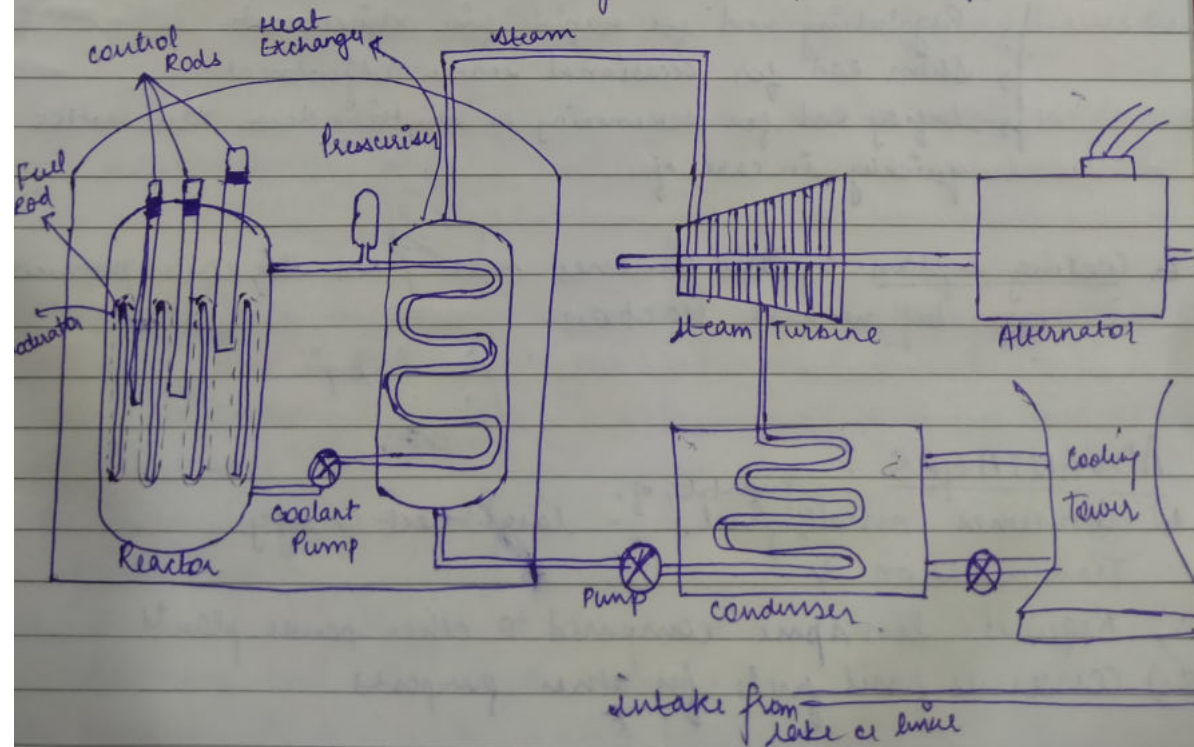


Modern Nuclear Power Plant.

- A nuclear reactor is the part of nuclear plant in which nuclear fuel is subjected to controlled nuclear fission.
- In the process of fission heat is generated which is used to heat a coolant. The coolant transfers heat to the heat exchanger to produce steam.
- The steam generated in the heat exchanger is admitted to the turbine which is coupled to the alternator.
- The alternator converts mechanical energy $\rightarrow$ electrical energy.
- The steam after expansion through the turbine is condensed in the condenser.
- The condensate pump sends the condensate back to the heat exchanger thus forming a close-feed system.
- The reactor and heat exchanger are equivalent to furnace & boiler.



1. Reactor Core :- Consists of no. of fuel rods made of fissile material.
2. Moderator :- Used to moderate or reduce the neutron speeds to a value that increases the probability of fission occurring.
3. Reflector :- Completely surrounds the reactor within the thermal shielding arrangement and helps to bounce escaping neutrons back into the core. This conserves nuclear fuel, as the low speed neutrons thus returned are useful in continuing chain rxn.
4. Shielding :- It helps in giving protection from deadly α and β particles, radiations that neutron gives off. (concrete)
5. Reactor Control Rods :- made up of neutron absorbing materials ^(Cd and B) to keep the chain rxn at a desired level.
 - Regulating rod for rapid fine adjustment
 - Shim rod for occasional coarse adjustment
 - Safety Rod for scramming or shutting down the reactor quickly in case of
6. Cooling system :- This removes heat from the core produced by nuclear reaction.

ADVANTAGES :-

- 1.) Consumes small quantity of fuel. - large heat energy.
Transportation ↓
- 2.) Requires less space compared to other power plants
- 3.) Conserves fossil fuels for other purposes

Disadvantages

- 1) Initial cost $\uparrow$
- 2) Hazardous as radioactive in nature.
- 3) Not suitable for variable loads.
- 4) Nuclear waste disposal is a serious problem.
- 5) Efficiency of nuclear plants is less than 30%.

b.) Boiling Water Reactor

- Fuel used is enriched uranium.
- Light water is used as both moderator and coolant.
- Uranium fuel elements are arranged in a particular lattice form inside the pressure vessel by nuclear fission.
- Feed water enters the reactor tank at the bottom and it absorbs heat produced by nuclear fission.
- The steam is generated in the reactor itself and leaves the reactor at the top.
- The steam after passing through the turbine and condenser returns to the reactor.

Advantages :-

1. Water boils — pressure inside the vessel of a BWR is smaller than that in PWR. Hence the cost of BWR $\downarrow$ (low)
2. Heat exchanger, pressuriser and circulating pump not required (low cost)
3. Thermal efficiency :- 30%

Disadvantages :-

- Steam - radioactive - shielding of turbine and piping circuitry is necessary and extra safety measures are to be taken.
- Power density of a BWR is nearly half that of PWR, the size of vessel is large.
- Sudden increase in load.

• PWR Pressurised Water Reactor.

- The fuel used is enriched uranium clad with stainless steel or zirconium alloy.
- Light water is used both as moderator and coolant.
- Water passes through the reactor and takes up the heat liberated due to nuclear fission of the fuel.
- In order that water may not boil (due low b.p. 100°C) and remain in liquid state, it is kept under a pressure of 100 to 130 atm by pressuriser.
- This enables water to take more heat from the reactor. Water from pressuriser passes through the heat exchanger where it is converted to steam. Steam $\therefore 250^{\circ}\text{C}$ and pressure 40 atm.
- The steam is condensed in the condenser and the condensate returns to the heat exchanger forming a closed circuit.
- Since water passing through the reactor becomes radioactive, the entire primary circuit including heat exchanger must be shielded.

Advantages :- • Relatively compact in size as compared to others

- Reactor has a high power density.
- Can meet sudden increase in load.
- Maintenance is easier and safer.
- Produces plutonium by providing a blanket of U-238.

Disadvantages :- High pressure vessels are required.

- Shut down for few months for recharging.
- Thermal efficiency 20%.
- Expensive cladding material is required to prevent corrosion.
- No. of safety devices are more for a PWR.

• PHWR.

- ~~Uses~~ Uses natural uranium as fuel as
- Heavy water as moderator and coolant (CANDU)
- The coolant is passed through the pressurised fuel tubes and heat exchanger, circulated in primary circuit in same way as PWR.
- Steam is produced in secondary circuit.
- Power output can be varied by varying level of moderator.
- Control Rods are not required.
- For fast shut down of the plant, the moderator can be dumped into a tank, provided below reactor.

Advantages

- Natural uranium is used as fuel.
- Control rods not required, control of reactor is simple.
- The reactor vessel needs to be built to withstand low pressure.
- Since the moderator is at a low temperature, it is more effective in slowing down the neutrons.
- Plant can be constructed in a shorter time as compared to BWR, PWR.

Disadvantages

- Cost of heavy water is high.
- Design, construction and maintenance of a PHWR is complex.

Liquid Metal Cooled Reactor (Sodium Graphite Reactor SGR)

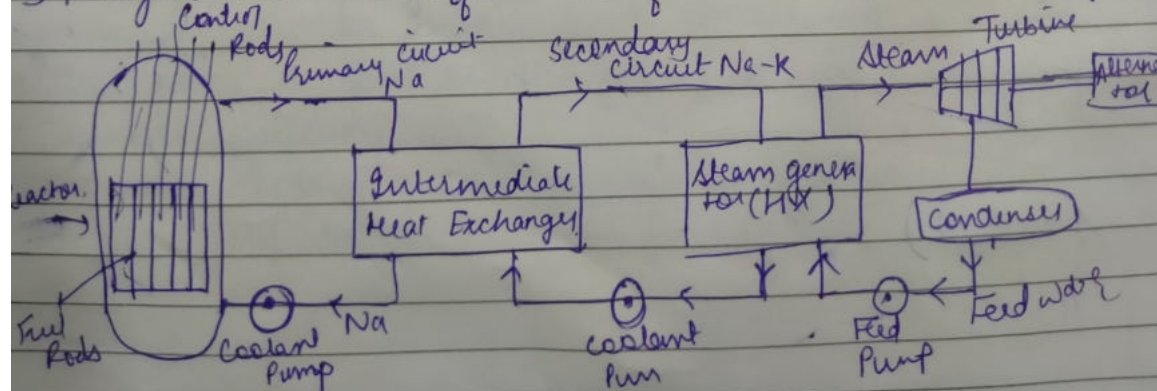
- Uses slightly enriched uranium
- Graphite is used as moderator
- Two liquid metal coolants are used.
- Liquid sodium (Na) is circulated through the reactor core and the intermediate heat exchanger.
- This prevents steam from becoming radioactive.
- In the intermediate heat exchanger the heat from the sodium is transferred to the sodium (Na-K) liquid metal which gives up its heat to heat exchanger (HX) to generate steam. This is fed to turbine.

Advantages :-

1. Steam of 540°C is obtained. $\uparrow$ thermal efficiency.
2. Low pressure in the primary and secondary coolant $\downarrow$ size.
3. Excellent heat transfer properties of liquid metal sodium. Volume of coolant needed is less.

Disadvantages :-

1. Enriched uranium is used as fuel
2. Leakage of Na may result in health hazard as Na becomes highly radioactive when passed through reactor core.
3. Higher initial cost ^{HX} because of their adequate shielding

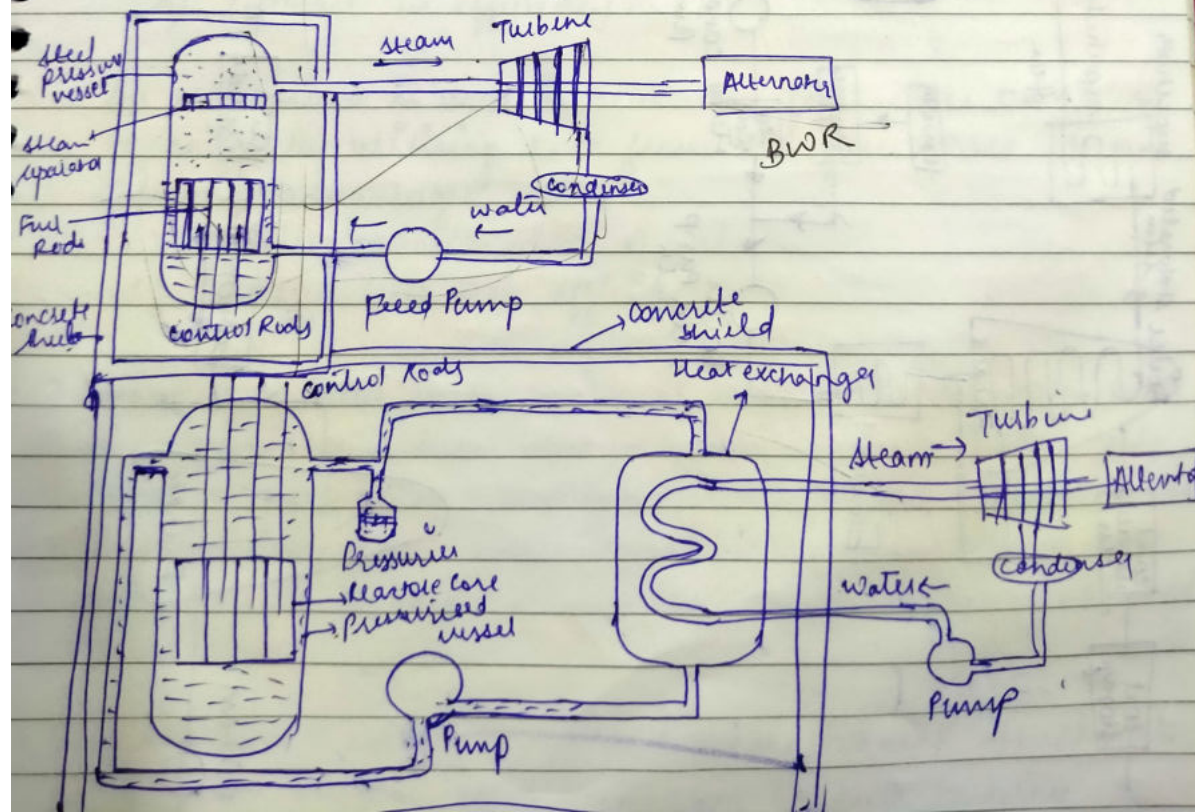


FBR

- A FBR generates electrical energy like others and at the same time converts a fertile material into a fissile material
- Central portion - stainless steel vessel in which there is a core of fissile material (U-233 or Pu-239)
- Core is surrounded by fertile material (U-238 or Th-232)
- Two liquid metal coolants are used.
- Same as (LMCR) from 4pt.

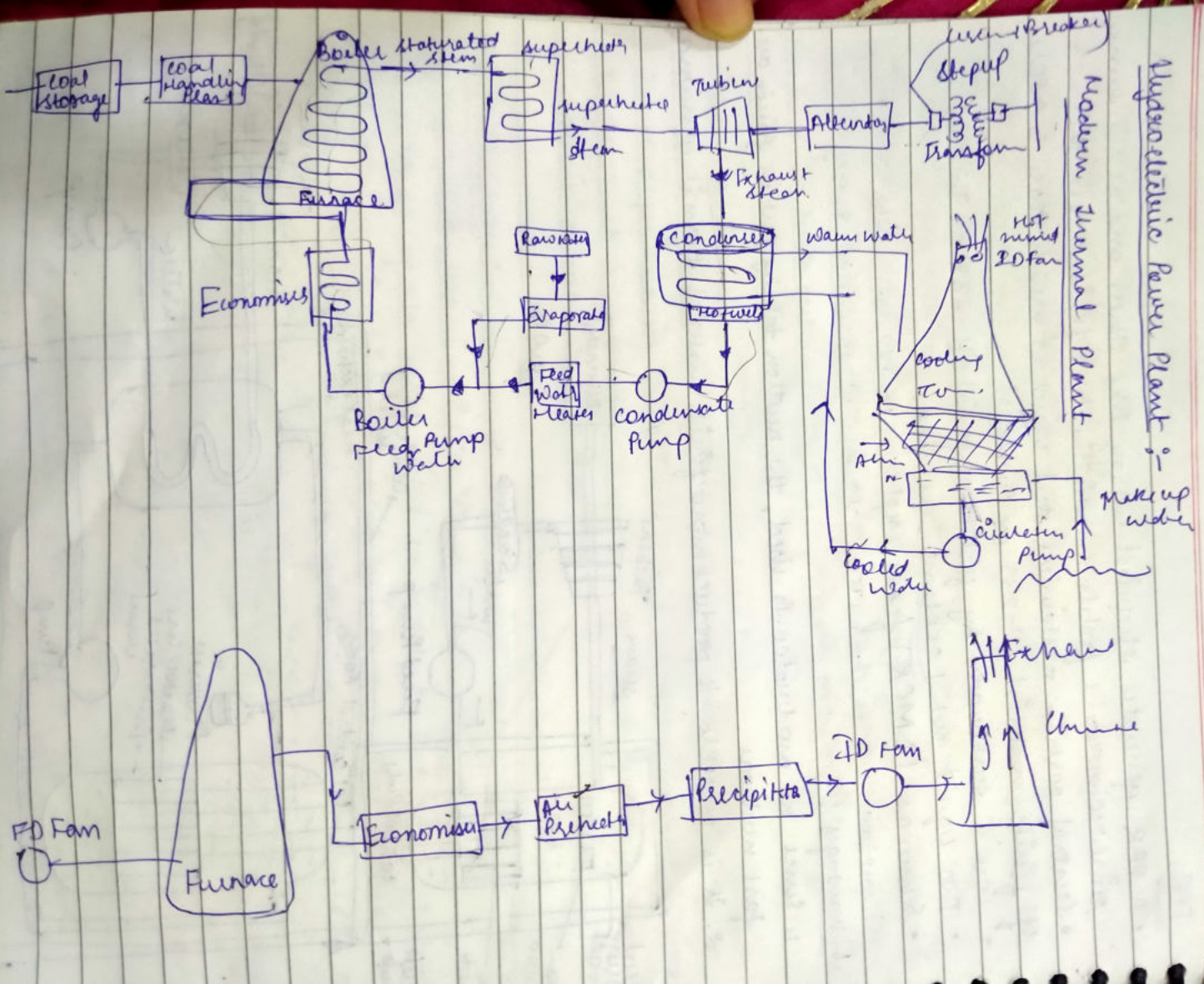
Advantages :-

1. Since no moderator is used, the neutron taking part in fission are fast neutrons.
2. It is possible to produce more fissile material than it consumes.



Hydroelectric Power Plant :-

Modern Thermal Plant



Coal is burned in the furnace. The combustion heat is taken up by the water and converted into steam. This steam drives the turbine mechanically which is coupled with an alternator.

- The combustion process requires supply of sufficient quantity of air and removal of exhaust gases. Air is taken by forced draft fans, and removal of exhaust gases is done by induced draft fans.
- The air is preheated in the air preheater before being supplied to the furnace. Heating of air has following advantages :-
 - 1.) Improved combustion
 - 2.) effective use of low grade fuel
 - 3.) saving in fuel combustion
 - 4.) increase in efficiency.
- An economiser is used to heat the feed water on its way to boiler by utilising heat from the flue gases. It has following advantages.
 - 1.) Reduces consumption of coal
 - 2.) Improves thermal efficiency.
- Steam generated in the boiler is superheated in superheater. A superheater reduces the moisture content in the last stages of the turbine. Therefore lesser erosion of turbine blade combined (convection and radiation) type superheaters are used because it keeps temperature constant throughout load range.

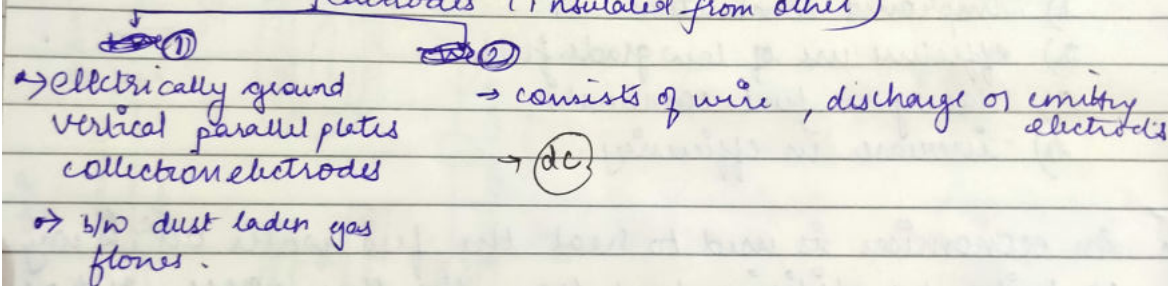
This superheated steam is supplied to the turbine which acts as a prime mover. After expansion through turbine, the

gas to condenser —

Circulating water pumps circulate cooling water through the condenser tubes and ~~the~~ condense the exhaust steam into water which is pumped back to the boiler.

Ash precipitators

- Avoid air pollution — gases should be free from dust particles
 - mechanical and electrical precipitators.
 - Mechanical precipitators — coarse ash particles — centrifugal action
 - electrostatic precipitators — remove fine ash particles.
- (electrodes (insulated from other))



- 1) It increases the efficiency of the boiler
- 2) It makes possible the use of wide variety of coal
- 3) Reduces time of raising temp. of steam
- 4) Combustion of pulverised coal can readily be adopted to automatic ^{coal} ~~coal~~
- 5) This system works successfully with oil in combustion with gas and oil
- 6) Large amount of heat release is possible in this system

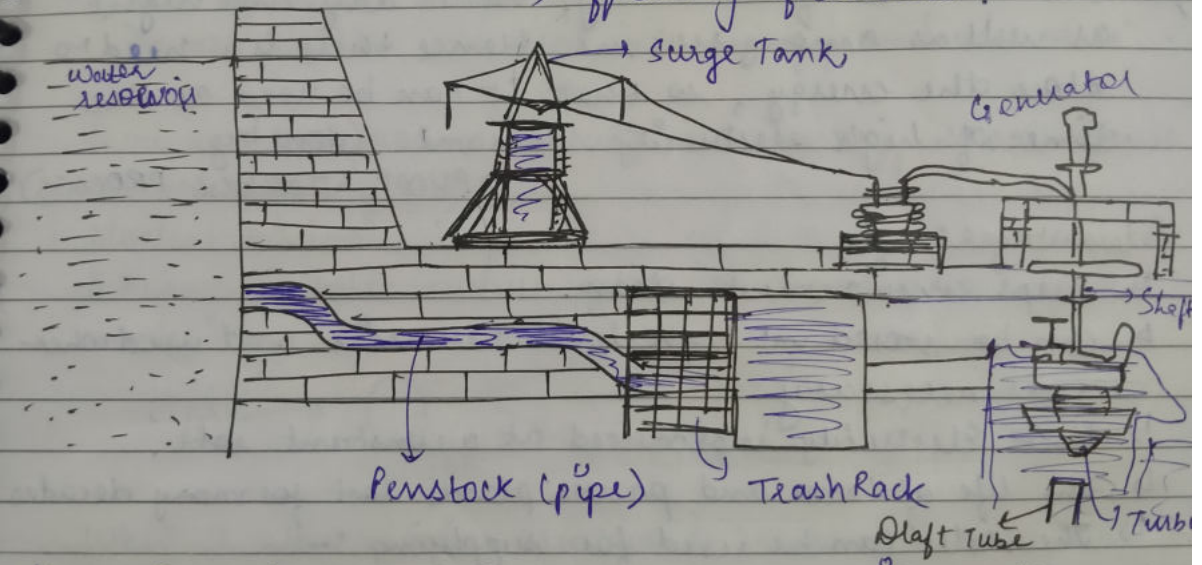
• Hydroelectric Power Plant

↳ Hydro energy is the ^{electrical} energy generated by the force of water.

