ch-1 Generation of Electricity Date- 19-04-21

Introduction :-

Energy is the basic necessity for the economic development of a country.

-> The availability of huge amount of energy in the modern times has resulted in a shorter working day, higher agricultural and industrial production, a healthier and more balanced diet and better transportation facilities.

-> Energy exists in different forms in nature but the most important form is the electrical energy.

Importance of electrical energy :-

The present-day advancement in science and tenchnology has made it possible to convert electrical energy into any desired form.

Electrical energy is superior to all other forms of energy due to the following reasons-

i) Convenient Form :-

-> Electrical energy is a very convenient form of energy.

-> It can be easily converted in to other forms of energy.

-> For example, if we want to convert electrical energy in to heat, the only thing to be done is to pass electrical current through a wire of high resistance e.g. a heater, similarly, electrical energy can be converted in to light (electric bulbs)

ii) **Easy control:-**

-> The electrically operated machines have simple and convienient starting, control and operation.

iii) **Greater flexibility:-**

-> One important reason for preferring electrical energy is the flexibility that it offers.

-> It can be easily transported from one place to another with the help of conductors.

iv) **cheapness:-**

-> Electrical energy is much cheaper than other forms of energy.

-> Thus it is overall economical to use this form of energy for domestic, commercial and industrial purpose.

v) **Cleanliness:-**

-> Electrical energy is not associated with smoke, fumes or poisonous gases.

-> Therefore, it's use ensures cleanliness and healthy conditions.

vi) **High transmission efficiency:-**

-> The consumers of electrical energy are generally situated quite away form the centres of it's production.

-> The electrical energy can be transmitted convenientlly and efficiently from the centres of generation to the consumers with the help of overhead conductors known as transmission lines.

20-04-21

Different types of energy sources :-

a) Solid fuel (coal)
b) liquid fuel (petrol, Diesel)
c) Gases fuel (Nutral Gas)
d) water (Hydro power)
e) Nuclear
f) sun
g) Tide
h) wind
i) Biogas.

Thermal power plant :-

-> A generating system which convert heat energy of coal combustion in to electrical energy is known as steam power station or Thermal power station.

-> A steam power station basically works on the Rankine cycle.

-> steam is provides in the boiler by utilizing the heat of coal the steam is then expened in the turbine and condensed in a condenser to be fed into the boiler again.

-> The steam turbines drives the alternator which convert mechanical energy from the turbine into electrical energy.

-> This type of power station is suitable where coal and water are available and a large amount of electric power is to be generated.

Advantages:-

i) The fuel is used to quite cheap.
ii) Less initial cost is compare to the other station.

iii) It requires less space compare to the hydro power plant.

Disadvantages! –

-) It pollutes the atmosphere due to the production of large amount of ashes and smokes.

-) It is costlier in running charge compare to the hydro power plant.

Selection sites! –

-) Availability of water.

-) Supply of fuel.

-) Transportation facilities.

