heat exchanger is passed through the steam turbine. After doing the useful work in the turbine, the steam is exhausted to condenser. The condenser condenses the steam which is feed to the heat exchanger.

(iv) Alternator:— The steam turbine drives the alternator which converts the mechanical energy into electrical energy. The output from the alternator is delivered to the bus-bars through the transformer.

Advantages: – (1) The amount of fuel required is less.
(2) Less space is required.
(3) Very economical for producing bulk electrical power.
(4) It has low running charges.

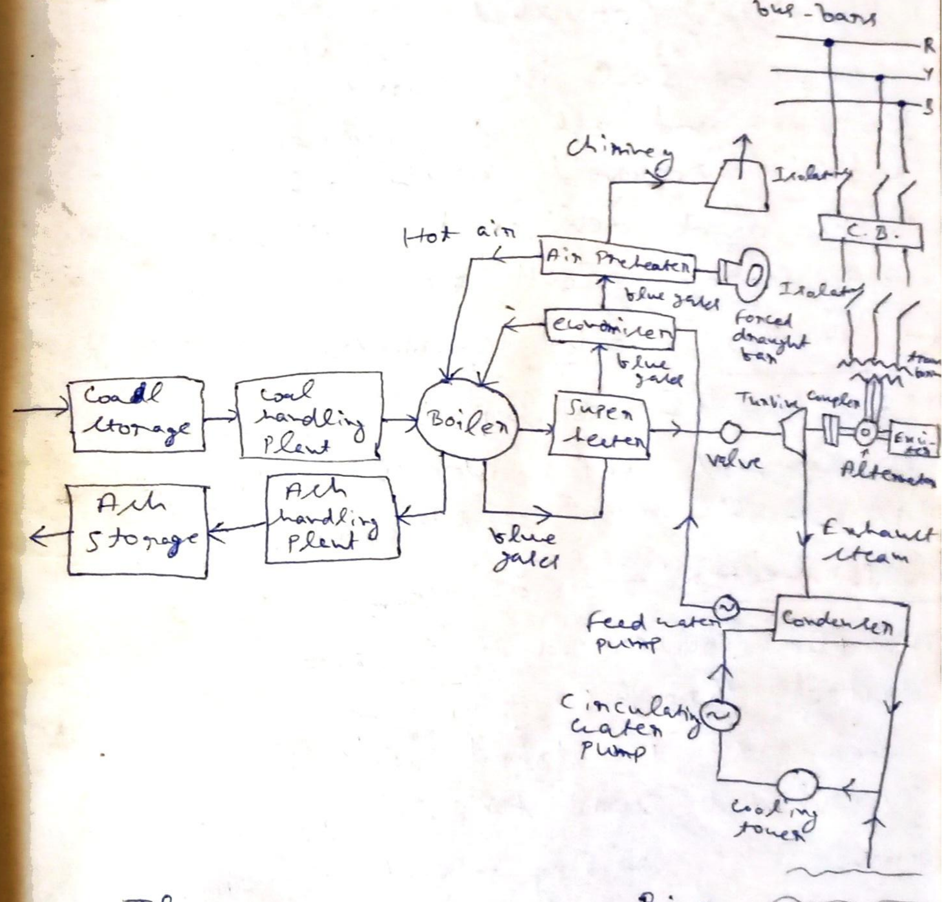
Disadvantages: – (1) The fuel used is expensive.
(2) The capital cost is high.
(3) The by-products are generally radioactive and may cause the radioactive pollution.
(4) Maintenance charges are high.

Thermal power station

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

Steam is produced in the boiler by utilising the heat of coal combustion. The steam is then expanded in the prime mover and condensed in the condenser to be fed into the boiler again. The steam turbine drives the alternator which converts the mechanical energy of turbine into electrical energy. This type of power station is suitable where coal & water are available plentily and a large amount of electrical power is to be generated.

Schematic Arrangement of steam power station: –



The whole arrangement can be divided into the following stages.
(1) Coal and ash handling arrangement.
(2) Steam generating Plant
(3) Steam turbine
(4) Feed water
(5) Cooling arrangement.

(1) The coal is transported to the power station by rail or road 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 (crushed into small pieces).

The coal is burnt in the boiler and ash is produced. The ash is removed to the ash handling plant and delivered to the ash storage plant for disposal.

(2) Boiler: — The combustion of coal in the boiler is utilised to convert water into the steam at high temp. & pressure.

Superheater: — The steam produced in the boiler is wet and is passed through a superheater where it is dried and is superheated (steam temp. increased above the boiling point of water) by the flue gases on their way to chimney.

Economiser: — It is a feed water heater and derives heat from the flue gases.

to the economiser before supplying to the boiler. The economiser extracts a part of heat of flue gases to increase the feed water temp.

Air Preheater: — It increases the temp. of the air supplied for coal burning by deriving heat from flue gases.

(3) The dry and superheated steam from the superheater is fed to the steam turbine through main valve. When steam is passing over the blades of turbine, the heat energy of steam is converted into mechanical energy. After giving heat energy to the turbine, the steam is exhausted to the condenser that condenses the exhausted steam by means of cold water circulation.

(4) Feed water: — The condensate from the condenser is used as feed water to the boiler. The feed water on its way to the boiler is heated by water heaters and economiser.