• Working Principle

In the following power plant production of electricity depends upon :-

- 1) Water level from ground
- 2) Volume of water flowing per unit time
- 3) Efficiency of turbine.



- Hydro Power Plants requires a water reservoir so they are constructed near big dams.
- Water stored in dams have potential energy. The water under pressure is carried by penstock (pipe) and supplied to the turbine through the inlet valve.
- Penstock is a pipe made up of steel or concrete.
- A surge tank reduces excessive water force on penstock.
- Trash Rack prevents entry of debris into powerhouse.

- Due to the force of water the turbine starts rotating due to which mechanical energy is produced
- The shaft from the turbine is connected to the generator which converts mechanical energy to electrical energy
- The voltage of this electricity is raised by using a transformer and is transferred by distribution line
- After running the turbine the water is passed through draft tube to the downstream water level by the draft tube.

* The demand of electricity, varies day and night as well as among seasons. Hence there is a need to store the energy, so that it can be used at the time of high electricity demand. (done by PUMP STORAGE PROCESS)

Advantages:

- ↳ Keeps environment clean.
- ↳ Can be stored in high level reservoir and used whenever necessary.
- ↳ ~~Electric~~ Electricity is produced at a constant rate.
- ↳ The life of dams and power plants last for many decades
- ↳ The water can be used for supplying :-
drinking water, irrigation, industries, power plants etc.
- ↳ When electricity is not needed the sluice gate is ~~closed~~ closed, and hence allows storage of water as generation of electricity can be stopped. ↳ can be used whenever needed

Disadvantages:

- ↳ expensive
- ↳ Requires large Areas
- ↳ Disruption of living of people, local species of plants & animals

- 1) Reservoir :- a large natural or artificial lake used as a source of water supply, and to store water.
- 2) Dam :- A dam is a barrier that stops or restricts the flow of water or underground stream. Reservoirs created by dams not only suppress floods but also provide water for activities such as irrigation, human consumption, industrial use etc.
- 3) Forebay :- It is an artificial pool of water in front of a larger body of water. Functions :-
 - i) Used in flood control to act as a buffer during flood impounding water and releasing in a controlled way the larger water body.
 - ii) To trap sediment and debris in order to keep the reservoir clean.
- 4) Surge tank :- A tank connected to a pipe carrying a liquid and intended to neutralise sudden changes of pressure in the flow by filling when the pressure increases and emptying when it drops.
- 5) Penstock :- A channel or pipe for conveying water to hydroelectric station or water wheel.

Comparison

Parameters	Hydro	Thermal	Nuclear
Investment per kW	High	Lower	Very High
Fuel cost	Very High	Low	-
Energy cost	Low	High	Very High
Transmission line	Long	Shorter	Shorter
Building time	Long	Lower	Long
Life time	Long	Small	Medium
Environmental impact	Reservoir	Atmosphere	Radioactivity
Green House effect	Low	High	None

2. Introduction To Transmission & Distribution

↳ AC (Alternating Current) electric Transmission.

- is the means by which large blocks of electrical energy are moved from generating sites to load areas.

- Electricity can be moved from generating sites to load areas to an interconnection with a distribution system.

- Transmission system is the backbone that ties many generating stations together along with the primary sub stations. It can be a complex maze of interconnections also referred to as 'grid'.

► Variety of transmission systems:-

operating voltages greater than 60kV

↳ as low as 40kV

↳ as high as 115kV

► Transmission Ranges classification:-

1. Ultra High Voltage (UHV) - above 765kV

2. Extra High Voltage (EHV) - 345 to 765kV

3. Transmission - 115, 138, 161 and 230 kV

4. Sub Transmission - 34.5 to 115 kV

5. Distribution - 34.5 kV and below.

Transmission voltages can be found at ~~69, 115, 128, 220, 345~~ ^{16.5 and 21 kV, 220} ~~400~~, 765kV in various parts of U.S.

Transmission lines can also be designed to transmit as +
however cannot be designed both.

- ↳ Most transmission lines in India are AC
- ↳ The efficiency of electric power transmission is greatly increased by operating at increased voltages. as a result the current in conductors is reduced and power transmitted more closely matches the power. (i.e. less power loss).
- ↳ This increase in voltage is provided by a step up Transformer.

- High Voltage Direct Current (HVDC) transmission lines.
 - are increasingly imp where isolating features are stabilise against control problems.
 - These features are necessary in large power distribution networks when encountering system ~~int~~ interruptions or sudden loads can cause synchronising ^{tion} problems in rest of power system.

Construction

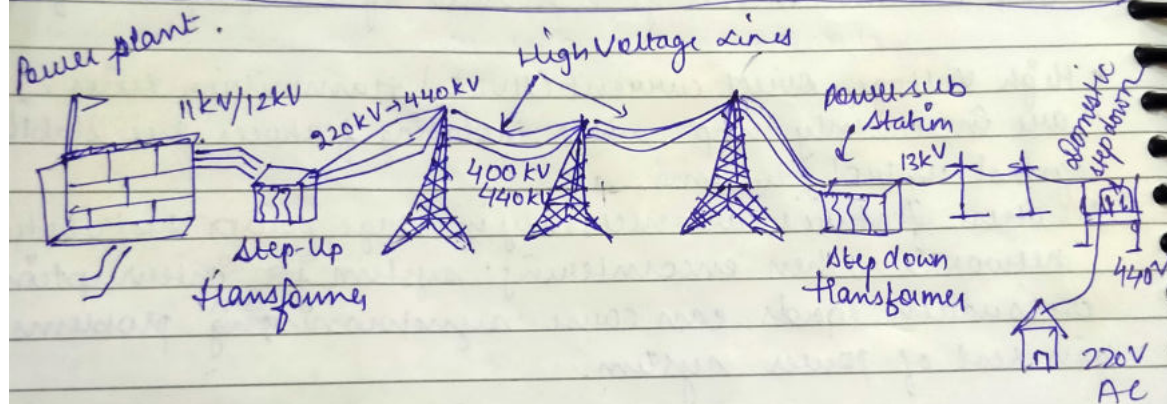
Besides the transmission lines, the transmission system consists of station transformers, switchyards and transmission substations.

Switchyard :- ^{typically} located outside the generating unit and provides a special transformer and increases the power voltage from the unit voltage to the transmission voltage.

- It is also equipped with switchgear, breakers, bus-bars as well as protective equipments. This switchyard equipment is used for configuring the electric power flow from the generating unit as well from protecting unit and transmitting ~~exist~~ 'grid'.

From this point the transmission system connects to a distribution system.

Transmission lines typically installed above ground on overhead lines. In urban areas, underground cable systems or bus bars is more common.



It uses 220 V AC power

Power plant → generation station of electricity

Step up transformer → Power losses minimised, fast transmission

Transmission lines → To transmit high voltage AC.

SOME DEFINITIONS

1. Charge :- It is the electrical property of elements or atomic particle of which the matter is consist of.
 $1e^- = -1.602 \times 10^{-19} \text{ C.}$

2. Electric Current :- Rate of change of / flow of charge. It is measured in Amperes (A).

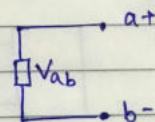
$$i = \frac{dq}{dt}$$

→ Direct Current

→ Alternating Current

3. Voltage :- It is the energy required to move a unit charge through an element.

$$V = \frac{dw}{dq}$$



$$1V = 1J/C$$

4. Power :- It is the time rate of expanding or absorbing the energy measured in Watts (W). Rate of doing work.

$$P = Vi$$

$$P = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = V \cdot i$$

5. Linear Elements :- Those elements that follows $y = mx$ eqⁿ such that their straight line passes through origin.
 Eg. Resistance, Capacitor, ohmic elements.

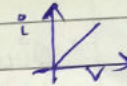
6. Non-Linear Elements :- Elements other than linear elements which do not follow $y = mx$.
 Eg. Diodes.

Resistance :- It is the physical property of a material to resist the flow of electric charge. Its unit is ohm (Ω)

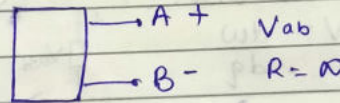
$R \propto l$; $R \propto \frac{1}{A}$ i.e. $R = \frac{\rho l}{A}$

3. Ohm's Law :- It states that current flowing through the resistor is directly proportional to the voltage across the resistor provided all the physical and chemical conditions remains the same.

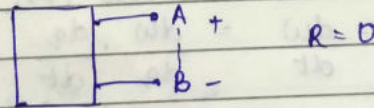
$i \propto V$ $i = \frac{1}{R} \cdot V$ or $V = iR$



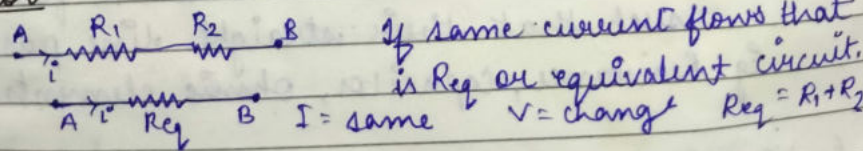
3. Open Circuit :- No current flows b/w the terminals.



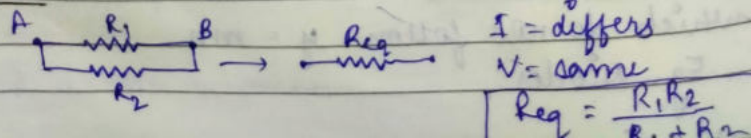
4. Short Circuit :- Current flows as they are connected.



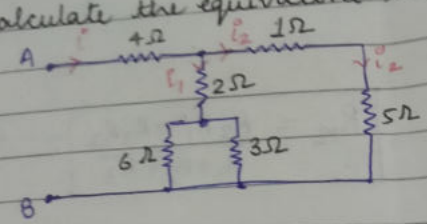
11. Series Resistor



12. Parallel Resistor

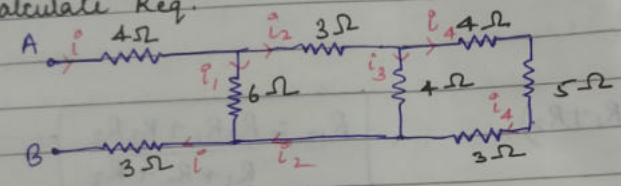


Q. Calculate the equivalent resistance of the circuit.



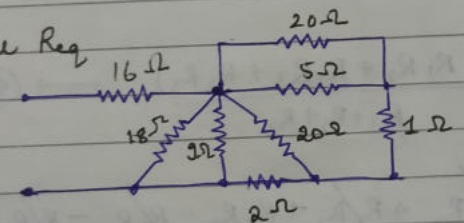
$R_{eq} = 2.4 \Omega$

Q. Calculate R_{eq} .



$R_{eq} = 10 \Omega$

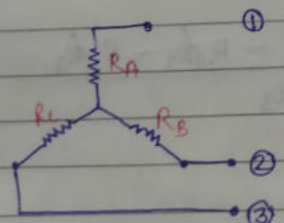
Q. Calculate R_{eq} .



$R_{eq} = 19 \Omega$

STAR AND DELTA

Delta to Star :-



Across terminal ① and ②

Star

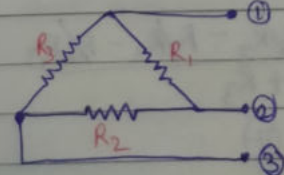
$R_{12} = R_A + R_B$

Delta

$R_{12} = R_1 \parallel (R_3 + R_2)$

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

→ (i)



Across terminal ② and ③

NOTE: If $R_1 = R_2 = R_3$ then $R_A = R_B = R_C = \frac{R}{3}$

Star

$$R_{23} = R_B + R_C$$

Delta

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

$$R_{23} = \frac{R_2 R_1 + R_2 R_3}{R_1 + R_2 + R_3} \quad \text{--- (ii)}$$

Across terminals ① and ③

Star

$$R_{13} = R_A + R_C$$

Delta

$$R_{13} = R_3 \parallel (R_1 + R_2)$$

$$R_{13} = \frac{R_3 R_1 + R_3 R_2}{R_1 + R_2 + R_3} \quad \text{--- (iii)}$$

$$\textcircled{i} + \textcircled{ii} + \textcircled{iii}$$

$$\cancel{R_A} + \cancel{R_B} + \cancel{R_C} = \cancel{R_1 R_2} + \cancel{R_1 R_3} + \cancel{R_2 R_3} \quad \text{--- (4)}$$

$$\textcircled{4} - \textcircled{i}$$

$$\cancel{R_A} + \cancel{R_B} + \cancel{R_C} - \cancel{R_A} - \cancel{R_B} = \frac{R_2 R_3 + R_1 R_2 + R_2 R_3}{R_1 + R_2 + R_3} - \cancel{R_1 R_2} - \cancel{R_1 R_3}$$

$$R_C = \frac{R_2 R_3}{R_1 + R_2 + R_3} \quad \text{--- (5)}$$

$$\textcircled{4} - \textcircled{iii}$$

$$\cancel{R_A} + \cancel{R_B} + \cancel{R_C} - \cancel{R_A} - \cancel{R_C} = \frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{R_1 + R_2 + R_3} - \cancel{R_1 R_2} - \cancel{R_2 R_3}$$

$$R_B = \frac{R_1 R_3}{R_1 + R_2 + R_3} \quad \text{--- (6)}$$

$$\textcircled{4} - \textcircled{ii}$$

$$\cancel{R_A} + \cancel{R_B} + \cancel{R_C} - \cancel{R_B} - \cancel{R_C} = \frac{R_1 R_2 + R_1 R_3 + R_2 R_3}{R_1 + R_2 + R_3} - \cancel{R_1 R_3} - \cancel{R_2 R_3}$$

$$R_A = \frac{R_1 R_2}{R_1 + R_2 + R_3} \quad \text{--- (7)}$$

Star and Delta:-

$$\textcircled{6} \textcircled{5} \textcircled{6} + \textcircled{6} \textcircled{7} + \textcircled{5} \textcircled{7}$$

$$\Rightarrow R_C R_A + R_A R_B + R_C R_B$$

$$\Rightarrow \frac{R_1 R_2 R_3}{(R_1 + R_2 + R_3)^2} + \frac{R_1^2 R_2 R_3}{(R_1 + R_2 + R_3)^2} + \frac{R_1 R_2 R_3^2}{(R_1 + R_2 + R_3)^2}$$

$$\Rightarrow \frac{R_1 R_2 R_3 (R_1 + R_2 + R_3)}{(R_1 + R_2 + R_3)^2}$$

$$\Rightarrow \boxed{\frac{R_1 R_2 R_3}{R_1 + R_2 + R_3} = R_A R_C + R_A R_B + R_C R_B} \rightarrow \textcircled{8}$$

$$\frac{\textcircled{8}}{\textcircled{5}} \Rightarrow \frac{R_A R_C + R_A R_B + R_C R_B}{R_C} = \frac{R_1 (R_2 + R_3)}{R_1 + R_2 + R_3}$$

$$\boxed{R_1 = \frac{R_A R_C + R_A R_B + R_C R_B}{R_C}}$$

Similarly,

$$\frac{\textcircled{8}}{\textcircled{6}} \text{ gives } \boxed{R_2 = \frac{R_A R_C + R_A R_B + R_C R_B}{R_B}}$$

$$\frac{\textcircled{8}}{\textcircled{7}} \text{ gives } \boxed{R_3 = \frac{R_A R_C + R_A R_B + R_C R_B}{R_A}}$$

NOTE: If $R_A = R_B = R_C$ then $R_1 = R_2 = R_3 = 3R$.

:- Kirchhoff's ^{current} Law (KCL)

It is based on the law of conservation of charges. It states that algebraic sum of current entering a node is zero.

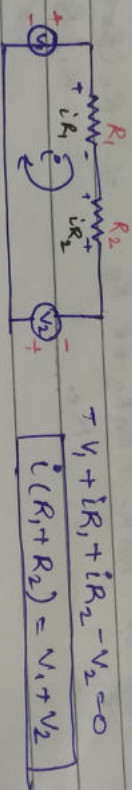
NOTE: It is the point of connection b/w two or more branches.

OR

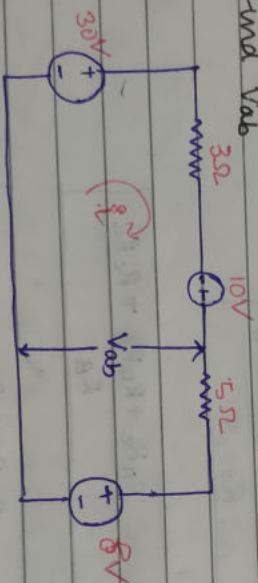
The sum of current entering a node = the sum of current leaving the node.



!- Kirchhoff's Voltage Law
It states that algebraic sum of voltages around a closed loop is zero. It is based on conservation of energy.



Q. Find V_{ab}



Apply KVL

$$-30 + 3i - 10 + 5i + 8 = 0$$

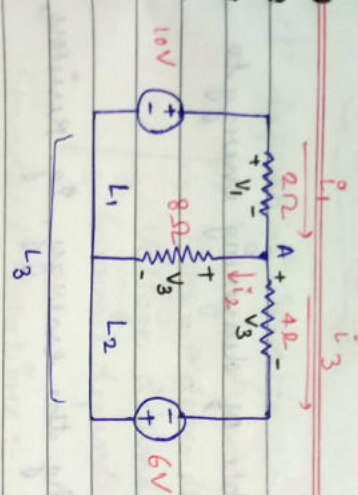
$$-32 + 8i = 0$$

$$8i = 32$$

$$i = 4A$$

$$V_{ab} = 20V + 8V = 28V$$

Q. Find V_1, V_2, V_3 and i_1, i_2, i_3 in the following circuit



Applying KCL at A
 $i_1 = i_2 + i_3 \rightarrow (1)$

For loop 1, Apply KVL
 $-10 + 2i_1 + 8i_2 = 0$

$$2i_1 + 8i_2 = 10$$

$$i_1 + 4i_2 = 5 \rightarrow (2)$$

For loop 3

$$-10 + 2i_1 + 4i_3 - 6 = 0$$

$$2i_1 + 4i_3 = 16$$

$$i_1 + 2i_3 = 8 \rightarrow (4)$$

$$(2) + (3)$$

For loop 2

$$-8i_2 + 4i_3 - 6 = 0$$

$$4i_3 - 8i_2 = 6$$

$$2i_3 - 4i_2 = 3 \rightarrow (3)$$

$$\Rightarrow i_1 + 2i_3 = 8$$

$$i_2 + i_3 + 2i_3 = 8$$

$$4i_2 + 12i_3 = 32$$

$$(3) + (5)$$

$$12i_3 + 2i_3 = 35$$

$$21i_3 = 35$$

$$i_3 = 2.5 \text{ A} \rightarrow (6)$$

Putting value of i_3 from (6) in (4) and (3)

$$i_1 + 5 = 8$$

$$i_1 = 3 \text{ A}$$

$$2 \times 2.5 - 4i_2 = 3$$

$$5 - 4i_2 = 3$$

$$2 - 4i_2 = 2$$

$$i_2 = 0.5 \text{ A}$$

• ACTIVE ELEMENTS

The elements which are capable of delivering energy to the circuit. Eg. Battery, cell.

• PASSIVE ELEMENTS

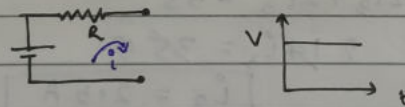
Which are capable of absorbing the energy. Eg. Resistors, capacitors etc.

⚡ Independent Source

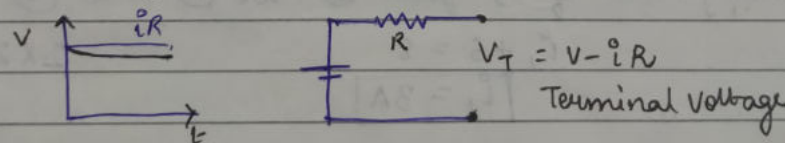
Those sources whose value does not change or does not get affected as a result of change in some other components in the circuit.

• Ideal Voltage Source $\Rightarrow$

It is an active element that provides a specified voltage independent of other circuit elements.

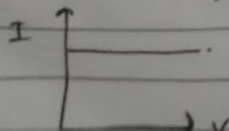


• Practical Voltage source $\Rightarrow$

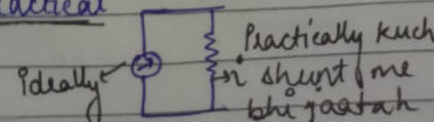


• Ideal Current Source $\Rightarrow$

It is an active element capable of delivering constant current irrespective of the variation in the load.