-) Types and cost of land

-) Distance from populated area

Schematic Arrangement of steam power station

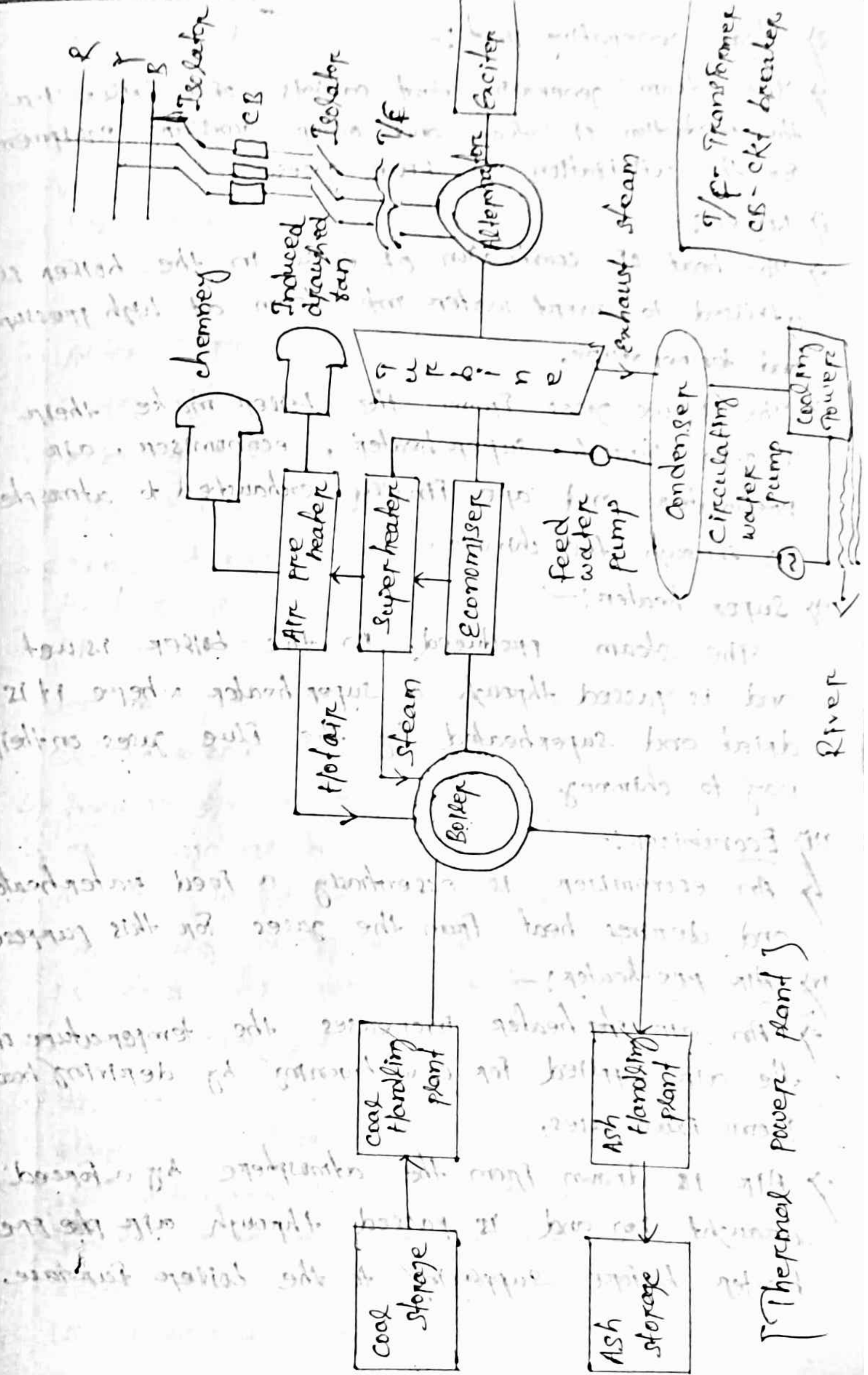
The whole arrangement can be divided into the following stages for the sake of simplicity –

1) Coal and ash handling arrangement
2) Steam generating plant
3) Steam turbine
4) Alternator
5) Feed water
6) Cooling arrangement.

1) Coal and ash handling plant! –

-) The coal is transported to the power station by road or rail and is stored in the coal storage plant.

-) From the coal storage plant, coal is devided to the coal handling plant where it is pulverised in order to increase it's surface exposure



[Thermal power plant]

2) Steam generating plant :-

-> The steam generating plant consists of a boiler for the production of steam and other auxiliary equipment for the utilization of flue gases.

i) Boiler :-

-> The heat of combustion of coal in the boiler is utilised to convert water into steam at high pressure and temperature.

-> The flue gases from the boiler make their journey through super heater, economiser, air pre-heater and are finally exhausted to atmosphere through the chimney.

ii) Super heater :-

The steam produced in the boiler is wet and is passed through a super heater where it is dried and superheated by the flue gases on their way to chimney.

iii) Economiser :-

-> An economiser is essentially a feed water heater and derives heat from the gases for this purpose.

iv) Air pre-heater :-

-> An air pre heater increases the temperature of the air supplied for coal burning by deriving heat from flue gases.

-> Air is drawn from the atmosphere by a forced draught fan and is passed through air pre-heater before supplying to the boiler furnace.

3) Steam turbine :-

-> The dry and super heated steam from the super-heater is fed to the steam turbine through main valve.

-> The heat energy of steam when passing over the blades of turbine is converted into mechanical energy.

-> After giving heat energy to the turbine, the steam is exhausted to the condenser.

4) Alternator :-

-> The steam turbine is coupled to an alternator.

-> The alternator converts mechanical energy of turbine in to electrical energy.

-> The electrical output from the alternator is delivered to the bus bars through transformer, ckt breakers and isolators.

5) Feed water :-

-> The condensate from the condenser is used as feed water to the boiler.

-> The feed water on it's way to the boiler is heated by water heaters and economiser.

6) Cooling arrangement :-

-> In order to improve the efficiency of the plant, the steam exhausted from the turbine is condensed by the mean of condenser.

-> Water is drawn from a natural source of supply such as a river, canal or lake and is circulated through the condenser.

Thermal efficiency :-

The ratio of heat equivalent of mechanical energy transmitted to the turbine shaft to the heat of combustion of coal is known as thermal efficiency of steam power station.