(5) Cooling arrangement: — The water is drawn from ~~the~~ a river & is circulated through the condenser.

the circulating water takes up the heat of the exhausted steam and becomes hot. Then, the hot water coming out from the condenser is discharged at a suitable location down the river. If water is not available in the river, then cooling towers are used. The hot water from the condenser is passed on to the cooling towers where it is cooled. Then, the cold water from the cooling tower is reused in the condenser.

Advantages :— ① The fuel used is cheap.

② The initial cost is less as compared to other generating stations.

③ It can be installed at any place irrespective of the existence of coal.

④ As compared to the hydroelectric power station, less space is required.

Disadvantages :— ① It pollutes the atmosphere because of the production of large amount of smoke & fumes.

... is compared to hydroelectric plant costlier in running ...

Measuring Instruments

Introduction :— The various electrical instruments are divided into two types. ① absolute instruments & ② secondary instruments.

Absolute instruments :— The instruments that give the value of the quantity to be measured in terms of the constant of the instruments and their deflection only.

Secondary instruments :— The instruments 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.

Another way of classifying secondary instruments are (a) indicating instruments, (b) recording instruments, (c) integrating instruments.

Indicating instruments :— The instruments that 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.

Recording instruments: — The instruments that give a continuous record of the variations of such a quantity over a selected period of time.

Integrating instruments: — The instruments that measure and register by a set of dials and pointers either the total quantity of electricity or the total amount of electrical energy supplied to a circuit in a given time.

Torques in instruments

Deflecting Torque: — The deflecting torque causes the moving system to move from its zero position.

Controlling Torque: — If there were no controlling torque, the deflection of the moving system would be indefinite. The torque opposes the deflecting torque and increases with the deflection of the moving system. The pointer is brought to rest when the two opposing torques are equal.

Damping Torque: — The damping torque acts on the moving system of the instrument only when it is moving and always opposes its ~~motion~~ motion.

Different use of PMMC type of instruments: —

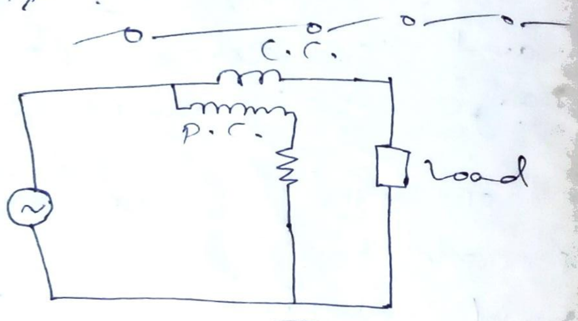
1. It has low power consumption.
2. It is modified with the help of shunts and resistances to cover a wide range of currents and voltages.
3. As the operating fields of such instruments are very strong, they are not much affected by stray magnetic fields.
4. It is mainly used for d.c. work.
5. It can be used as ammeters with the help of a low resistance shunt.
6. It can be used as voltmeters with the help of a high series resistance.

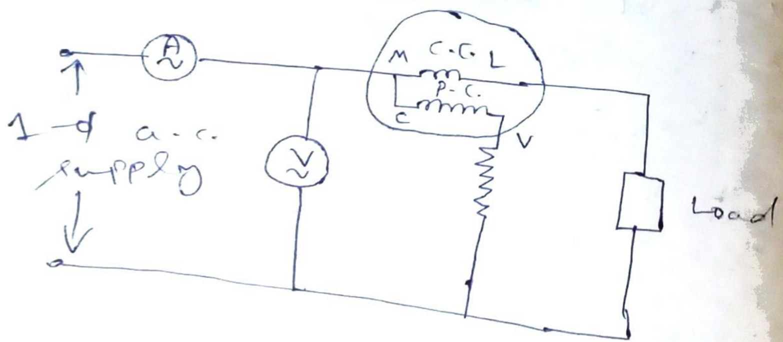
Different use of MI type of Instruments: —

1. It can be used both on a.c. & d.c. ckts.

2) The range of the moving-iron instrument as ammeter can be extended by using a suitable shunt across its terminals.

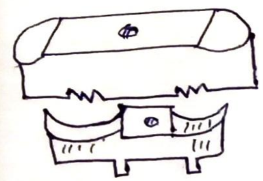
3) The range of the instrument when used as a voltmeter can be extended by using a high non-inductive series resistance connected in series with it.

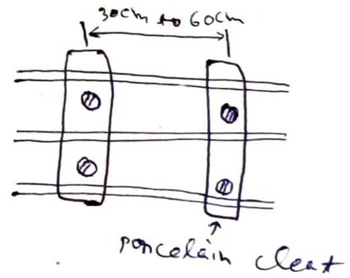




CLEAT WIRING

In this system of internal wiring, cables are supported and gripped between porcelain cleat 10mm above the wall or ceiling. The porcelain cleats are made in two halves. The main part is base that is grooved to accommodate the cable and the cap is put over it. The lower cleat and upper cover after placing cables between them are then screwed on wooden plugs (gutties). The gutties previously fixed into wall or ceiling at regular interval should be 30cm to 60cm apart.





Advantages: —

1. Its installation and dismantling is easy and quick.
2. The inspection work is easy as the cables are within sight.
3. The installation is very cheap and the material after dismantlement is recoverable for re-use.
4. An unskilled electrician can do the job.