Practical



-:- Dependent Sources

- Voltage dependent Voltage Source (VDVS)
- Current dependent Voltage Source (CDVS)
- Voltage dependent Current Source (VDCS)
- Current dependent Current Source (CDCS)

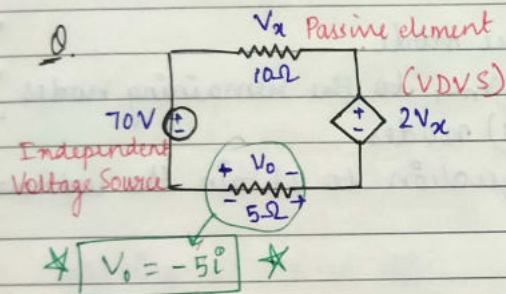
Standard Notations :-



Voltage



Current



using KVL

$$V_x = 10i \quad (\text{Ohm's Law}) \rightarrow \text{①}$$

$$\Rightarrow -70 + 10i + 2V_x + 5i = 0$$

$$\Rightarrow -70 + V_x + 2V_x + \frac{V_x}{2} = 0$$

(From eq. ①)

$$\Rightarrow -70 + \frac{7V_x}{2} = 0$$

$$V_x = 10i$$

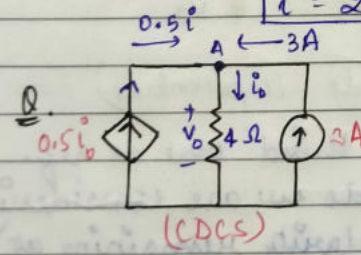
$$i = \frac{20}{10} = 2 \text{ Amp.}$$

$$\frac{7V_x}{2} = 70$$

$$V_x = 20 \text{ V}$$

$$i = 2 \text{ A}$$

$$V_0 = -10 \text{ V}$$

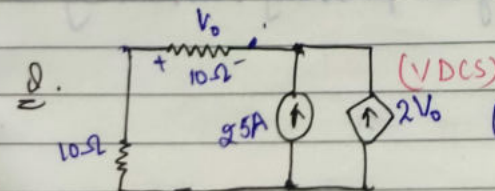


Using K.C.L. at point A

$$0.5i_0 + 3 = i_0$$

$$3 = 0.5i_0$$

$$i_0 = 6 \text{ A}$$



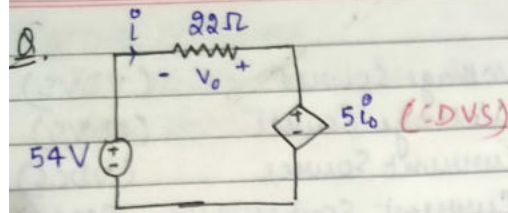
$$V_0 = -10i$$

$$i = -\frac{V_0}{10}$$

(K.C.L.) $25 + 2(-10i) = i$

$$\Rightarrow 25 = 21i$$

$$i = \frac{25}{21} \text{ A}$$



Using K.V.L in the loop

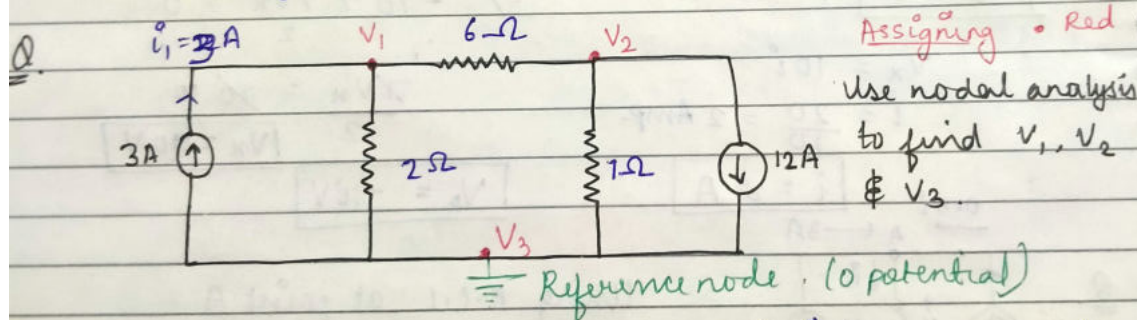
$$-54 + 22i_o + 5i_o = 0$$

$$-54 + 27i_o = 0$$

$$\boxed{i_o = 2A}$$

NODAL ANALYSIS

1. Select a node as a reference node.
2. Assign voltages $V_1, V_2, \dots, V_{n-1}$ to the remaining nodes.
3. Apply K.C.L to each $(n-1)$ nodes.
4. Solve the simultaneous equation to obtain the unknown node voltage.



Ans. So there are 3 nodes take the third one as ref. We assume that whichever node we are considering we assume it to be at higher polarity remaining at low voltage.

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

Applying K.C.L. at node ①

as we consider V_1 at higher potential so current coming will be of opposite direction.

$$\Rightarrow -3 + \left(\frac{V_1 - 0}{2}\right) + \left(\frac{V_1 - V_2}{6}\right) = 0 \quad \rightarrow (1)$$

$$\Rightarrow -3 + \frac{V_1}{2} + \frac{V_1}{6} - \frac{V_2}{6} = 0$$

$$\Rightarrow \frac{V_1}{2} + \frac{V_1}{6} - \frac{V_2}{6} = 3$$

Applying K.C.L. at node (2)

$$\Rightarrow \frac{12 + V_2 - 0}{7} + \frac{V_2 - V_1}{6} = 0$$

$$\Rightarrow \frac{12 + V_2 + V_2 - V_1}{7} = 0$$

$$\frac{V_2 + V_2 - V_1}{7} = -12 \quad \rightarrow (2)$$

Solving (1) and (2)

$$V_1 = -6V$$

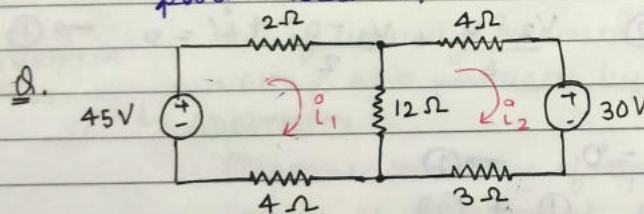
$$V_2 = -42V$$

MESH ANALYSIS

1. Assign mesh current $i_1, i_2, \dots$ in to n mesh.
2. Apply K.V.L. to all n meshes
3. Solve simultaneously eqⁿ to obtain branch current and node voltage.

⚡ Loop :- It is any closed path in a circuit where 2 nodes are not traversed twice except the initial one (repeat)

⚡ Mesh :- It is a closed path in a circuit with no other part inside it.



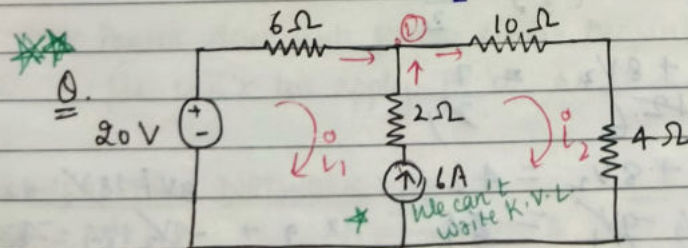
Find branch current of all branches using mesh analysis.

Ans. $\Rightarrow 2i_1 + 12(i_1 - i_2) + 4i_1 - 45 = 0$

$\Rightarrow 4i_2 + 30 + 3i_2 + 12(i_2 - i_1) = 0$

Solve, $i_1 = 2.5A$

$i_2 = 0A$



Ans.

So in complete loop we apply K.V.L.

$$-20 + 6i_1 + 10i_2 + 4i_2 = 0$$

KCL at ①

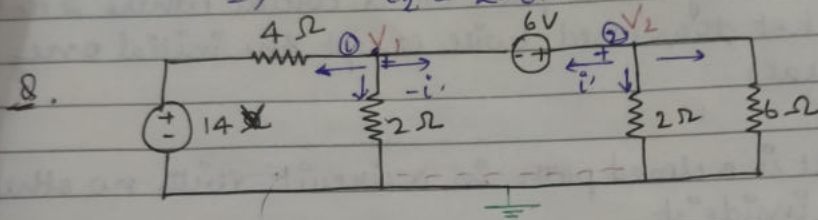
$$i_1 + 6 = i_2$$

$$i_2 - i_1 = 6 \rightarrow \textcircled{1}$$

$$\Rightarrow 6i_1 + 14i_2 = 20$$

$$\Rightarrow 3i_1 + 7i_2 = 10$$

$$\Rightarrow i_2 = 2.6 \text{ A} \quad i_1 = -3.2 \text{ A}$$



Ans. By node, at ② $\frac{V_2 - 0}{6} + \frac{V_2 - 0}{2} + i' = 0 \rightarrow \textcircled{1}$

at ①

$$\frac{V_1 - 14}{4} + \frac{V_1 - 0}{2} - i' = 0 \rightarrow \textcircled{2}$$

① + ②

$$\frac{V_1 - 14}{4} + \frac{V_1 - 0}{2} + \frac{V_2 - 0}{2} + \frac{V_2 - 0}{6} = 0 \rightarrow \textcircled{3}$$

$$V_1 + 6 = V_2 \rightarrow \textcircled{4}$$

solve ③

$$\Rightarrow V_1 \left(\frac{3}{4} \right) + V_2 \left(\frac{2}{3} \right) = \frac{7}{2}$$

$$\Rightarrow \frac{9V_1 + 8V_2}{12} = \frac{7}{2}$$

$$\Rightarrow 9V_1 + 8V_2 = 42$$

$$+ 9V_2 - 9V_1 = 54$$

$$17V_2 = 96$$

$$V_2 = \frac{96}{17}$$

$$\begin{array}{r} 9V_1 + 8V_2 = 42 \\ \times 9 + -8V_2 + 8V_1 = -48 \\ \hline 17V_1 = -6 \end{array}$$

$$V_1 = \frac{-6}{17}$$

SUPERPOSITION THEOREM

In any linear bilateral network consisting of two or more independent and dependent sources, the response (current or voltage) of any element is the algebraic sum of the responses produced due to each independent source acting alone keeping all other independent sources turned off. i.e. voltage sources replaced by short-circuit and current sources replaced by open circuit and dependent sources are left intact.

Linear Property

Combination of both HOMOGENITY and ADDITIVITY.

↳ HOMOGENITY

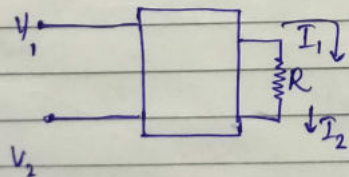
$$V = IR$$

$$aV = (aI)R$$

Here if current is increased by a constant k then voltage also increases by k . or decrease by k .

↳ ADDITIVITY

Response to a sum of inputs is the sum of responses of each input applied separately.



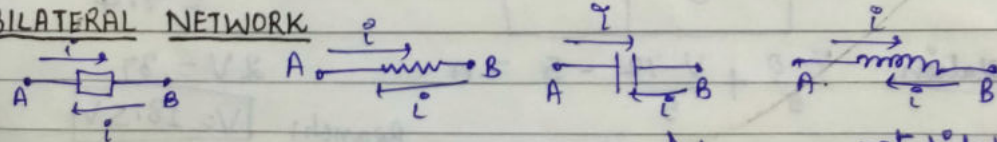
$$V_1 = I_1 R$$

$$V_2 = I_2 R$$

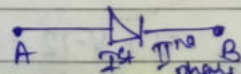
$$V_1 + V_2 = (I_1 + I_2) R$$

* Power does not follow Linear Property, Hence superposition principle can't be applied to it as it is NON-LINEAR.

BILATERAL NETWORK

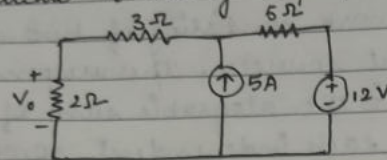


Current does not depend if we



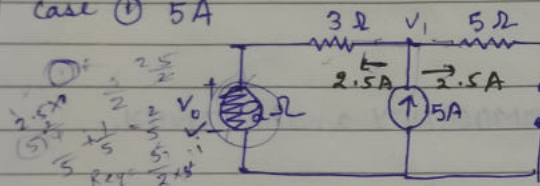
not bilateral

Q Calculate V_0 using Superposition Theorem.



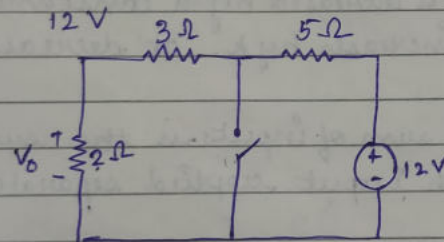
Ans. As per superposition theorem considering one independent source at a time -

Case ① 5A



$$V_1 = 5V \quad I = 2.5A$$

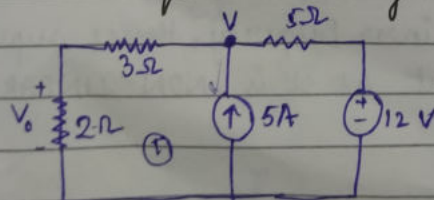
Case ②



$$V_2 = 2.4V \quad I = \frac{12}{10} = 1.2$$

$$V_0 = V_1 + V_2 = 7.4V$$

Q. Do the same question using Nodal Analysis.

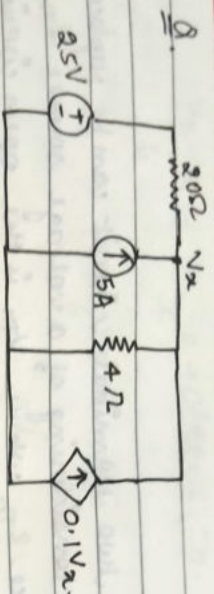


$$\begin{aligned} V_0 &= I_1 \times R \\ &= 3.7 \times 2 \\ &= 7.4 \end{aligned}$$

Solution. $\frac{V-0}{5} + \frac{V-12}{5} - 5 = 0$

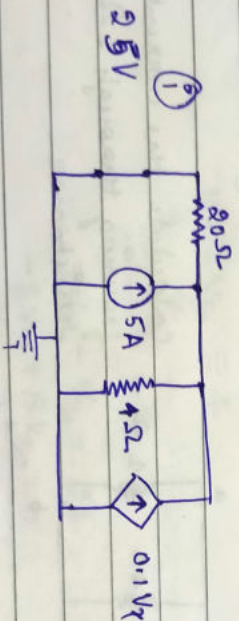
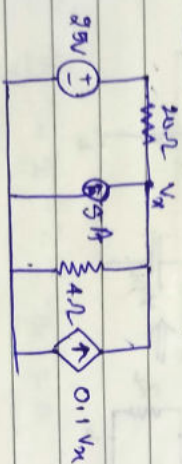
$$V + V - 12 - 25 = 0$$

Branch 1 $V = 18.5V$
 $I_1 = \frac{18.5}{5} = 3.7A$



Find V_x using
superposition theorem

Ans. As per superposition theorem taking one independent source at a time.



At point A

$$\frac{V_x}{4} + \frac{V_x - 25}{20} + (-0.1V_x) = 0$$

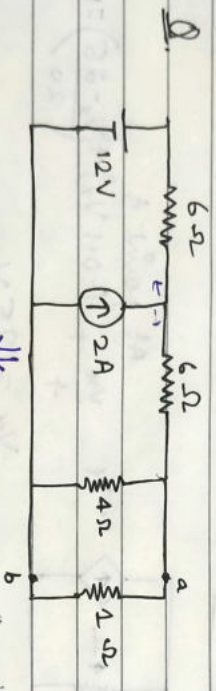
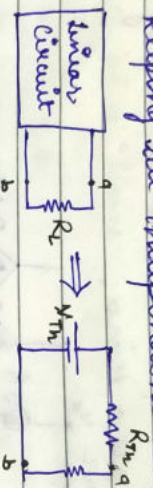
$$V_x = \frac{25}{4} \text{ V}$$

$$\frac{V_x}{20} - 5 + \frac{V_x}{4} - 0.1V_x = 0$$

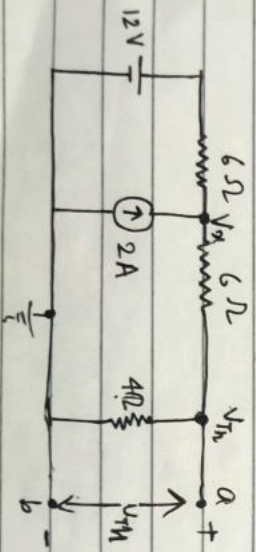
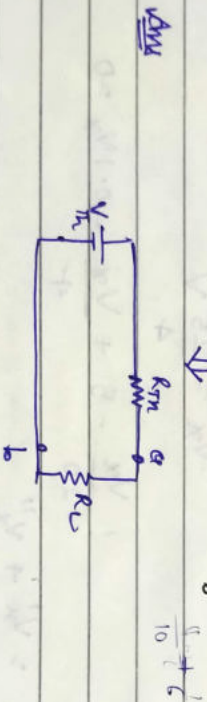
$$V_x = V'_x + V''_x$$

THEVENIN'S THEOREM

It states that a linear two terminal circuit can be replaced by an equivalent circuit consisting of a voltage source V_{th} in series with a resistance R_{th} where V_{th} is the open circuit voltage at that terminal and R_{th} is the equivalent resistance at the terminal keeping all independent sources turned off.



Calculate the current flowing through 1Ω resistance.



Apply nodal analysis at V_x

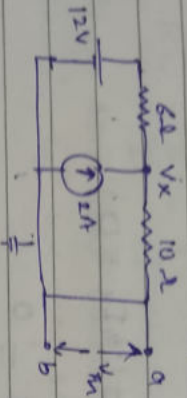
$$\frac{V_x - 12}{6} + \frac{V_x - V_m}{6} - 2 = 0 \quad \text{--- (1)}$$

Apply nodal analysis at V_m

$$\frac{V_m - V_x}{6} + \frac{V_m - 0}{4} + 0.5 = 0$$

$$\frac{V_m - V_x}{6} = -\frac{V_m}{4}$$

OR,



$$\frac{V_x - 12}{6} + \frac{V_x - 0}{10} = 0$$

$$\frac{V_x - 12}{6} + \frac{V_x}{10} = 0$$

$$\frac{V_x - 12}{6} + \frac{V_x}{10} = 0$$

$$\frac{V_x}{3} - 2 - 2 - \frac{V_m}{6} = 0$$

$$\frac{V_m - V_x}{3} = 4$$

$$\frac{2V_m - V_x}{6} = 4$$

$$2V_m - V_x = 24$$

$$-2V_m + 5V_x = 0$$

$$4V_m = 24$$

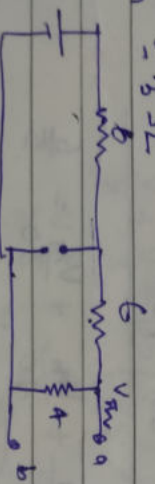
$$V_m = 6V$$

$$\frac{V_m}{6} + \frac{V_x}{6} + \frac{V_m}{4} = 0$$

$$10V_m - V_x = 0$$

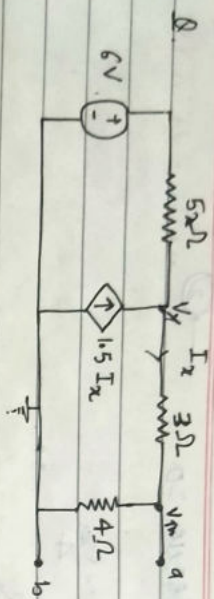
$$5V_m - 2V_x = 0$$

$$R_m = 3\Omega$$



$$(6+6)114$$

$$30 I_L = \frac{V_m}{R_m + R_L} = \frac{6}{3+1} = 1.5A$$



Calculate V_m and R_m across a and b

Ans. applying nodal analysis

$$\frac{V_x - 0}{5} + \frac{V_x - V_m}{3} - 1.5 I_x = 0$$

$$\frac{V_m - 0}{4} + \frac{V_m - V_x}{3} = 0$$

I_x flows from V_x to V_m i.e. higher to lower
 so $\frac{V_x - V_m}{3} = I_x$

$$\frac{V_x - 6}{5} + \frac{V_x - V_m}{3} - \frac{1.5(V_x - V_m)}{3} = 0$$

$$\frac{1}{5} - \frac{1}{5} = -\frac{10}{10} + \frac{2}{3} + \frac{1}{3} = \frac{1}{3}$$

$$-\frac{1}{3} + \frac{1}{3} = 0$$

$$\frac{1}{3} V_x + \frac{V_m}{6} = \frac{6}{5}$$

$$\frac{V_m - 0}{40} + \frac{V_m - V_x}{30} - \frac{V_x}{30} = 0$$

$$\frac{V_m}{6} + \frac{V_m}{40} + \frac{V_m}{30} = \frac{6}{5}$$

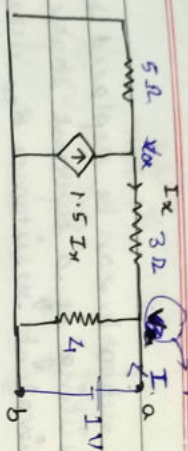
$$\frac{40 \times 30 + 30 \times 6 + 40 \times 6}{6 \times 40 \times 30} V_m = \frac{6}{5}$$

$$\frac{1300}{1620} V_m = \frac{6}{5}$$

$$V_m = 6.2$$

$$V_m = 16V$$

R_{th}

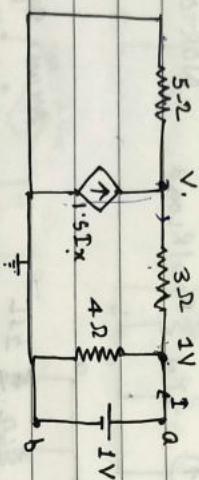


$$R_{th} = \frac{V}{I}$$

Now diff 1V as voltage source is now short circuit. change and we assume 1V

$$R_{th} = \frac{V}{I} = \frac{1}{I}$$

If we somehow calculate I in this branch and with this Ohm's eqⁿ we may calculate R_{th} .



Applying nodal analysis at 1V

$$\frac{1-V}{3} + \frac{1-0}{4} + I = 0$$

At V,

$$\frac{V-0}{5} + \frac{V-1}{3} - 1.5I_x = 0$$

$$\frac{V}{5} + \frac{V-1}{3} - 1.5\left(\frac{V-1}{2}\right) = 0$$

$$\frac{V}{5} + \frac{V-1}{3} + \frac{1}{2} = 1$$

$$\frac{6V + 10V - 15V}{5 \times 3 \times 2} = \frac{1}{3} - \frac{1}{2}$$

$$I = \frac{9}{4} A$$

$$\frac{V}{5 \times 3 \times 2} = \frac{2-3}{2 \times 2}$$

$$\frac{1+5}{3} + \frac{1}{4} = I$$

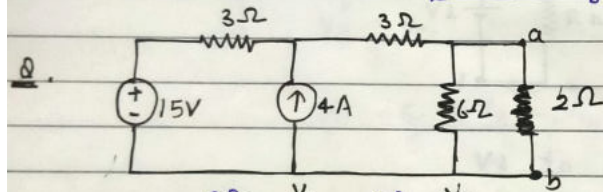
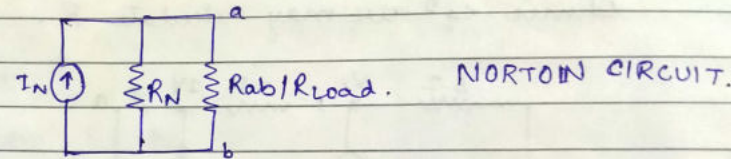
$$\frac{2+1}{4} = I$$

$$V = -5$$

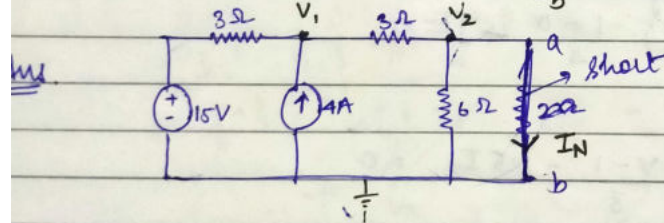
$$R_{th} = \frac{4}{9} = 0.44$$

NORTON'S THEOREM

A linear two terminal network can be replaced by an equivalent circuit consisting of a current source I_N in parallel with the equivalent resistance R_N where I_N is the short circuit current through the load terminal and R_N is the equivalent resistance seen at the load terminal by keeping all the independent sources turned off.



Draw eqt Norton circuit of the given circuit across a, b



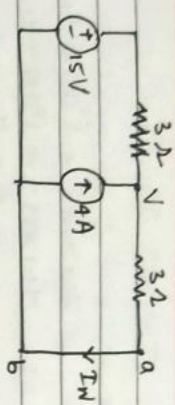
Applying nodal analysis at V_1

$$\frac{V_1 - 15}{3} + \frac{V_1 - V_2}{3} - 4 = 0 \quad \times$$

Applying nodal analysis at V_2

$$\frac{V_2 - V_1}{3} + \frac{V_2 - 0}{6} + I_N = 0 \quad \times$$

If we short ab then it ideally have no resistance and any current at pt. V_2 will all pass through ab and not through 6Ω resistance because current passes through least resistance, hence



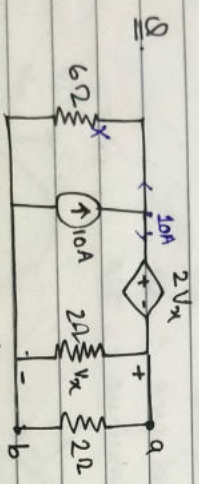
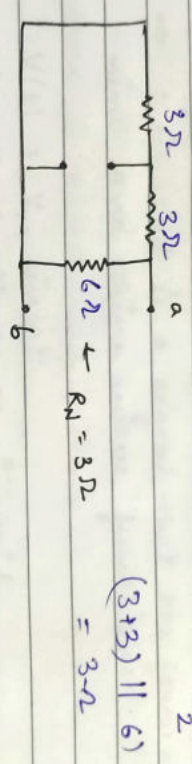
$$\frac{V-15}{3} - 4 + \frac{V-0}{3} = 0$$

$$\frac{V+V}{3} - 5 - 4 = 0$$

$$I_N = \frac{27}{2 \times 3} = \frac{9}{2} = 4.5 \text{ A}$$

$$\frac{2}{3} V = \frac{9}{2}$$

$$V = \frac{27}{4}$$

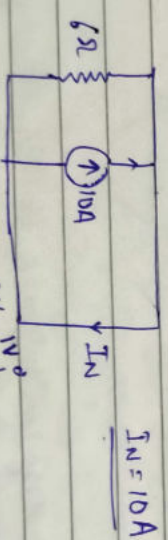


When 3Ω will be taken out or when ab is short then V_x becomes 0 as it was because

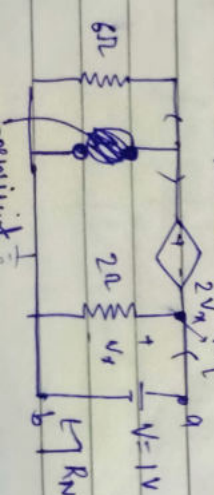
since current flows in the least resistance branch

so when current divides at various dependent source. So there

is 1 all current goes toward is only 1 current source in the $2V_x$ branch as the resistance is least.



$$I_N = 10 \text{ A}$$

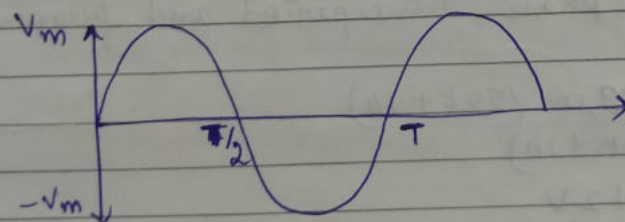
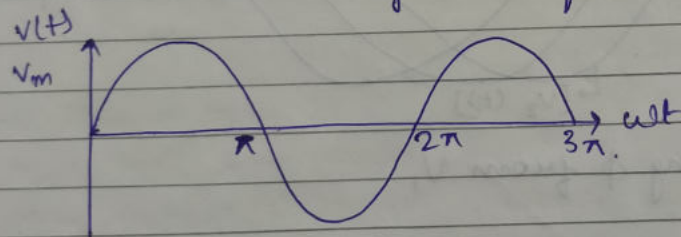


2. AC CIRCUIT

$$\begin{aligned}\sin(\omega t \pm 180^\circ) &= -\sin \omega t \\ \cos(\omega t \pm 180^\circ) &= -\cos \omega t \\ \sin(\omega t \pm 90^\circ) &= \pm \cos \omega t \\ \cos(\omega t \pm 90^\circ) &= \mp \sin \omega t\end{aligned}$$

• Sinusoid $\Rightarrow$ A sinusoid is a signal that has form of sine and cosine wave functions.

Eg. $V(t) = V_m \sin \omega t$
 V_m = Amplitude of sinusoid
 ω = angular frequency
 ωt = argument of sinusoid



$$T = \frac{2\pi}{\omega}$$

unit $\omega = \text{rad/s}$
 $T = \text{seconds}$

Frequency $\Rightarrow$ No. of revolutions per second.

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

Unit = Hz

$$\omega = 2\pi f$$

Let us consider a more general expression of a sinusoid

$$v(t) = V_m \sin(\omega t + \phi)$$

$$\Rightarrow \omega t + \phi = \text{argument} \quad \text{rad / deg.}$$

$$\phi = \text{phase}$$

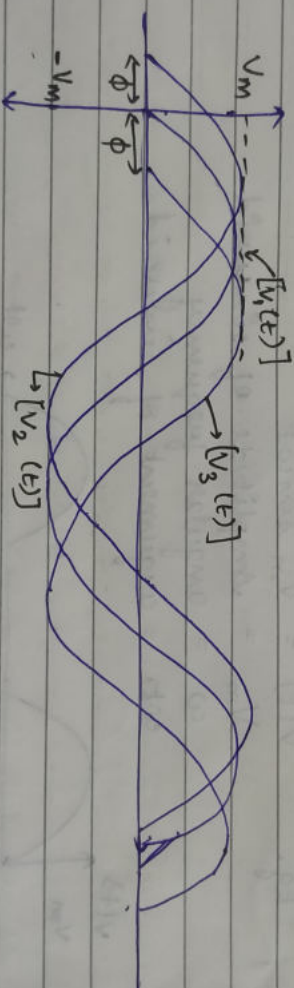
* Definitions (argument, phase difference, etc. from book)

Let us consider two sinusoid voltages

$$V_1 = V_m \sin \omega t$$

$$V_2 = V_m \sin(\omega t + \phi)$$

$$V_3 = V_m \sin(\omega t - \phi) \quad \text{It leads } \phi \text{ by } V_1, \text{ so it moves } \phi \text{ angle earlier}$$



V_3 - lagging ϕ from V_1

Q. Find the amplitude, phase, time period and frequency of given sinusoid

$$V_t = 12 \cos(50t + 10)$$

$$V_t = 12 \cos(50t + 10)$$

$$\text{Amplitude} = 12 \text{ V}$$

$$\text{phase} = 10^\circ$$

$$\text{Angular frequency} = \omega = 50 \text{ rad/s}$$

$$T = \frac{2\pi}{\omega} = 0.1257 \text{ seconds}$$

$$f = \frac{1}{T} = 7.96 \text{ Hz}$$

8. Calculate the phase angle b/w $V_1 = 10 \cos(\omega t + 50^\circ)$

and $V_2 = 12 \sin(\omega t - 10^\circ)$. State which is leading.

Ans. $\Rightarrow V_1 = 10 \sin(\omega t + 50 - 90^\circ) = 10 \sin(\omega t - 40^\circ)$

$V_2 = 12 \sin(\omega t - 10^\circ)$

$\Rightarrow 12 \sin(\omega t - 40 + 30^\circ)$

V_2 is leading V_1 by 30°

OR

$\Rightarrow V_1 = 10 \cos(\omega t + 50 \pm 180^\circ) = 10 \cos(\omega t + 230^\circ)$ or $10 \cos(\omega t - 130^\circ)$

$V_2 = 12 \cos(\omega t - 10 - 90^\circ) = 12 \cos(\omega t - 100^\circ)$
 $12 \cos(\omega t - 130 + 30^\circ)$

V_2 is leading by 30° .

9. Calculate phase angle b/w

$i_1(t) = -4 \sin(377t + 55^\circ)$

$i_2(t) = 5 \cos(377t - 65^\circ)$

Ans. $\Rightarrow i_1(t) = 4 \sin(377t + 55 \pm 180^\circ)$

$= 4 \sin(377t + 235^\circ)$

$i_2(t) = 5 \sin(377t - 65 + 90^\circ)$

$= 5 \sin(377t + 25^\circ)$

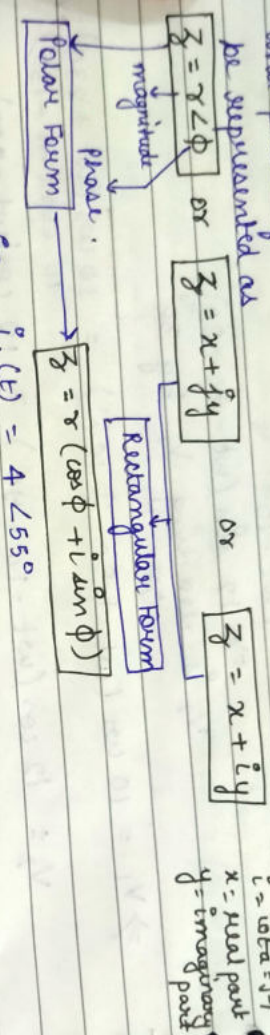
$= 5 \sin(377t - 125 + 180^\circ)$

OR

$i_1(t) = 4 \cos(377t + 55 + 90^\circ)$

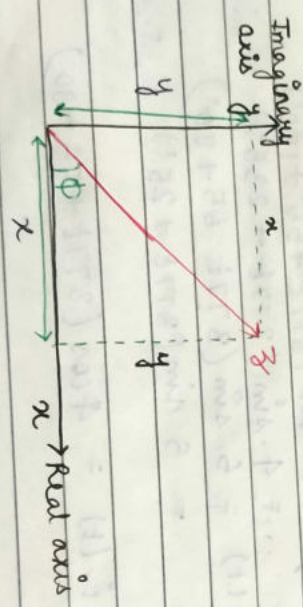
• PHASOR

A phasor is a complex number that represents the amplitude and phase of a sinusoid. A phasor (complex number) Z can be represented as

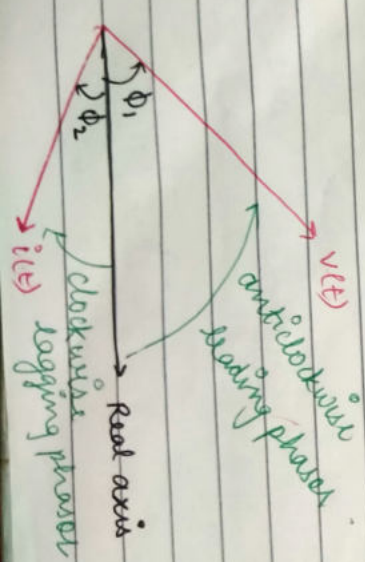


comparing, $Z = x (\cos \phi + i \sin \phi)$ and $Z = x + iy$

we get,
 $x = r \cos \phi$; $y = r \sin \phi$

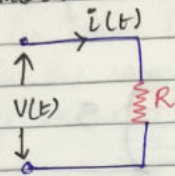


- $V(t) = V \angle \phi_1$
 $i(t) = I \angle -\phi_2$



PHASOR RELATIONSHIP FOR CIRCUIT ELEMENTS

1. Resistor

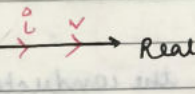


$$V = Ri$$

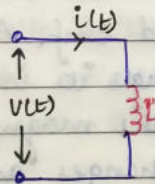
$$\dot{I}(t) = I_m \cos \omega t$$

$$V(t) = I_m \cos(\omega t) R$$

Imaginary



2. Inductor



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

$$\text{or } V = L \frac{di}{dt} \rightarrow (1)$$

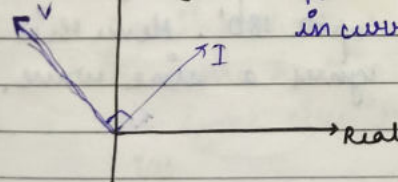
$$i = I_m \cos \omega t$$

$$V = -L I_m \sin(\omega t) \cdot \omega$$

$$V(t) = -L I_m \omega \cos(\omega t + 90^\circ)$$

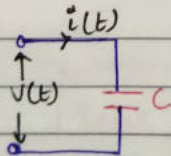
Current lags by 90°

Imaginary



opposes change
in current

3. Capacitor



$$\dot{V} = C \frac{dV}{dt}$$

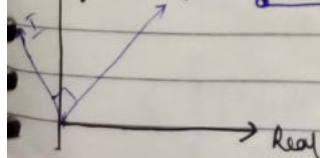
$$V = V_m \cos \omega t$$

$$i = -C \omega V_m \sin \omega t$$

$$i = +C \omega V_m \cos(\omega t + 90^\circ)$$

Current leads by 90°

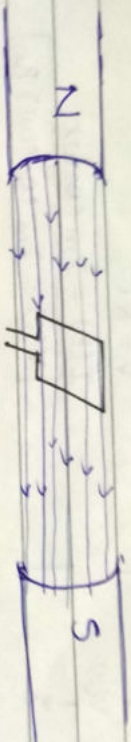
Imag



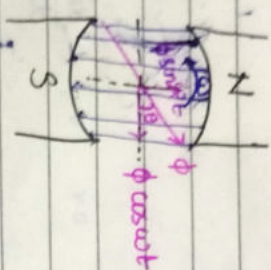
opposes change
in voltage

FARADAY'S LAW OF EMI

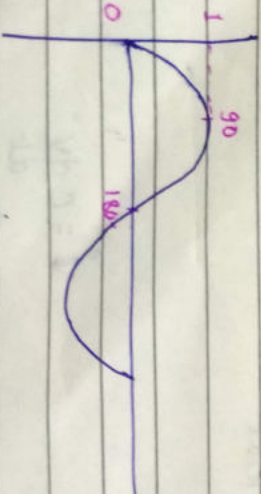
Whenever there is a relative motion between the conductor and the magnetic field in it is kept, an emf is induced in the conductor.



Induced emf is always sinusoidal in nature.



As the conductor is in the direction of magnetic field the magnetic field flux associated with it is 0 as $\theta = 0$ and so is the induced emf. As θ increases or conductor changes its inclination with magnetic field as the magnetic flux associated with it also changes and hence the induced emf. It increases upto $\theta = 90^\circ$ and then decreases again upto 180° . Hence this phenomenon when shown graphically gives a sine wave.



1- AVERAGE VALUE OF A.C.

Average value of A.C. over a half cycle is that value of steady current (d.c.) that would send same amount of charge in same interval of time that would be sent by the d.c. in the same time.

⇒ Average value of A.C. over a complete cycle is 0.

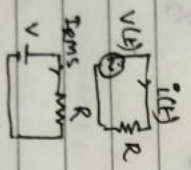
$$I_{avg} = \frac{\text{Area over half cycle}}{\text{Time Period}}$$

$$= \frac{\int_0^{T/2} i(t) dt}{T/2}$$

2- RMS VALUE / ROOT MEAN SQUARE

It is the d.c. current that delivers the same avg. power to a resistor as the periodic current, (a.c.).
OR.

It is given by; that value of steady current which when flowing through a given circuit for a given time produces the same heat as produced by a.c. when flowing through the same circuit for the same time.



$$P = I_{RMS}^2 R \quad \rightarrow (1)$$

$$P = \int_0^T i^2 R dt \quad \rightarrow (2)$$

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

$$I_{RMS} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt}$$

$$(1) = (2)$$

$$\frac{R}{T} \int_0^T i^2 dt = I_{RMS}^2 R$$

$$I_{RMS} = \frac{1}{T} \int_0^T i^2(t) dt$$

For sinusoid

Let $i(t) = I_m \cos \omega t$

$$I_{RMS} = \sqrt{\frac{1}{T} \int_0^T I_m^2 \cos^2 \omega t \, dt}$$

$$= \sqrt{\frac{1}{T} \times I_m^2 \int_0^T (1 + \cos 2\omega t) \, dt}$$

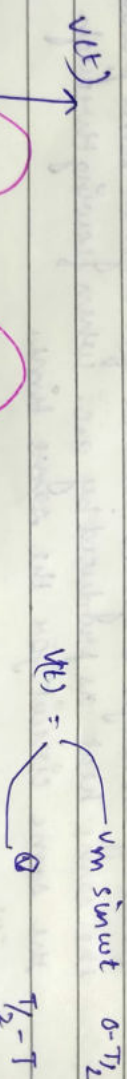
$$= I_m \sqrt{\frac{1}{T} \left[\frac{1}{2} t + \frac{\sin 2\omega t}{2\omega} \right]_0^T}$$

$$= I_m \sqrt{\frac{1}{T} \left[\frac{1}{2} T + \frac{\sin 2\omega T}{2\omega} \right]}$$

$$= I_m \sqrt{\frac{1}{2} + \frac{\sin 2\omega T}{2\omega T}}$$

$$\approx \frac{I_m}{\sqrt{2}}$$

$\omega = \frac{2\pi}{T}$
 $\frac{2 \times 2\pi \times T}{T} \times T$



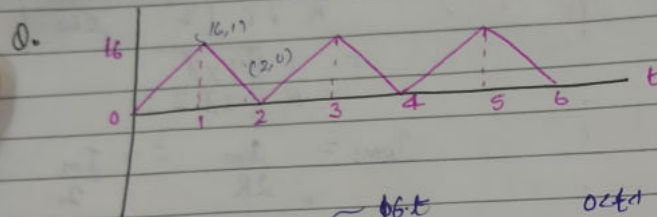
$$I_{RMS} = \sqrt{\frac{1}{T} \int_0^T i^2(t) \, dt}$$

$$= \sqrt{\frac{1}{TR^2} \int_0^{T/2} V_m^2 \sin^2 \omega t \, dt + \int_{T/2}^T 0 \, dt}$$

$$P = I_{RMS}^2 R$$

$$= 100 \times \frac{2}{3} \times 2$$

$$= \frac{400}{3} \text{ watt.}$$



$$y - 0 = 16(x - 2)$$

$$y = 16t - 32$$

Ans.

$$i(t) = \begin{cases} 16t & 0 \leq t < 1 \\ 16(t-2) & 1 \leq t < 2 \end{cases}$$

$$I_{RMS} = \sqrt{\frac{1}{T} \left[\int_0^1 (16t)^2 dt + \int_1^2 (-16(t-2))^2 dt \right]}$$

$$= \sqrt{\frac{1}{2} \left[\left(\frac{16^2}{3} t^3 \right)_0^1 + \left(\frac{16^2}{3} (t-2)^3 \right)_1^2 \right]}$$

$$= \sqrt{\frac{(16)^2}{2} \left[\frac{1}{3} + \frac{1}{3} \right]}$$

$$= \frac{16 \times 2}{\sqrt{3}}$$

$$I_{RMS} = \frac{32}{\sqrt{3}}$$

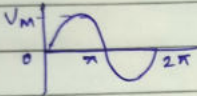
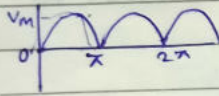
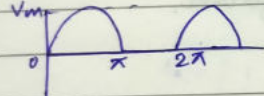
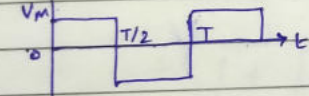
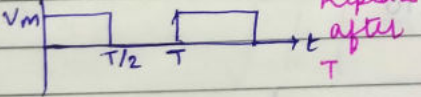
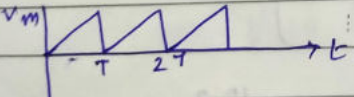
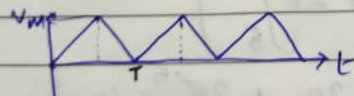
$$\frac{(16)^2}{2} \left[\frac{1}{3} + \frac{8}{3} - 1 + 8 - \frac{1}{3} + 1 - 1 \right]$$

$$\frac{(16)^2}{2} \times \frac{12}{3}$$

ASSIGNMENT 2 :- Calculate Average and RMS value of these wave forms, and also calculate Form Factor.

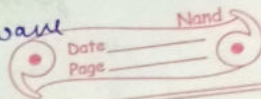
Date _____
Page _____

V_m direct connect
 V_m connect
 V_m connect

Signal	Average	R.M.S
 Pure sinusoid wave	$\frac{2 V_m}{\pi}$	$\frac{V_m}{\sqrt{2}}$
 Full wave rectified waveform	$\frac{2 V_m}{\pi}$	$\frac{V_m}{\sqrt{2}}$
 Half wave rectified waveform	$\frac{V_m}{\pi}$	$\frac{V_m}{2}$
	V_m	V_m
 Repeats after T	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$
	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{3}}$
	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{3}}$

d.c. form factor = 1

form factor tells about the quality of the wave
for good quality it should be more than 1
F.F. for A.C = 1.11



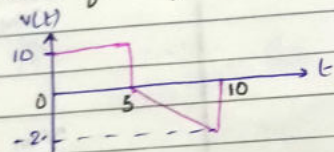
FORM FACTOR

The ratio of r.m.s. value to the avg. value.

OR

It defines the ratio of d.c. of equal power relative to the a.c.

Q. Calculate form factor for the given wave form.



Ans.

$$v(t) = \begin{cases} 10 & 0 \leq t \leq 5 \\ -\frac{2}{5}t + 2 & 5 < t \leq 10 \end{cases}$$

$$V_{avg} = \frac{1}{10} \left[\int_0^5 10 dt + \int_5^{10} \left(-\frac{2}{5}t + 2 \right) dt \right]$$

$$= \frac{1}{10} \left[(10t) \Big|_0^5 + \left[-\frac{2}{5} \cdot \frac{t^2}{2} + 2t \right] \Big|_5^{10} \right]$$

$$= \frac{1}{10} \left[50 + \left(-\frac{100}{5} + 20 + \frac{25}{5} - 10 \right) \right]$$

$$= \frac{1}{10} \left[50 + [10 - 15] \right]$$

$$= \frac{1}{10} [50 - 5]$$

$$= \frac{45}{10}$$

$$= 4.5$$

$$V_{RMS} = \sqrt{\frac{1}{T} \int_0^T V^2(t) dt}$$

$$= \sqrt{\frac{1}{70} \left[\int_0^5 100 dt + \int_5^{10} \left(\frac{2}{5}t + 2 \right)^2 dt \right]}$$

$$= \sqrt{\frac{1}{10} \left[(100t)_0^5 + \left(\frac{2}{25}t^3 + 4t - \frac{4}{5}t^2 \right)_5^{10} \right]}$$

$$= \sqrt{\frac{1}{10} \left[500 + \left[\frac{4 \times 1000}{125 \times 3} + 4 \times 10 - \frac{4 \times 100}{25} - \frac{4 \times 125}{25 \times 3} \right] \right]}$$

$$= \sqrt{\frac{1}{10} \left[500 + \frac{160}{3} + 40 - 80 - \frac{20}{3} - 20 + 20 \right]}$$

$$= \sqrt{\frac{1}{10} \left[500 + \frac{140}{3} \right]}$$

$$= \sqrt{\frac{1}{10} \left[\frac{1380}{1520} + \frac{152}{10 \times 3} \right]}$$

$$= \sqrt{152/3} = 7.012$$

$$\text{Form factor} = \frac{RMS}{Avg} = \frac{7.012}{4.15} = 1.58$$

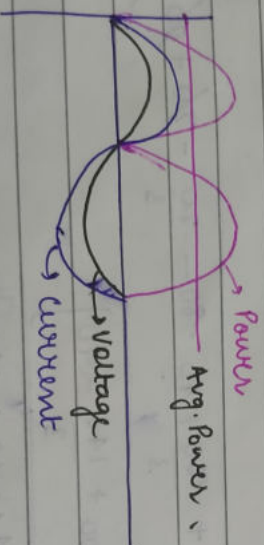
INSTANTANEOUS POWER

The product of instantaneous voltage $v(t)$ across any element and the instantaneous current $i(t)$ through it.

$$P(t) = v(t) \cdot i(t)$$

AVERAGE POWER

The average value of instantaneous power.

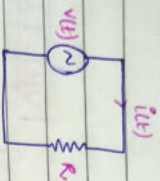


$$P = \frac{1}{T} \int_0^T P(t) dt$$

$$P = \frac{1}{T} \int_0^T P(t) dt$$



RESISTOR



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

$$i(t) = \frac{v(t)}{R}$$

$$= \frac{V_m \sin \omega t}{R}$$

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

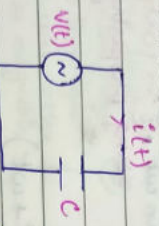
$$P = V_{rms} I_{rms}$$

$$P = \int_0^T v(t) i(t) dt$$

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

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

CAPACITOR



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

$$C = \frac{d(i(t))}{d(v(t))}$$

$$C = \frac{Q}{V} = \frac{dQ}{dV}$$

$$\frac{dv(t)}{dt} = \frac{d(i(t))}{C}$$

$$\frac{d(V_m \sin \omega t)}{dt} = \frac{i(t)}{C}$$

$$V_m \omega \cos \omega t = \frac{i(t)}{C}$$

$$V_m C \omega \sin \omega t = i(t)$$

$$i(t) = V_m C \omega \sin(\omega t - 90^\circ) = V_m C \omega \sin(\omega t - 90^\circ)$$

$$i(t) = V_m C \omega \cos \omega t$$

$$P(t) = \frac{1}{T} \int_0^T v(t) i(t) dt$$

$$= \frac{V_m C \omega}{T} \int_0^T \sin(\omega t - 90^\circ) \cos \omega t dt$$

$$P = 0$$

$$\text{Capacitive Reactance} = \frac{1}{\omega C}$$

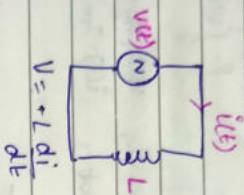
is a $i =$ magnitude = 1
angle = 90°

mag $\angle \Phi_2$
 $\angle \Phi_1 + \Phi_2$
 $\angle \Phi_1 - \Phi_2$

$i = 1 \angle 90^\circ$

Date _____
Page _____
Name _____

INDUCTOR



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

$$v(t) = L \frac{d(i(t))}{dt}$$

$$= L \frac{d(I_m \sin \omega t)}{dt}$$

$$v(t) = L I_m \omega \cos \omega t$$

$$v(t) = I_m L \omega \sin(90^\circ + \omega t)$$

$$= I_m L \omega \sin \omega t \cdot \angle 90^\circ$$

using property

$$P = \frac{1}{T} \int_0^T i(t) v(t) dt$$

$$= \frac{1}{T} \int_0^T I_m \sin \omega t \times I_m L \omega \sin(90^\circ + \omega t) dt$$

$$= \frac{I_m^2 L \omega}{T} \int_0^T \sin \omega t \sin(90^\circ + \omega t) dt$$

$$= \frac{I_m^2 L \omega}{T} \int_0^T 2 \sin \omega t \cos \omega t dt$$

$$= \frac{I_m^2 L \omega}{2T} \int_0^T \sin 2\omega t dt$$

$$= 0$$

$$P = 0$$

$$\text{Inductive Reactance} = (i L \omega) = X_L$$

1. Phase :- The phase of an alternating quantity is defined as the divisional part of a cycle through which the quantity moves forward from a selected origin.

Phase Difference :- The phase difference between the two electrical quantities is defined as the angular phase difference between the max. possible value of the two alternating quantities having the same frequency.

Peak factor :- Peak factor is defined as the ratio of maximum value to rms value of an alternating supply.

$$P.F. = \frac{I_m}{I_{rms}} \text{ or } \frac{E_m}{E_{rms}}$$

Maximum value $\rightarrow$ Peak value / crest value / amplitude

RMS $\rightarrow$ amt. of heat produced by the a.c. will be same when d.c. is supplied through same resistance for same time t .

Avg $\rightarrow$ Avg. of all instantaneous values of current & voltage over one complete cycle

Form factor :- The ratio of r.m.s value to avg. value of an a.c.

$$\text{Form Factor} = \frac{I_{rms}}{I_{av}} \text{ or } \frac{E_{rms}}{E_{av}}$$

Physical Significance of F.F.

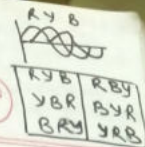
Most of the A.C. multimeters are designed to display the RMS value of a sinusoidal wave. Since RMS value can be difficult to calculate digitally, the avg. value is calculated and result is multiplied to Form Factor.

6/11/19

3 Phase Supply: 3 identified wave forms whose phase difference is 120°



Date: _____
Page: _____

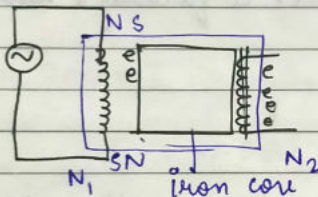


3. TRANSFORMER

Transformer is a static electrical device which transfers electrical energy from one circuit to another through electromagnetic induction without change in frequency. It only steps up or steps down the voltage and current.

$$P_1 = E_1 I_1 \quad P_2 = E_2 I_2$$

The flux lines will now prefer to go through iron core rather than air as magnetic flux follows the path which shows min inductance.



$$E_1 = (e + e \dots)$$

$$E_1 = e N_1$$

$$E_2 = e N_2$$

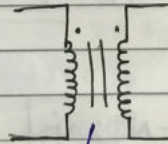
If transformer is setup then no. of turns in secondary coil is more than in primary coil, thus $E_2 > E_1$, so that it means $I_1 > I_2$ (Ideal Transformer $P_1 = P_2$)

$$\text{Now, } \frac{E_1}{E_2} = \frac{e N_1}{e N_2} = \frac{N_1}{N_2} = \frac{100}{200} = \frac{1}{2}$$

$$\frac{N_1}{N_2} = \frac{I_2}{I_1}$$

$$E_2 = 2 E_1$$

Symbol $\rightarrow$



And the dot (.) represents direction of current.

Flux lines represents iron core.

(single phase) (1 ϕ)

* EMF equation of 1 ϕ Transformer:-

Working:-

When an alternating voltage is applied to the transformer's primary side, an alternating flux will set up in the core which links with both primary and secondary winding.

So,

$$\text{let } \phi = \phi_m \sin \omega t$$

Now, acc. to Faraday's law of EMI, the induced emf is directly proportional to the rate of change of flux linkage

$$\Psi = \text{Flux linkage}$$

$$\phi = \text{Flux}$$

$$\boxed{\Psi = N\phi} \rightarrow \text{Total no. of turns}$$

$$E = -\frac{d\Psi}{dt} \quad (\text{acc. to Faraday's law})$$

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

$$= -N \frac{d\phi}{dt}$$

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

$$\boxed{e = -N\phi_m \omega \cos \omega t}$$

$$\omega = \text{angular frequency} \\ = 2\pi f$$

$$\Rightarrow e = -N\phi_m 2\pi f \cos \omega t$$

this will be the max. value of emf which is being induced in primary and secondary coil.

$$\text{Thus, } \boxed{e_{\max} = -N\phi_m 2\pi f}$$

$$\text{Thus, } \boxed{e_{\text{RMS}} = \frac{e_{\max}}{\sqrt{2}}}$$

$$\boxed{e_{\text{RMS}} = 4.44 f \phi_m N}$$

Transformer ka Power factor defines nhi hota hai that means we don't know load side pe kya hai
 Inductor, Capacitor etc

kilovolt Ampere
 transformer

Date _____
 Page _____

Q1. A 125 KVA, having primary voltage of 2000V at 50Hz 182 primary and 40 secondary turns. Neglecting the losses, calculating

- full load primary and secondary winding current
- No load secondary induced emf.
- Max. flux in the core.

Ans. $P = V_1 I_1 = V_2 I_2$ (no losses i.e. $N_1 = 182$
 (ideal transformer) $N_2 = 40$
 $125 \text{ KVA} = P$
 $V_1 = 2000 \text{ V}$

$$125 = 2000 \times I_1 = V_2 I_2$$

$$I_1 = 62.5 \text{ A}$$

Since, $\frac{N_1}{N_2} = \frac{I_2}{I_1}$

$$\Rightarrow \frac{182}{40} = \frac{I_2}{62.5}$$

$$I_2 = \frac{182 \times 62.5}{40}$$

$$= 284.375 \text{ A}$$

$$V_2 I_2 = 125000$$

$$V_2 = \frac{125000}{284.375} = 439.56 \text{ V}$$

Now, $E_1 = 4.4 f \Phi_m N_1$

$$\Phi_m = \frac{2000}{4.4 \times 50 \times 182} = 0.0495 \text{ Wb}$$

Thus a) $I_1 = 62.5 \text{ A}$

$$I_2 = 284.37 \text{ A}$$

b) $V_2 = 439.56 \text{ V}$

c) $\Phi_m = 0.0495 \text{ Wb}$

Date _____
Page _____

* IDEAL TRANSFORMER

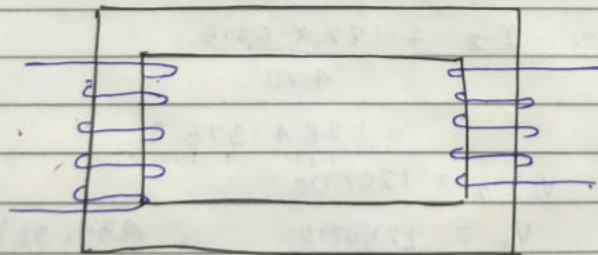
- a) Primary and secondary winding has no resistance
- b) All the flux produced by the primary side will link with the secondary side, i.e., no flux loss.
- c) The permeability of iron core is ∞ .
- d) No losses.

Permeability is the measure of ability of material to support the formation of magnetic field within itself.

* CONSTRUCTION OF TRANSFORMER

Transformer consists of two inductive winding and a laminated steel core. The coils are insulated from each other as well as from steel core.

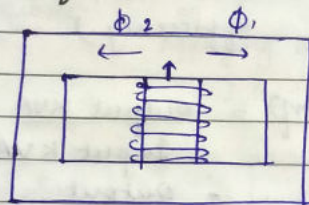
A transformer may also consist of a outer assembly that is known as Tank.



core type transformer.

Based on the construction of core, the transformer may be categorised as:

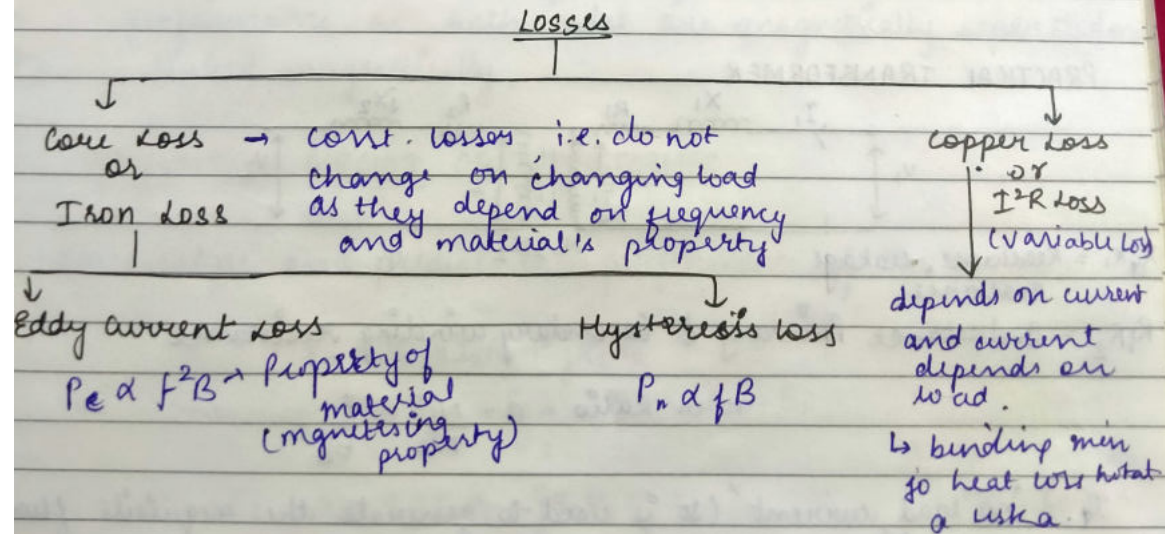
- ① core type transformer
- ② shell type transformer



→ shell type transformer

✧ PRACTICAL TRANSFORMER

Losses:



EFFICIENCY OF TRANSFORMER

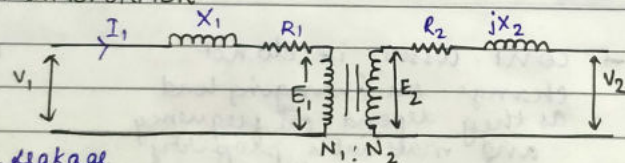
Output power } (for any device the output gained
Input power } w.r.t the input entered is k/a
efficiency)

$$\text{Efficiency } (\eta) = \frac{\text{Output KVA}}{\text{Input KVA}}$$

$$= \frac{\text{Output}}{\text{Losses} + \text{Output}}$$

$$= \frac{\text{Output}}{\text{Output} + W_i + W_c \rightarrow \text{copper loss, iron loss}}$$

PRACTICAL TRANSFORMER



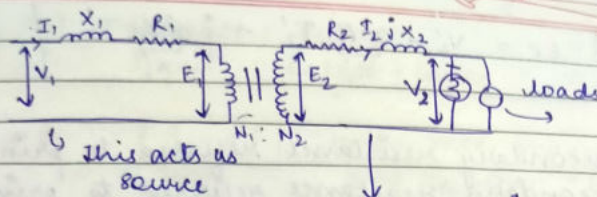
X_1 = Reactance, leakage
Reactance

R_2 = Inductance Primary & Secondary winding resistance

$$\text{Turn Ratio} = a = \frac{N_1}{N_2} = \frac{E_1}{E_2}$$

I_f = 'no load current' (It is used to generate the requisite flux OR 'excitation current' so that emf is induced).

g. when the switch of charger plug is 'ON', supply toh aa rhi h but without charger and phone (secondary) there is no current flowing so jo current aya woh wapas wahi turn ho gaya hence that is called no load current.



Applying KVL in secondary loop.

$$I_2 R_2 + jX_2 I_2 + V_2 - E_2 = 0$$

KVL equation

$$E_2 = I_2 R_2 + jX_2 I_2 + V_2$$

↳ Both primary and secondary sides consists of electrical components but for their combine analysis we need to make an equivalent circuit of transformer that measures its performance as both sides are magnetically separated or linked magnetically.

EQUIVALENT CIRCUIT OF TRANSFORMER

To analyse and predict the performance of the device.

$$E_2 = V_2 + I_2 R_2 + jX_2 I_2$$

$$a = \frac{N_1}{N_2} = \frac{E_1}{E_2}; \quad aE_2 = E_1$$

$$a = \frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{I_2}{I_1}$$

$$aE_2 = aV_2 + aI_2 R_2 + jI_2 X_2 a$$

$$E_1 = V_2' + a^2 \left(\frac{I_2}{a} \right) R_2 + jX_2 \left(\frac{I_2}{a} \right) a^2$$

$$E_1 = V_2' + a^2 I_2' R_2 + a^2 j I_2' X_2$$

$$I_2' = \frac{I_2}{a}$$

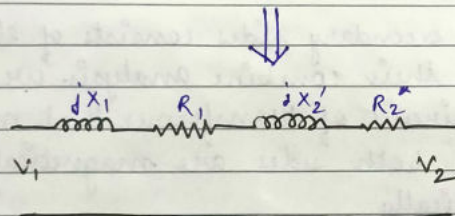
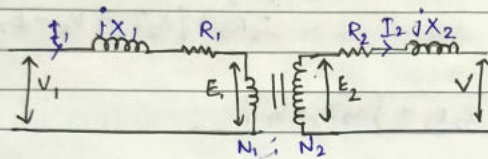
$$I_1 = \frac{I_2}{a} + I_0$$

No load current is lost.
∴ i.e. $\frac{I_2}{a} \neq I_1$ in practical mtd.

$$E_1 = V_1 - \underbrace{I_1 R_1}_{R_1'} - j \underbrace{I_1 X_1}_{X_1'}$$

R_1' = secondary resistance referred to primary side.

X_1' = secondary reactance referred to primary side.



1) A 200 KVA single phase transformer with voltage ratio 6350/660 has the following parameters

Step down transformer
 $R_1 = 1.56 \Omega$ $X_1 = 4.67 \Omega$
 $R_2 = 0.016 \Omega$ $X_2 = 0.048 \Omega$

Calculate resistance and reactance of transformer referred to high voltage side.

Ans. $R_2' = a^2 R_2 = \left(\frac{6350}{660} \right)^2 \times 0.016 = 1.481 \Omega$

$$X_2' = a^2 X_2 = \left(\frac{6350}{660} \right)^2 \times 0.048 = 4.443 \Omega$$

$$R_{eq} = R_1 + R_2' = 3.041 \Omega$$

$$X_{eq} = X_1 + X_2' = 9.113 \Omega$$

hysteresis loss $\propto$ frequency.
eddy current loss $\propto$ (frequency)²

$$P_h \propto f$$

$$P_e \propto f^2$$

$$\begin{aligned} P_h &= k_h B_m f \\ P_e &= k_e B_m^2 f^2 \end{aligned}$$

Max. rate of change of magnetic flux density B_m is constant

$$\text{Efficiency } (\eta) = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{losses}} = \frac{VI \cos \phi}{VI \cos \phi + \omega i + \omega_c}$$

$$P_h \propto f$$

$$P_h = af$$

when max. magnetic flux is B_m and k_h then becomes max. & const. so P_h at max. B_m is only $\propto f$.

Q. In a transformer the core losses 100 W when the frequency is 40 Hz. and the core losses 72 W when the frequency is 30 Hz. Find eddy current and hysteresis loss.

$$\Rightarrow 100 = k_h B_m f + k_e B_m^2 f^2$$

$$2.5 = a$$

$$72 = k_e B_m^2 (30)^2$$

$$0.08 = b$$

$$100 = 120a + 4800b$$

$$b =$$

$$a = 2.1$$

$$\Rightarrow 100 \text{ W} = a(40) + b(3600)$$

$$\Rightarrow 72 \text{ W} = a(30) + b(900)$$

$$a = 2.1$$

$$b = 0.01$$

$$P_h = 2.1 \times 50 = 105 \text{ W}$$

$$P_e = 0.01 \times (50)^2 = 25 \text{ W}$$

$$130$$

$$f \uparrow \quad P_h \uparrow$$

$$\frac{VI \cos \phi}{VI \cos \phi + \omega_i + \omega_e} = \frac{VI \cos \phi}{VI \cos \phi + \omega_i + I^2 R_{eq}} = \text{Efficiency}$$

$$\eta = \frac{V \cos \phi}{V \cos \phi + \omega_i + I^2 R_{eq}}$$

Here 'I' varies so to find max. efficiency we eliminated 'I' term from numerator.

So now $V \cos \phi$ is constant and only 'I' is variable.

As now to find max. condition differentiate it w.r.t 'I' $\frac{d(\eta)}{dI}$. Again numerator and denominator derive

we 'I' term beta so it would have been difficult. $\frac{d(\eta)}{dI} = 0$ gives the max. cond.

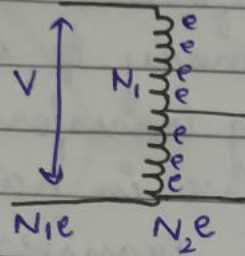
denominator ↓ Efficiency ↑

Condition : $\boxed{\omega_i = I^2 R_{eq}}$

$$\frac{d(\eta)}{dI} \xrightarrow{\text{denominator}} \frac{-\omega_i + R_{eq}}{I^2} = 0$$

$$\boxed{\omega_i = I^2 R_{eq}}$$

Autotransformer



When primary and secondary windings are the same winding so then it is called autotransformer.

ADVANTAGES

- ↳ Copper is same as windings are same.
- ↳ Weight is reduced
- ↳ Losses are minimised.

DISADVANTAGES

- ↳ Electrically isolation is not possible.
 so if suddenly voltage / current bad jaye so that will be reflected in secondary also because windings are same or linked electrically so woh pura ka pura current secondary me jaeega and hence to the loads which are connected to it so that will also get damage.

'PROTECTION'

X

AUTO TRANSFORMER

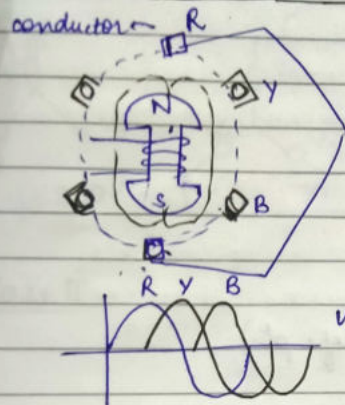
An auto transformer is a transformer in which a part of winding is common to primary & secondary circuit both. Unlike a two winding transformer where the power transfer is only inductive in nature, an auto-transformer offers inductive transfer as well as conductive transfer because of the electrical link provided b/w the two sides. As compared to a two winding transformer for the same duty, ~~ratio~~ an auto transformer utilises less copper and less iron resulting into smaller size and light weight and hence lower cost.

↳ It does not provide electrical isolation and therefore disturbance on one side may quickly spread to other side.

Generator $\rightarrow$ Right hand rule
 motor $\rightarrow$ Left hand rule.

Hand
 Date _____
 Page _____

Three Phase Transformer



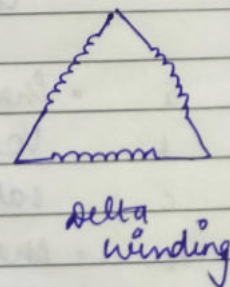
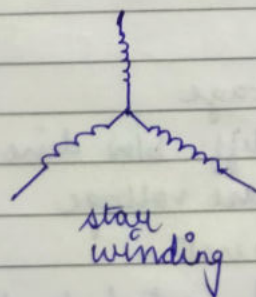
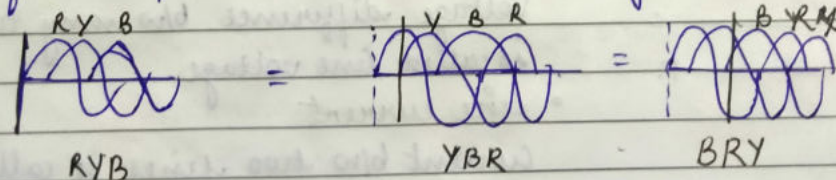
If due to some mechanical force the electromagnet is made to rotate flux will be generated according to Faraday's law.

Wave form of this conductor.
 phase difference

Now if at 120° conductors are placed so waveforms are generated with a phase difference of 120° .

Phase Sequence

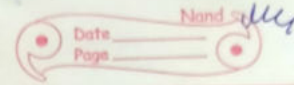
The phase whose maximum is first w.r.t our reference point that is the starting.



$$V_L = \sqrt{3} V_p$$

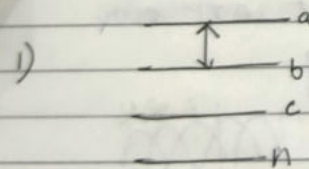
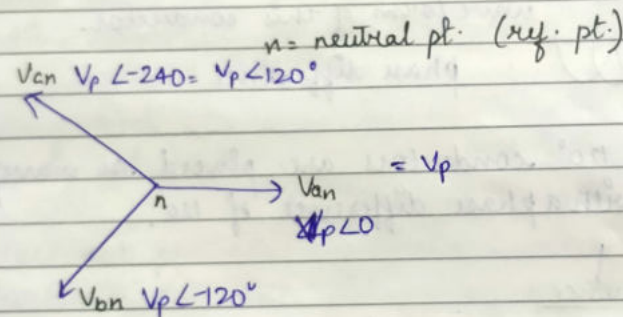
same.

star
delta

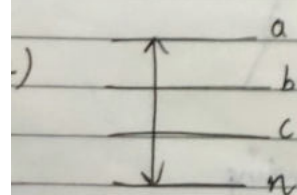


connection

Source	Load
1. Star	Star
2. Star	Delta
3. Delta	Star
4. Delta	Delta



- line voltage
Voltage difference b/w any two lines is called line voltage
- line current
current b/w two lines is called line current



- Phase voltage
Voltage diff. b/w line and neutral is called phase voltage
- Phase current
line and neutral ke beech me current

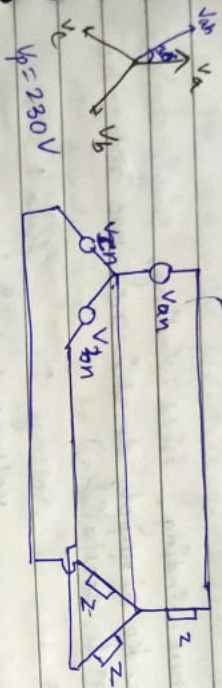
line voltage = 400 V
 phase voltage = 230 V

3 phase

V_{bc} V_{ca} same as V_{ab}



Case I Balance Y-Y connection (star-star connection)



$$\begin{aligned} V_{ab} &= V_{an} - V_{bn} \\ &= V_p \angle 0^\circ - V_p \angle -120^\circ \\ &= V_p \left[1 + \frac{1}{2} + j \frac{\sqrt{3}}{2} \right] \\ &= \sqrt{3} V_p \angle 30^\circ \end{aligned}$$

Case II

Nand
Date _____
Page _____

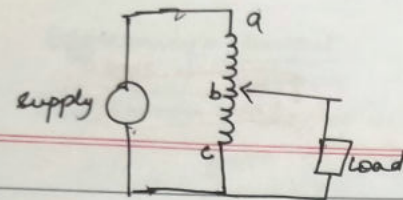
What is Auto Transformer ?

Variac or Auto transformer is an electrical transformer with only one winding. The word auto here means self (greek) not for any automatic mechanism as here a single coil acts alone. In an autotransformer portions of the same windings acts as both primary and secondary windings or sides of a transformer. In contrast an ordinary transformer has separate primary and secondary windings which are not electrically connected. The windings has tapping arrangements where electrical connections are made. Since a part of winding have double duty they often has an advantage of being small in size, lighter, cheaper than ordinary dual winding transformers.

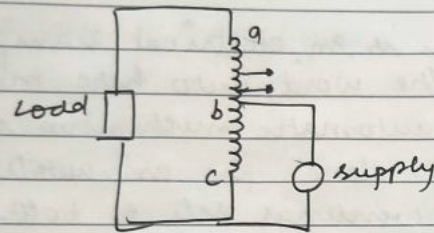
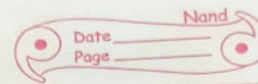
Disadvantage :- No electrical isolation b/w primary & secondary winding circuits

Advantage :- Lower leakage reactance
Lower losses
Lower excitation current
Increase VA rating

Autotransformers are often used to step-up or step-down voltages

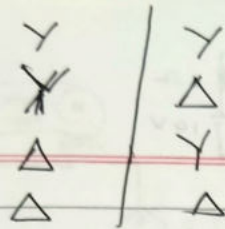


step down

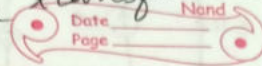


step up

- Variac can generate different levels of voltage.
- And this is achieved by changing the setting of arrangement of tapping at the secondary windings.
- As we connect the Variac with AC mains and switch it ON its primary winding gets energised which can be noticed by the indicators. The voltage at its output terminal depends upon the setting of the knob.
- As we move the knob gradually from its initial position the voltage at the output terminal; rises.
- In this way, with the help of a Variac, we can change the level of voltage from the available value to the desired one.
- It facilitates safe operation and to avoid various faults.

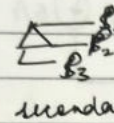


Three phase connections
of a transformer



Step up

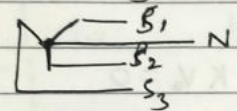
Y/ Δ
Primary



easy to transmit over long distances.

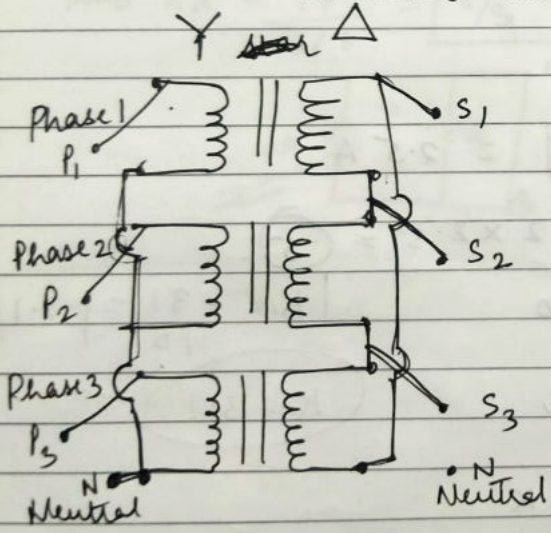
Step down

Y/ Δ



Phase 1
Phase 2
Phase 3

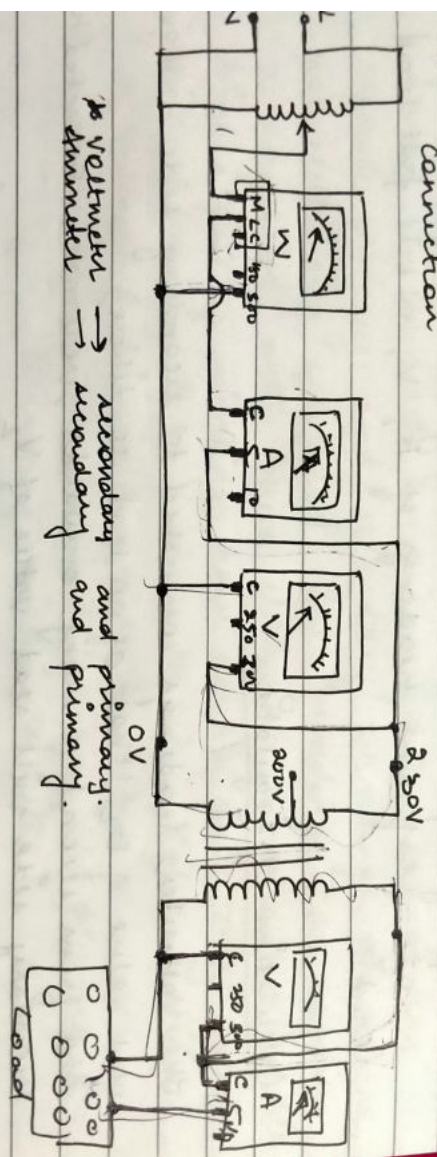
at distribution time we need both phase and neutral so neutral star me milta h



1. Auto Transformer (0-500 V) $1 P_c$
2. Test Transformer $1 P_c$
3. Watten meter (0-300 W) $1 P_c$
4. Ammeter (0-10 A) $2 P_c$
5. Volt meter (0-500 V) $2 P_c$
6. Load

Note:- M and C are short circuited.

Connection



Voltsmeter $\rightarrow$ secondary and primary.
Ammeter $\rightarrow$ secondary and primary.

1 ϕ supply is given. There will Neutral and lead supply transformer ki input side par connect kriga, so output me bhi do miliga ek neutral or phase.
Neutral is

connection
auto transformer ko rated value.
Initial readings
Load is applied
meter reading

Efficiency = $\frac{W_2}{W_1}$
% regulation =

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

Regulation = change in secondary terminal voltage from no load to full load.

Procedure:

- 1) Do the connections as shown
- 2) Have lamp bank as loading system
- 3) Note first readings of A, V, W without connecting any load across secondary of transformer.
- 4) Step by step increase the loading on transformer and note respective readings of A, V, W till full load load.

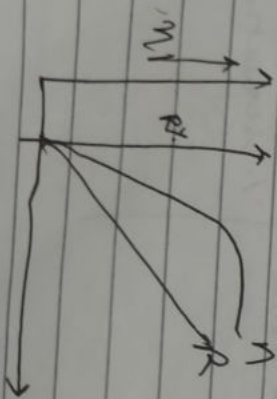
Calculation of regulation

The voltmeter readings connected to secondary side will give you value of E_2 (that of no load condition) and from second reading onwards, voltmeter connected to secondary side will read value of V_2

taking ratio $\frac{E_2 - V_2}{E_2}$ for each reading

Efficiency For each reading we will get input power (W_1) and $W_2 = V_2 \cdot I_2$ (load applied across secondary is purely resistive)

taking $W_2 / W_1 \times 100$ efficiency.



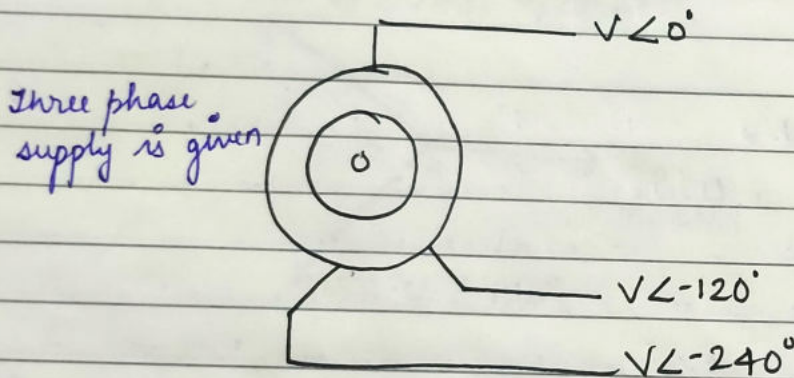
3-Phase Induction Motor.

↳ Stator, Rotor, Armature winding, Field winding, single excited machine, (only stator ko hi supply de rhe a.c. me rotor ko nhi dete the so single excitation)

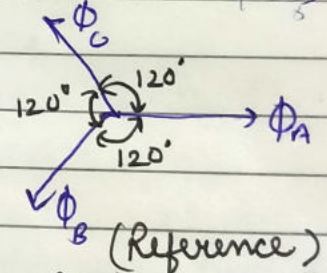
Voltage $\propto$ flux

$V=0$ flux $=0$.

Voltage $\uparrow$ flux $\uparrow$
voltage polarity changes
flux polarity changes



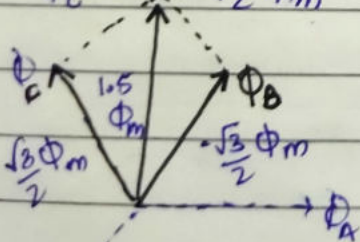
$$\begin{aligned}\Phi_A &= \Phi_m \sin \omega t \\ \Phi_B &= \Phi_m \sin(\omega t - 120^\circ) \\ \Phi_C &= \Phi_m \sin(\omega t - 240^\circ)\end{aligned}$$



concept of Rotating Magnetic Field

$\omega t = 0^\circ$

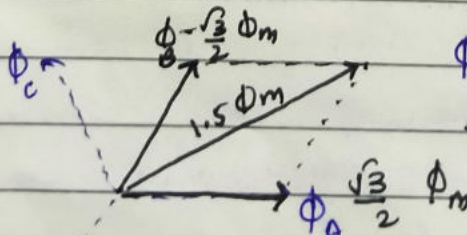
$$\begin{aligned}\Phi_A &= 0 \\ \Phi_B &= -\frac{\sqrt{3}}{2} \Phi_m \\ \Phi_C &= +\frac{\sqrt{3}}{2} \Phi_m\end{aligned}$$



Resultant $= 1.5 \Phi_m$
 $\Phi_A + \Phi_B + \Phi_C$

$\omega t = 60^\circ$

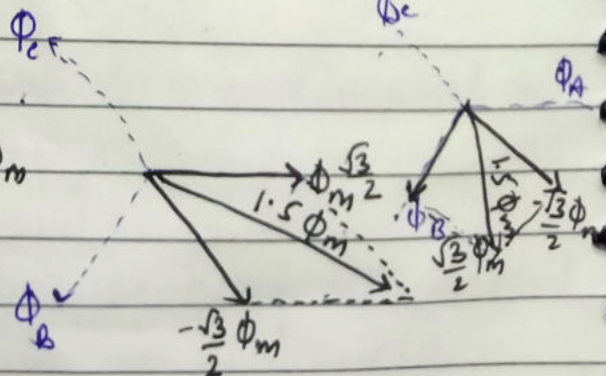
$$\begin{aligned}\Phi_A &= \frac{\sqrt{3}}{2} \Phi_m \\ \Phi_B &= -\frac{\sqrt{3}}{2} \Phi_m \\ \Phi_C &= 0\end{aligned}$$



Resultant $= 1.5 \Phi_m$

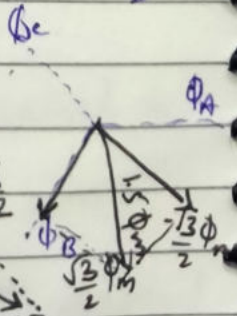
$\omega t = 120^\circ$

$$\begin{aligned}\Phi_A &= \frac{\sqrt{3}}{2} \Phi_m \\ \Phi_B &= 0 \\ \Phi_C &= -\frac{\sqrt{3}}{2} \Phi_m\end{aligned}$$



$\omega t = 180^\circ$

$$\begin{aligned}\Phi_A &= 0 \\ \Phi_B &= \frac{\sqrt{3}}{2} \Phi_m \\ \Phi_C &= -\frac{\sqrt{3}}{2} \Phi_m\end{aligned}$$



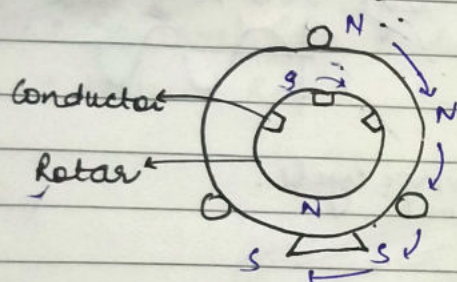
-ve aa raha toh vector banate samay sub se opp. direct ho jayega

2 magnetic field ^{synchronous speed} rotating magnetic field
magnetic field due to rotor ^{rotor short-circuit} magnetic field
conductor.

Date _____
Page _____
Handwritten notes:
relativ motion = speed diff
poles x

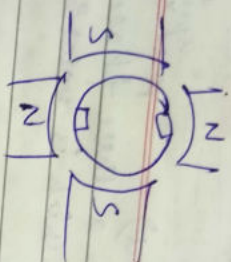
When an induction motor is given a three phase supply a ~~flr~~ magnetic field is generated which is rotating in nature.

No supply is given to rotor. we have first given supply to stator.



When stator is given ^{3 phase} supply, a magnetic field which is rotating in nature is setup. This magnetic field links the armature or rotor windings which have conductors there in so acc. to Faraday's

law whenever there is relative motion b/w conductor and magnetic field there is an emf induced so when the rotor are short current flows due to induced emf due to the rotating magnetic field. Now let us consider N and S are north & south of rotating magnetic field at an instant which is moving with a constant speed called synchronous speed. since current is flow in the conductor so, ^{a second} magnetic field is also generated in there and now consider S and N are south and north of that second magnetic field so S of inside m.f. will attract N of outside m.f. and ~~the path for~~ since the outside m.f. is moving constantly so S of inside m.f. will move after it with a constant speed which is less than synchronous speed because if they both follow each other with same speed so there will be no relative motion and hence they can't move with same speed also if they move with same speed poles will also not developed.



Is se A point tak
half cycle hoga phir A se B aur
B se A point tak
paunchega tab tak
half cycle hoga phir A se B aur



ab 4 poles tak

2 poles $\rightarrow$ 1 comp cycle.

Right side wala S me jaayega tab tak one half cycle phir mehe wala N ke liye one half cycle aur, phir wala



4 poles $\rightarrow$ 2 comp cycle.

$N \Rightarrow$ Revolution per minute

$P \Rightarrow$ No. of poles

$$\text{cycle/rotation} = \frac{P}{2}$$

$$\text{Rotation per sec} = \frac{N}{60}$$

cycle

$$\frac{\text{cycle}}{\text{rotation}} \times \frac{\text{Rotation}}{\text{second}} = \frac{P}{2} \times \frac{N}{60}$$

$$\frac{\text{cycle}}{\text{second}} = \frac{PN}{120} = f \quad (\text{frequency})$$

$$N_s = N_r = \Delta \omega_p$$

$$N_s = \frac{120 f}{P}$$

speed of motor

$N_r =$

$$\% \text{ slip} = \frac{N_s - N_r}{N_s} \times 100$$

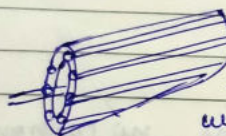
Types of 3-Phase Induction Motor

Question

- Squirrel Cage Induction Motor. (Lab)
- Wound Rotor.

Induction Motor Principle Working

The Squirrel Cage Diagram.



These bars are not st. but they are inclined tangentially by changing their inclination we can get desired relation b/w torque & speed.

When 3 phase supply is given to the stator windings it setup a rotating magnetic field in space. This rotating magnetic field (R.M.F.) has a speed which is known as synchronous speed.

$$N_s = \frac{120f}{P}$$

This rotating magnetic field induces the voltage in rotor bars and hence short circuit current starts flowing through rotor bars. These rotor current generate their self mag. field which will interact with the field of the stator. Now the rotor field will try to oppose its cause so the rotor starts following the rotating magnetic field.

Applications.

1. S.C.I.M. are commonly used in many industrial application. They are particularly suited for application where the motor

must maintain a constant speed and desired for low maintenance.

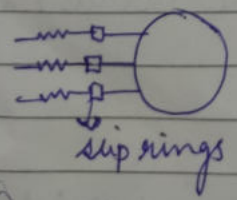
2. These motors are commonly used in
- ↳ Centrifugal Pump
 - ↳ Large blower and fans
 - ↳ Conveyor Belts
 - ↳ Lathe
 - ↳ Machine tool.

Advantages :-

1. Low cost
2. Low maintenance (No slip rings, no carbon brushes)
3. Good speed regulation (constant speed)
4. Efficiency is high (No external R' , slip rings, brushes so losses)
5. Small and Light weight
6. Explosion proof (As there are no brushes, this eliminates the risk of sparking)

Disadvantages :-

1. Less speed control
 2. High starting current.
 3. Poor starting torque.
 4. They are more sensitive to the fluctuation in supply voltage.
- Wound Rotor / slip Ring.



- maintenance ↑
- cost ↑
- efficiency ↓
- construction diff. than S.C.I.M.
- Advantage :-

when we need to minimise starting current.

$N_s - N_r$

A wound rotor motor is a type of induction motor where the rotor windings are connected through slip rings to the external resistance. Adjusting the resistance allows control of the speed - torque characteristic.



Q. A 12 pole 3-phase generator is coupled to an engine running at 500 RPM. It supplies an induction motor which has a full load speed of 1440 RPM. Find the slip and no. of poles in the induction motor.

Ans. ^{generator} $N_s = \frac{120f}{P}$ $f = 50 \text{ Hz}$
 $P \rightarrow \text{Poles (12)}$
 $\downarrow$
 synchronous speed (500)

$\% \text{ Slip} = \frac{N_s - N_r}{N_s} \times 100$ *yeh diff kum hona chahiye hence hit trial*

$N_r = 1440 \text{ RPM}$
 $N_s = \text{synchronous speed.}$

$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ *30/4 = 7.5, 7.5 x 200 = 1500*

$N_r = 1440$	$P = 2$	$P = 4$	$P = 6$	$P = 4$
	1440	1440	1440	
$N_s = 1500$ (approx)	3000	1500	1000	
	diff ↑	suited.	diff ↑	

3000 1440 N.P.
rotation 1 rotation

Principle :- slightly less speed se rotate
karega Rotor

Date _____
Page _____
Nand

$$\% \text{ slip} = \frac{60 - 4}{60} \times 100$$

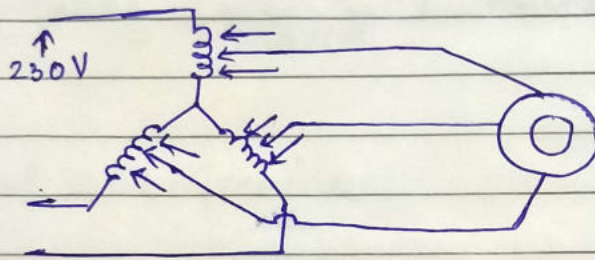
$$\% \text{ slip} = 4\%$$

Whatever is the speed of rotating mag. field use 4%
karm speed hogi rotor ki speed.

• STARTING OF 3 ϕ INDUCTION MOTOR.

1. Direct Online Starting (D.O.L.)
2. Auto transformer starting.

(Lab)

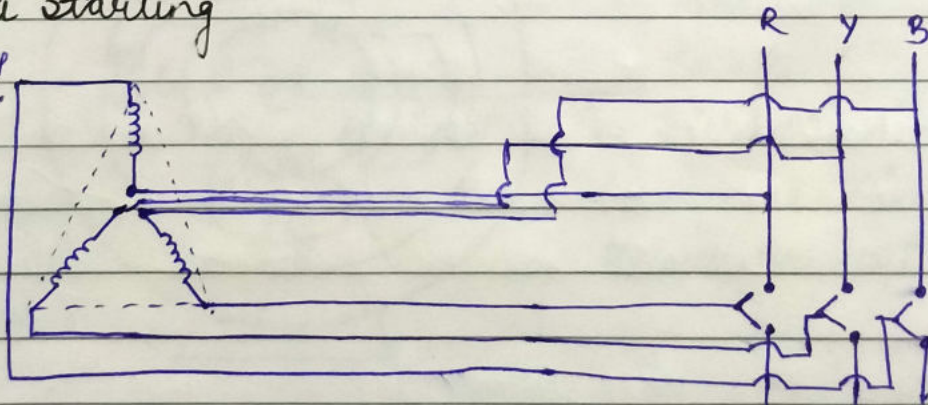


supply via auto transformer.

Starting current ko kum karne ke liye, these are the methods

3. Star-Delta Starting

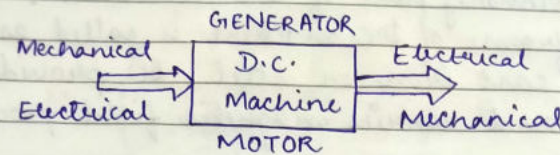
Start cond.
Running cond.



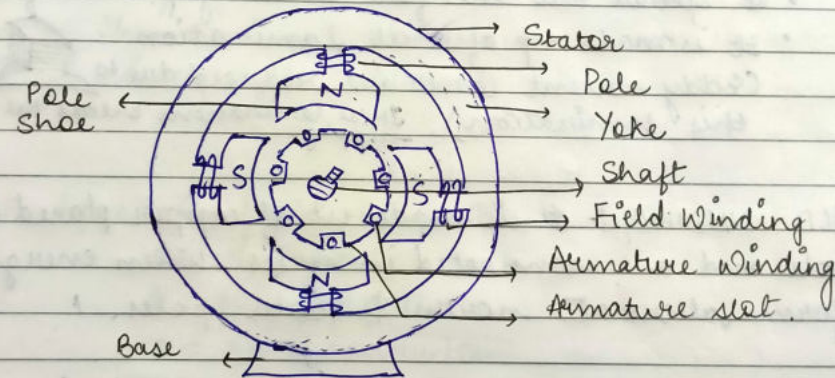
27/1/19

Date _____
Page _____

D.C. Machines



Construction of D.C. Machine.



The device capable of doing continuous electromechanical conversion are known as electrical machine.

A rotating electrical machine which is designed to take the advantage of electromagnetic induction in order to convert mechanical power into electrical power is known as D.C. generator & electrical power to mechanical power is known as D.C. motor.

Field winding (F, FF)
(Winding that generated magnetic field)
Armature winding
(Operation of D.C. generator)

$I_f \downarrow$ just to generate M.F.

$I_a \uparrow$ for operation

Construction :-

Stator $\rightarrow$ Stationary part of D.C. machine.

1. YOKE :- Outer frame of D.C. machine is called as yoke. It is made up of cast iron or steel. It provides mechanical strength and carries magnetic field produces by field winding.

2. POLE & POLE SHOE :- Poles are joined to yoke with the help of welding. Pole carries field windings.

$\hookrightarrow$ Pole shoes serves two purpose

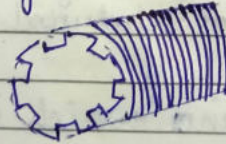
- It spread out the flux in air gap. (uniformly)
- It is made up of steel lamination.

(Eddy current losses are reduced due to this lamination) These laminations breaks the electrical supply.



3. FIELD WINDING :- It is made up of copper placed on each pole and are connected in series. When energised they form alternate north & south poles.

4. ARMATURE CORE AND ARMATURE WINDINGS :- It is the rotating part of d.c. machine, cylindrical in shape with slots to carry armature winding. It is also made up of thin lamina.



5. BASE :- D.C. machine is wound on a base which provides mechanical support.

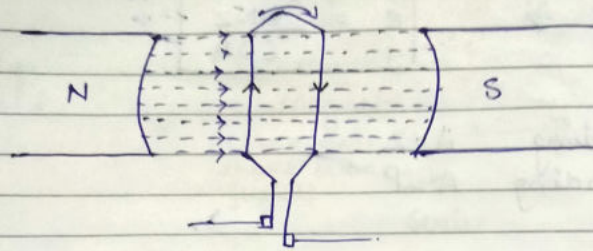
6. SHAFT :- Provides mechanical support to rotating part. Commutator :-

Types :- Armature series Field
 Armature parallel Field
 Armature series/parallel Field

D.C. series motor
 D.C. shunt motor
 D.C. compound motor

Date _____
 Page _____

† WORKING PRINCIPLE OF D.C. GENERATOR.



Fleming's Right Hand Rule :

Forefinger - Flux
 Thumb - Moment
 Middle finger - Current

† EMF Equation of D.C. Generator.

P = No. of pole
 Φ = flux per pole
 Z = No. of conductor
 N = Speed (RPM)
 A = No. of Parallel Path.

Acc. to Faraday's law of EMI avg. emf induced
$$e = \frac{N \frac{d\Phi}{dt}}{60}$$

 Here, N = No. of conductors

emf induced in one conductor = $\frac{d\Phi}{dt}$ $\rightarrow$ $\frac{P\Phi}{60 \times \text{Speed (seconds)}}$
 Total flux = $P\Phi$
 Time, t = $\frac{60}{N \rightarrow \text{Speed}}$ (sec).
 min $\rightarrow$ seconds.

$A =$ jisme parallel paths h utne me divide
hoga chene ek part me emf nikalke
ke liye use divide kr with A .

Date _____
Page _____

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

For total $Z \Rightarrow$

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

For wave winding $A=2$
Lap winding $A=P$

Once we have constructed a D.C. Generator then

$P =$ No. of Poles

$Z =$ No. of conductors

$A =$ No. of parallel paths (Wave / Lap)

Becomes constant, these parameters becomes ~~cons~~
permanent so emf induced

$$E_b \propto \phi N$$

In general, ϕ also almost gets constant so basically

$$E_b \propto N$$

$$\frac{E_1}{E_2} = \frac{\phi_1 \times N_1}{\phi_2 \times N_2}$$

Q. A 4 pole wave ^{wound} ~~form~~ armature has 720 conductors and is rotated at 1000 RPM. If the useful flux is 20 mWb Calculate the generated voltage.

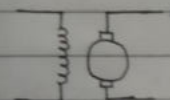
Ans.

$$e = \frac{P\phi NZ}{60A} = \frac{4 \times 20 \times 10^{-3} \times 1000 \times 720}{60 \times 2} = 20 \times 24 \times 1 = 480 \text{ V}$$

Q

TYPES OF D.C. MOTOR

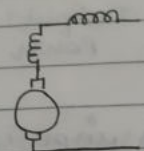
Separately
Excited



Permanent
Magnet

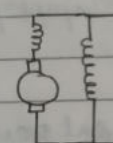
(China wali
short term
jugaad)

D.C.
Series

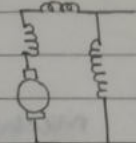


Self
Excited

D.C.
shunt



D.C.
compound



TORQUE EQUATION OF DC MOTOR

$$D = VR$$

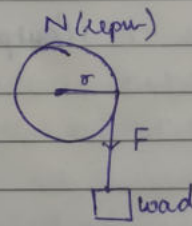
$$P = \frac{V^2}{R}$$

$$P \times 0.4 = 4 \times 10 = 40 \text{ V}$$

$$T = F \times r$$

$$P = \frac{W}{t}$$

$$W = F \cdot d$$



$$\text{Workdone} = F \times 2\pi r$$

$$t = \frac{60}{N}$$

$$P = \frac{\text{Workdone (W)}}{\text{time (t)}} = \frac{(F \times r) 2\pi N}{60}$$

$$= \frac{F \times 2\pi r}{60/N}$$

$$= \frac{F (2\pi r) N}{60}$$

$$P = \frac{2\pi N T}{60}$$

Torque

Torque, $T = \frac{P \times 60}{2\pi N}$



Output Power

Using K.V.L

$$V = E_b + I_a R_a$$

$$V I_a = E_b I_a + I_a^2 R_a$$

Input power Output power Power loss.

Mechanical power is inputted and we have converted it to electrical equivalent ($E_b I_a$) so we can replace P with $E_b I_a$.

$$P_{\text{output}} = E_b I_a$$

$$T = \frac{E_b I_a \times 60}{2\pi N} \quad \text{Nm}$$

$$E_b = \frac{P \Phi N Z}{60 A}$$

$$T = \frac{P \Phi Z}{60 A} \times \frac{I_a 60}{2\pi N}$$

$$T = \frac{P \Phi Z I_a}{2\pi A}$$

After construction:

$$T = \frac{1}{2\pi} \times \underbrace{\frac{Z P \Phi}{A}}_{\text{constant}} \times I_a$$

$$T \propto \Phi I_a$$

$$\frac{T_2}{T_1} = \frac{\Phi_2}{\Phi_1} \times \frac{I_{a2}}{I_{a1}}$$

- To lower down the starting current (ext. resistance is connected in series)

$$V = E_b + I_a R_a$$

$$\boxed{\frac{V - E_b}{R_a} = I_a} \rightarrow \textcircled{1}$$

$$E_b = \frac{P \Phi N Z}{60 A} \rightarrow \textcircled{2} \text{ In starting } E_b = 0 \text{ because speed of motor (N) = 0.}$$

So only V wala term is left in eq $\textcircled{1}$ so $V \uparrow I_a \uparrow$ hence to lower down $I_a \downarrow$ we need to increase $R_a \uparrow$.

Disadvantage:

- ↳ If suddenly power is lost so once when motor is normally operated and R_a (ext resistance) is 0 and power is lost motor drip hoke wapas start ho jae then the whole voltage comes across motor as resistance is 0 so there is a risk of damage due to starting high current in case of drip or sudden power loss and gain as we are not there to supervise the motor 24x7.

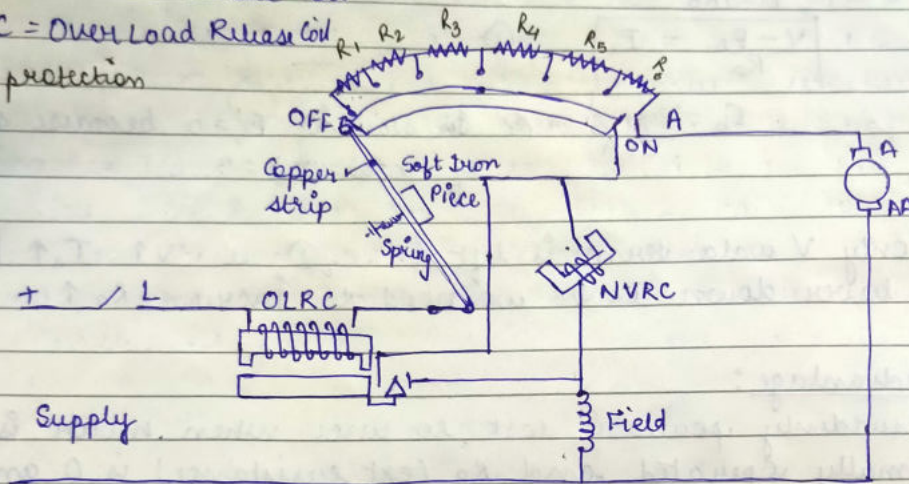
So in that case we use 3-point starter method.

3- Point Starter

NVRC = No Volt Release coil

OLRC = Over Load Release coil

For protection



When the OFF handle is touched to resistance wala part the supply current coming passes through this part which is connected to armature resistance and hence current is reduced. And the copper strip conducts current to the plane copper part which is connected to field winding. Now when motor starts operating normally the resistance is ↓ $\frac{(V - E_b)}{R_a} = I_a$ as E_b is ↑ and hence $(V - E_b)$ ↓ so R_a ↓ to maintain that ratio.

Field winding me current remains constant because field winding ka resistance ↑ and no effect of back emf so supply same hai and uska resistance humne zyada rakha h so that current constant रहे and kum bhi रहे.

NVRC is used for protection ki jab power is lost then starting current ko kum karne liye to resistance

It is also use to lower the resistance later.

change handle to full resistance pt. per release ka deta. It's working:

We know acc. to Faraday's law of Induction whenever current flows, magnetic field is generated. So NVRC me jab current ata h, magnetic field is generated hence it acts as a magnet and the soft iron piece is attracted towards it and so is the handle due to this movement the resistance through armature winding path is lowered and lastly when the motor is normally operated and we need resistance to be 0, so the soft iron piece gets fitted in the slot of NVRC and $R_a = 0$. When there is no voltage, no supply so current = 0, magnetism = 0 and it releases the handle and it comes to the full resistance value. Spring helps to attach piece to the handle and helps in the sudden movement to come back to OFF position.

OLRC

It is a protection coil which protects our motor from ~~case~~ damage in case of over load current. The OLRC winding are also magnetised (very low) till the rated value but when over load supply is given magnetism is increased and then it is capable of attracting the iron strip beneath it. Due to movement of iron strip towards the OLRC slot due to attraction the circuit gets short and the motor is protected.

$$\phi \propto \frac{1}{N}$$

Agar speed (N) badhane hai, toh ϕ ko kum karne padega (flux ko kum karne ke liye current ko kum karne padega)

Date _____
Page _____
Nand

I can be reduced by adding resistance. Let's again run field ke field ke saath series me R laga dete h toh pure route me I kam ho jata h jise N/R me hui I kam hojayege toh uska magnetism bhi kam hojayege, jiske karan N/R kahi kabhi zero power hui toh soft iron piece ko remove kar deta h, toh R ki value jhi se full hojayege that is OFF position That is why we use 4-point starter where ~~the~~ resistance aag se laga dete h field winding ke saath

:- most imp. part of motor is commutator (ac $\rightarrow$ dc) but when it is in motor then only it operates not in the stator that's why we can't interchange armature winding in stator and field winding in stator.

DC Machine

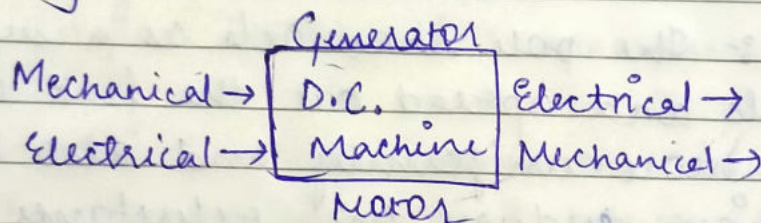
Constructional features

Construction wise a d.c. machine has four main parts

- 1) Field magnet
- 2) Armature
- 3) Commutator
- 4) Brush



Actually a d.c. machine means a d.c. motor or d.c. generator. Constructionally both are same.



- 1.) Field system :- to create uniform magnetic field within which the armature rotates. This magnetic field can be created by Permanent magnet or Electromagnet.
 - Electromagnets are preferred in comparison to permanent magnets on account of their greater magnetic effects, and field strength regulation which can be ^{achieved} controlled by controlling magnetising currents.
 - It further consists of four main parts :-

→ Frame :- It is also called yoke, cylindrical in shape. The yoke acts as a cover frame for the machine and carries the magnetic flux produced by the poles. Since the field is stationary there is no need to use laminated yoke for

Date _____
Page _____
Nand

normal machine. In small machines cast iron yokes are used because of cheapness, but in large machines it is made up of fabricated steel due to its high permeability.

→ Pole core :- Pole core of a d.c. machine is usually of circular section and is used to carry magnetising coils or coils of insulated wires carrying the field current. Pole cores are usually not laminated and generally made of cast steel. In some they are laminated and insulated from each other.

→ Pole shoe :- The pole shoe acts as a support to the field coils and spread out the flux over ^{the} armature periphery more uniformly and also being of larger cross section reduces the reluctance of ^{the} magnetic path. The pole shoes are always laminated to avoid heating and eddy current losses caused by the fluctuations in the flux distribution on the pole face due to movements of armature slots & teeth.

→ Armature :- The purpose of armature is to rotate the conductors in the uniform magnetic field. It consists of coil of insulated wire wound around an iron and so arranged that electric currents are induced in these wires when the armature is rotated in the magnetic field. In addition to providing support to the armature coils it also provides low reluctance path to magnetic flux.

The armature core is made up of thin laminations of steel. Each lamination is insulated from other by thin coating of

Armature is made up of silicon steel because in d.c. machines armature induces a.c. hence effect of hysteresis and eddy currents should be avoided.

- Slots :- The slots are either d'cut or punched on the outer periphery of the circular core normally open type and usually placed parallel to the axis of armature. but are also kept at small acute angles to avoid vibrations of teeth

↳ Commutator :- The commutator is a form of rotating switch placed between the armature and the external circuit and so arranged that it will reverse the connections of the external circuit at the instant of each reversal of current in the armature coil. It is cylindrical in shape and is built up of high conducting material.
a.c. $\rightarrow$ d.c.

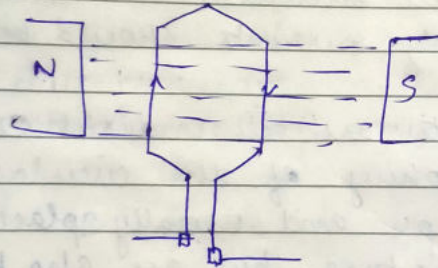
↳ Brushes :- The function of brushes is to collect current from the commutator and supply it to external load circuit of a d.c. generator. In case of d.c. motor brushes supply current to the commutator. Rectangular in shape & rest on commutator

A DC machine is an electromechanical energy conversion device

DC Motor

Date _____
Page _____

The working principle of DC machine is when electric current flows through a coil within a magnetic field, and ~~then the~~ magnetic force is experienced and this magnetic force generates a torque which rotates the ~~dc motor~~ coil.



Right Hand Rule

F.F. → Flux

Thumb → Moment

M.F. → Current

EMF Equation of a DC Machine (Generator)

Date _____
Page _____

Let

P = No. of poles of the machine

Φ = Flux per pole in Wb

Z = Total no. of armature conductors

N = Speed of armature in revolution per min (r.p.m.)

A = No. of parallel paths in the armature winding

As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf rotation is called generated emf or armature emf and is denoted as $E_g = E_b$. In case of motor, the emf rotation is known as Back emf or counter emf and represented as $E_r = E_b$. The expression for both operations, i.e., the generator as well as for motor is

In one revolution of the armature, the flux cut by one conductor is given as

$$\text{Flux cut by one conductor} = P\Phi \text{ Wb} \quad \text{--- (1)}$$

Time taken to complete one revolution is given as

$$t = \frac{60}{N} \quad \text{--- (2)}$$

$$N = \frac{60}{t}$$

Therefore the average induced emf in one conductor is

$$e = \frac{P\Phi}{t} \quad \text{--- (3)}$$

$$E = \frac{P\Phi N}{60} \text{ volts} \quad \text{--- (4)}$$

The no. of conductors connected in series in each parallel path = Z/A

Therefore the average induced emf across each parallel

path of the armature terminals is given as -

$$E = \frac{P\Phi N}{60} \times \frac{Z}{A} = \frac{PZ\Phi N}{60A} \text{ volts}$$

$$E = \frac{PZ\Phi n}{A} \rightarrow \text{Speed in (ops)} \quad n = \frac{N}{60}$$

For a given machine, the no. of poles and no. of conductors per parallel path ($\frac{Z}{A}$) are constant. Hence,

$$E = K\Phi n \text{ const}$$

$$K = \frac{PZ}{A}$$

Therefore the average induced emf equation can be written as

$$E \propto \Phi n$$

$$E \propto \Phi N$$

$$E \propto \Phi \omega$$

$$n = \frac{N}{60}$$

$$\omega = \frac{2\pi N}{60}$$

∝ speed and flux per pole

The polarity of induced emf depends upon the direction of magnetic field and the direction of rotation. If either of the two is reverse the polarity changes, but if two are reversed the polarity remains unchanged.

This induced emf is a fundamental phenomenon of all the DC machines whether they are working as motor or generator.

If the machine is generator

$$E_g = \frac{PZ\Phi N}{60} \text{ volts}$$

$$E_g = \text{Generated Emf}$$

If the dc machine is working as motor,

$$E_b = \frac{PZ\Phi N}{60} \text{ volts}$$

$$E_b = \text{Back emf}$$

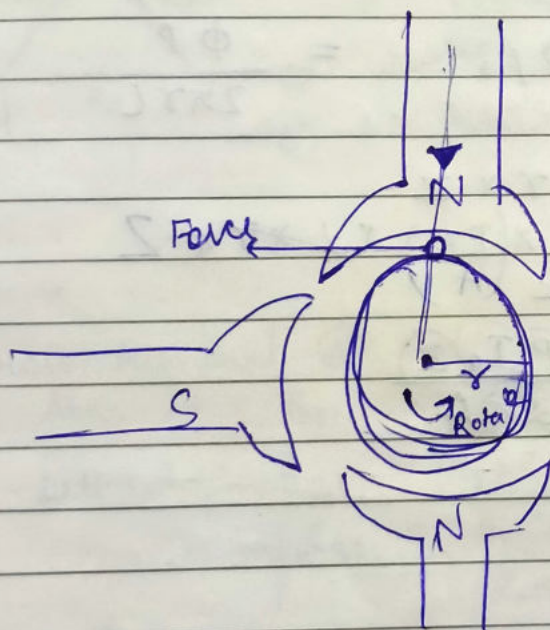
because it acts opposite to the supply voltage.

Torque Equation

Torque acting on a body is quantitatively defined as the product of force acting on the body and perpendicular distance of the line of action of force from the axis of rotation.

i.e. $T = F \times r \sin \theta$

Torque is the tendency of a force to cause a rotational motion or to bring about a change in rotational motion.



Each conductor experiences a force and the conductors lie near the surface of the rotor at a common radius from its centre. Hence torque is produced at the circumference of rotor and rotor starts rotating.

Since all conductors experience equal force and are equidistant from centre therefore

Total torque = torque on one conductor $\times$ total number of conductors.

Let

r = average armature radius

L = effective length of each conductor

Z = total number of armature conductors

A = number of parallel paths

I_a = Armature current

I = current through each conductor = I_a/A

B = average flux density

Φ = flux per pole

P = no. of pole

a = cross sectional area of flux path per pole at radius r .
($2\pi r l / P$)

Force on each conductor = BIL

Torque due to one conductor = $BILr$

As

$$I = I_a/A \quad B = \Phi/a \quad = \frac{\Phi P}{2\pi r l}$$

$$T_a = BILr \times Z$$

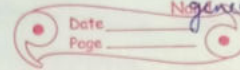
$$= \frac{\Phi P}{2\pi r l} \times \left(\frac{I_a}{A} \right) \times L \times r \times Z$$

$$= \frac{\Phi P I_a Z}{2\pi A}$$

$$\boxed{T_a \propto \Phi I_a}$$

Sync - Time greek word
asynchronous motor = induction motor

back emf armature filament
motor commutator
ac $\rightarrow$ dc
generator dc $\rightarrow$ ac



ALTERNATOR / SYNCHRONOUS GENERATOR

Any machine

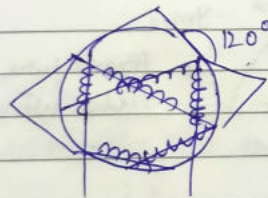
D.C. Induction Motor

1. Stator $\rightarrow$ Field winding
2. Rotor $\rightarrow$ Armature winding
3. Commutator present-
(ac $\rightarrow$ dc)

Synchronous Generator

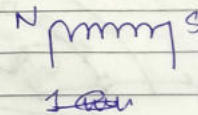
- Stator $\rightarrow$ Armature winding
Rotor $\rightarrow$ Field winding
No commutator

Armature



- $\rightarrow$ 6 winding
- $\rightarrow$ Heavy current (due to back emf)
- $\rightarrow$ Heavy winding
- $\rightarrow$ Heavy weight
- $\rightarrow$ Large size

Field

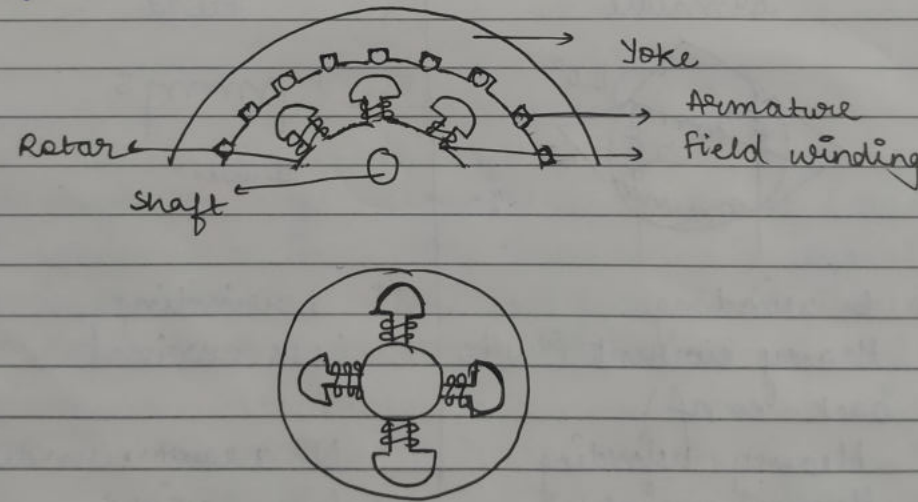


- $\rightarrow$ 1 winding
- $\rightarrow$ Less current
- $\rightarrow$ No heavy winding
- $\rightarrow$ Less weight
- $\rightarrow$ Small size

In generator there is no such use of commutator like in motor (so it is necessary to have armature winding in rotor) so hum kahi pe bhi Armature or field winding rakh sakte h generator me so applying logic, we put field winding in rotor in generator because of its advantages over

Armature winding. This will also benefit us as:
it is cost effective and cum loss honge.

Agar size bada h toh armature winding ko gumane me bhi zyada energy lagegi so we go for field winding. For eg. there are two generator 10kg and 1kg and water waves apply force on both on then 10kg me zyada force lagna padega & generation is less so weight kum karne ke liye field winding → rotor. And stator toh static rahega so use farak nhi padega.



Extra power is required to overcome inertia of the rotor. So field winding in rotor. (Less size, less wt.)

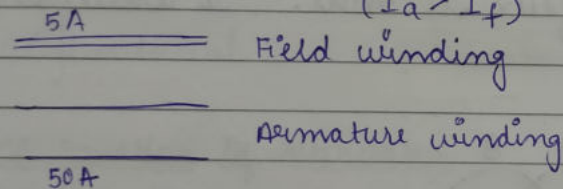
Types Of Motor

1. Salient Pole
2. Round / cylindrical.

Construction

1. Stator
2. Rotor

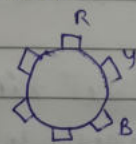
Winding : 1 Field winding :- induces magnetic field
2. Armature winding :- back emf, armature I.
($I_a > I_f$)



Connection : Brushes are used



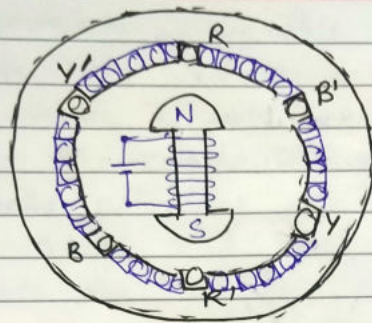
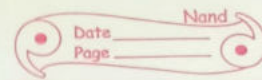
Field winding
(2 brushes)



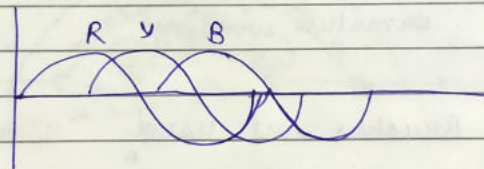
Armature winding
(6 brushes)

- ↳ Losses are more
- ↳ Sparking Risk
- ↳ Friction + heating.

Rotate me dc supply diya so as to make permanent N and S which then produces magnetic field.



First jab R' wali ke influence me h so rate of change of flux = 0 as $\sin 0^\circ = 0$ and when it is $\perp$ then rate of change of flux is max. So wave form is obtained as



No. of poles decide kitni speed se chalega.
because frequency here in India is constant = 50Hz.

R and B' ke beech me space empty h so flux loss / flux waste ho rha h so wah par bhi kuch conductors laga dete h so then waveform ka ek combined waveform aayega. These conductors are placed so that humara flux waste na ho.

* Agar single phase hota, only R, R' toh joh baaki extra flux hai side me vo waste hi hota hai But 3 phase me baaki jo alag conductors

like B and Y rakhe hote hai toh in a way
no utilise hojata hai for eg:- Agar Deepak
ek class me ek bachhe ko padhate hai aur
60 bago ko padhate hai, toh knowledge toh utna
hi share hota hai, bas utilization badh
jata hai, everyone is benefitted.

• Types Of Generator

- ↳ Salient
- ↳ Cylindrical.

• EMF Equation Of Alternator

P = No. of pole

Φ = Useful flux per pole

Z = No. of conductor

T = No. of turns per phase = $\frac{Z}{\text{phase 2}}$

N = Speed in RPM = $\frac{120f}{P}$

f = frequency (Hz)

Since the flux per pole is Φ each stator conductor cuts the
flux $P\Phi$. As per Faraday's law

$$e = \frac{d\Phi}{dt} = \frac{P\Phi}{60/N}$$

$$e = \frac{PN\Phi}{60}$$

$$e = \frac{120f\Phi}{60}$$

$$\boxed{e = 2f\Phi}$$

$$N = \frac{120f}{P}$$

$$PN = 120f$$

$$e_{\text{avg in one conductor}} = 2 f \phi$$

$$e_{\text{avg/phase in all conductors}} = Z \times 2 \phi f$$

$$e_r = 2 Z \phi f$$

$$e = 2 T \phi f$$

$$T = \frac{Zp}{2}$$

$$\text{Form Factor} = \frac{\text{RMS value}}{\text{Average}} \quad \text{for sin wave}$$

$$\text{RMS} = \text{FF} \times \text{avg}$$

$$= 1.11 \times 4 \phi f T$$

$$E_{\text{RMS/phase}} = 4.44 \phi f T$$

- $K_c = \text{coil factor} = 0.99$ > har question me aag hoga.
- $K_d = \text{distributing factor} = 0.929$
- $K_w = K_c K_d$ winding factor

↳ coil factor = connection of coil / manner in which coil is connected

↳ distributing factor - conductor ek dusre ke 180° pe hone chahiye but hum thoda phase shift karke use design karte h so that emf reduce ho jaye.

Yeh factors motor ke kuch drawbacks / faults in designing ke karn hote h.

$$E_{\text{RMS/phase}} = K_w \times 4.44 \phi f T$$

delta $E_L = E_p$
 star $E_L = \sqrt{3} E_p$

* A three phase 50Hz, 8 Pole Alternator, has star connected winding with 120 slots and 8 conductors/slot. The flux per pole is 0.05 Wb. Determine the phase and line voltages ($K_c = 1$ $K_d = 0.9567$)

Ans. 3 Ph $f = 50 \text{ Hz}$ $P = 8 \text{ Pole}$ $Z = 960$ $\phi = 0.05 \text{ Wb}$
 $T_p = \frac{Z_p}{\frac{P}{2}} = \frac{960}{8} = 320$ $= 160$ $K_c = 1$
 $K_d = 0.9567$

$$E_{\text{rms/phase}} = K \times 4.44 \phi f T$$

$$= 1 \times 0.9567 \times 4.44 \times 0.05 \times 50 \times 160$$

$$= 1699.099 \text{ V.}$$

$$E_{\text{line}} = \sqrt{3} E_{\text{phase}}$$

$$= \sqrt{3} \times 1699.099$$

$$= 2939.441 \text{ V.}$$

* A three phase 6 pole star connected alternator revolves at 1000 RPM. The stator has 90 slots and 8 conductors per slot. The flux per pole is 0.05 Wb. Calculate the voltage generated by the machine if $K_w = 0.96$.

Ans. 3 phase

$P = 6 \text{ pole}$

$f = 50 \text{ Hz}$

$\phi = 0.05 \text{ Wb}$

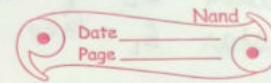
$Z = 90 \times 8 = 720$

$Z_p = 240$

$T = \frac{Z_p}{2} = \frac{240}{2} = 120$

$\frac{1000}{60} = \frac{120}{60} f$ $f = 50 \text{ Hz}$

KVA - 100

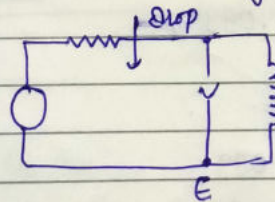


$$\begin{aligned} E_{\text{rms/phase}} &= 0.96 \times 4.44 \times 0.05 \times 50 \times 120 \\ &= 1278.72 \text{ V} \end{aligned}$$

$$\begin{aligned} E_{\text{line}} &= \sqrt{3} \times 1278.72 \\ &= 2212.1856 \end{aligned}$$

Voltage Regulation :-

$$\frac{\text{No load Voltage} - \text{Full load Voltage}}{\text{Full load Voltage}} = \text{Voltage Regulation}$$



$$V.R. = \frac{|E| - |V|}{|V|} \times 100$$

$$V.R. = \frac{E - V}{V} \times 100$$

V.R. depends on Power factor of load connected (Resistance, Inductor, Capacitance)

V.R. kmm generator of good quality.

7. (b) EMF Equation of a cylindrical rotor alternator

- Let
- ϕ = Useful flux per pole in wb.
 - P = Total no. of poles
 - Z_p = Total no. of conductors or coil sides in series per phase
 - T_p = total no. of coils or turns per phase
 - n = speed of rotation of rotor in rps.
 - f = frequency of generated voltage (Hz)
 - N = speed of rotation of rotor in rpm

Since ϕ per pole so total flux = $P\phi$

Now, avg. value of generated voltage per conductor
 = $\frac{\text{flux cut per revolution}}{\text{Time taken for one revolution}}$

n revolutions $\rightarrow$ 1 second
 1 revolution $\rightarrow$ $1/n$ seconds.

$$E_{av/\text{conductor}} = \frac{P\phi}{1/n} = P\phi n$$

We know

$$f = \frac{PN}{120} = \frac{Pn}{2} \quad \text{as } \boxed{n = \frac{N}{60}}$$

$$Pn = 2f$$

$$E_{av} = 2f\phi$$

Since there are Z_p conductors so

$$Z_p = 2T_p$$

$$E_{av/\text{phase}} = 2f\phi Z_p$$

$$E_{av/\text{phase}} = 4f\phi T_p$$

Form factor

$$k_f = \frac{\text{rms value}}{\text{average value}}$$

$$E_{rms/\text{phase}} = E_{av/\text{phase}} \times k_f$$

$$E_{rms} = 1.11 \times 4f\phi T_p = 4.44 f\phi T_p$$

Assumption :-

- a) coils have got full pitch.
- b) All the conductors are concentrated in one stator slot

Voltage Regulation

- The voltage regulation of a synchronous generator is the rise in voltage at the terminals when the load is reduced from full-load rated value to zero, speed and field current remaining constant.

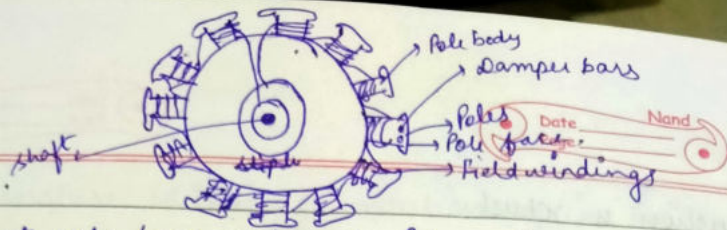
It is expressed as a fraction or a percentage.

$$\text{Per unit voltage regulation} = \frac{|E_a| - |V|}{|V|}$$

$$\text{Percentage voltage regulation} = \frac{|E_a| - |V|}{|V|} \times 100$$

The voltage regulation depends upon the power factor of the load. For unity and lagging power factors, there is always a voltage drop with the increase in load, but for a certain leading power factor, the full load regulation is zero. In this case, the terminal voltage is the same for both full load & no load condition. At lower leading power factors the voltage rises with the increase of load and the regulation is -ve.

unity	lagging	$V \downarrow$	$I \uparrow$	
	leading	0		terminal $V = \text{same}$
low	leading	$V \uparrow$	$I \uparrow$	$R (-ve)$



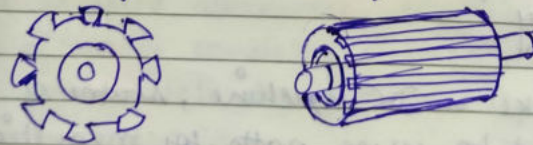
• Salient

In salient pole type rotor consist of large number of projected poles mounted on a magnetic wheel. The projected poles are made up from laminations of steel. The rotor winding is provided on these poles and it is supported by pole shoes.

- Salient pole rotors have large diameters and shorter axial lengths.
- They are generally used in lower speed electrical machines (100-1500 rpm).
- As rotor speed is lowered, more no. of poles are required to attain the required frequency, as $N_s = \frac{120f}{P}$. Typically no. of salient poles is between 4 to 60.
- Flux distribution is relatively poor than non-salient hence the generated emf waveform is not as good as cylindrical.
- Salient pole rotors generally need damper bars to prevent rotor oscillations during operations.
- Mostly used in hydro power plants.
- Slip rings carry current to or from the rotating part of the machine via carbon brushes.

• Non-Salient (Cylindrical)

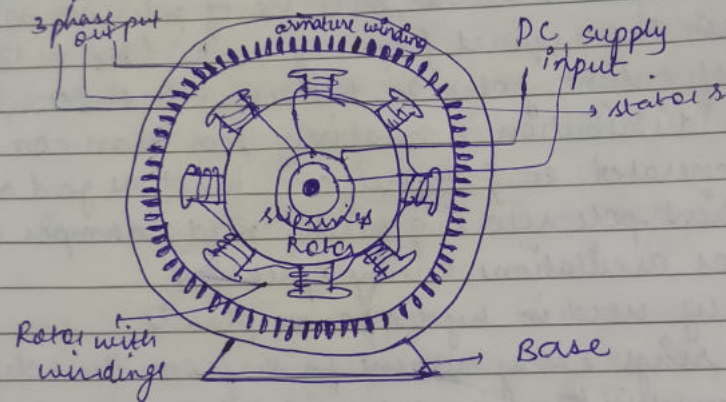
These are cylindrical in shape having parallel slots on it to place rotor windings. made up of solid steel.



- They have smaller diameter but having longer axial length.
- Used in high speed machine (1500-3000 rpm).
- Windage loss as well as noise is less.

- Construction is robust
- No. of poles 2 or 4
- Damper windings are not needed
- Flux distribution is sinusoidal hence gives better emf waveform
- Used gas, nuclear and thermal power plants

Construction of an alternator



Main parts of the alternator $\begin{cases} \text{Stator} \\ \text{Rotor} \end{cases}$

But in alternators field exciters are rotating and armature coil is stationary

1.) Stator :- Unlike in DC machine, stator of an alternator is not meant to serve path for magnetic flux. Instead the stator is used for holding armature winding. The stator core is made up of lamination of steel alloys or magnetic iron to minimise eddy current losses.

• Why Armature winding is stationary in An Alternator?

- ▶ At high voltages, it is easier to insulate stationary armature winding which may be as high as 30kV or more.
- ▶ The high voltage output can be directly taken out from the stationary armature. Whereas, for a rotary armature there will be large brush contact drop at higher voltages also the sparking of the brush surface will also occur.
- ▶ Field exciter winding is placed in rotor and the low d.c. voltage can be transferred easily.
- ▶ The armature winding can be braced well, so as to prevent deformation caused by the high centrifugal force.

2) Rotor :- Two types of rotor -

Salient

It is used in low and medium speed alternator.

This type of rotor consists of large no. of projected poles bolted on a magnetic wheel. These poles are laminated to minimise the eddy current losses. They are large in diameter and short in axial length.

Cylindrical

Used in high speed alternators, especially turbo alternators.

This type of rotor consists of a smooth and solid steel cylinder having slots along the outer periphery. Field windings are placed in these slots -

The DC supply is given to the rotor winding through the slip rings and brushes arrangements.

$$E = 4.44 \phi f T_p$$

$P = 10 \text{ poles}$ 3 phase

$$Z_p = 108 \text{ slots} \times 12$$

$$\phi = 0.06 \text{ wb}$$

$$f = \frac{PN_s}{60}$$

$$50 \times 120 = 10 \times N_s$$

$$600 \text{ rpm}$$

$$E_{\text{rms/phase}} = 4.44 \times 0.06 \times 50 \times 108 \times 12$$

$$3 \times 2$$

(7)

b.) Water turbines are relatively low speed machine as compared to steam turbines. So alternators driven by water turbines adopt a low synchronous speed and therefore they have to accommodate a large number of poles on its rotor periphery. Also due to low speed, there is no restriction on diameter. Now there is any compulsion to use round rotor for mechanical integrity. Thus all turbines are salient pole type. Thus all turbines are salient pole type. Thus all turbines are salient pole type.

$$N_s = \frac{120 \times 1.5}{15} = 22.5 \text{ rpm}$$

$$N_s = \frac{120 \times 50}{81} = 750 \text{ rpm}$$

$$\text{slip speed} = N_s - N_r$$