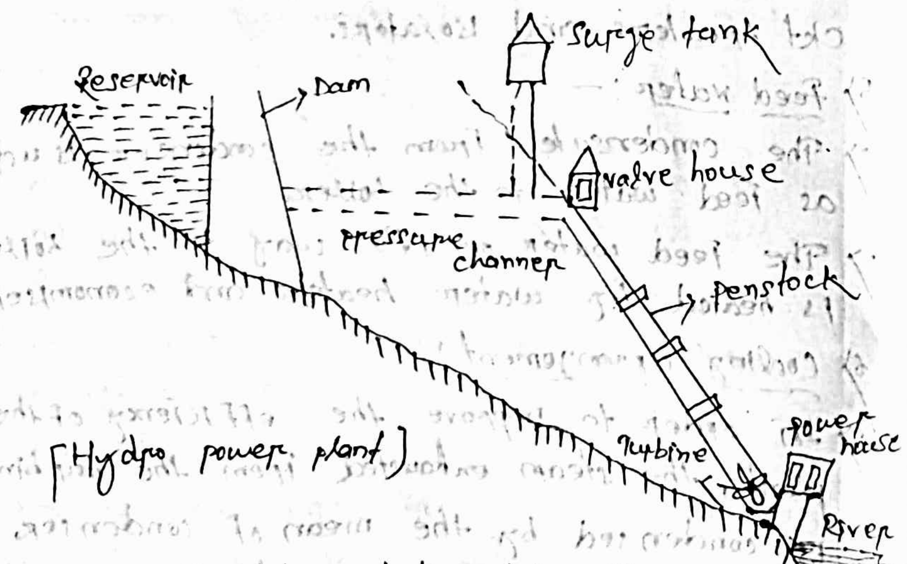
$$\text{Thermal efficiency} = \frac{\text{Heat equivalent of mech. energy transmitted to the turbine shaft}}{\text{Heat of coal combustion.}}$$

Overall efficiency :-

The ratio of heat ~~energy~~ equivalent of electrical output to the compustion of coal is known as overall efficiency of steam power station.

$$\text{overall efficiency} = \frac{\text{Heat equivalent of elect. output}}{\text{Heat of coal combustion.}}$$

Hydro power plant :-



[Hydro power plant]

- A generating station which utilize the potential energy of water for the generation of electrical energy is known as hydro electric station / hydro power plant.

- Hydro electric power stations are generally located in hilly areas where domms can be build and a large water reservoirs can be obtain.
- In hydro electric power station water had is created by concerning a dam across a river or lake.
- From the dam water is left to a water turbine by valve house. The water turbine capture the energy in the falling water and chages the hydraulic energy into mechanical energy at the turbine.
- The turbine drives the alternator which converts mechanical energy into electrical energy.

Advantages :-

- No fuel as water is used for generation of electrical energy.
- It is quate net and clean as no smoke / ash is produced.
- It requires very small running cost because water is available for free cost.
- It is comparatively simple in construction and less maintance.
- Such plants solves many purpose in addition to the generation of the electrical energy they also helped in irrigation and controlling floods.

Dis advantages :-

- It involves high capital cost.
- There is uncertainty about the availability of huge among of water due to depends on water condition.

-> Skilled and experienced required to build the plant.

-> It requires high cost of transmission lines at the plant is located in hilly area, which are away from the consumers.

Selection sites :-

-> Availability of water

-> Storage of water

-> Types and cost of land.

-> Transportation facility.

Schematic Arrangement of Hydropower plant :-

-> The dam is constructed across a river/lake and water from the catchment area collects at the back of the dam to form a reservoir.

-> A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the penstock.

-> The valve house contains main sluice valves and automatic isolating valves.

-> The former controls the water flow to the power house and the latter cuts off supply of water when the penstock bursts.

-> From the valve house, water is taken to water turbine through a huge steel pipe known as penstocks.

-> The water turbine converts hydraulic energy into mechanical energy.

-> The turbine drives the alternator which converts mechanical energy into electrical energy.

-> A surge tank (open from top) is built just before the valve house and protects the penstock from bursting in case the turbine gates suddenly close due to electrical load being thrown off.

-> When the gates close, there is a sudden stopping of water at the lower end of the penstock and consequently the penstock can burst like a paper log.

-> The surge tank absorbs this pressure swing by increase in it's level of water.

Nuclear power plant

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

-> The heat energy thus released is utilised in raising steam at high temp^r and pressure.

-> The steam runs, the steam turbine which converts steam energy into mechanical energy.

-> The turbine drives the alternator which converts mechanical energy in to electrical energy.

-> The most important feature of a nuclear power station is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power station.

-> It is has been found that complete fission of 1kg of uranium can produce as much energy as can be produced by the burning of 4,500 tons of high grade coal.

Advantages :—

-> The amount of fuel is required small, nuclear power plant requires less space as compare to any other plants.

-> It has low running cost as a small amount of fuel is required.

Dis advantages :—

-> The fuel used in expensive and difficult to recover.

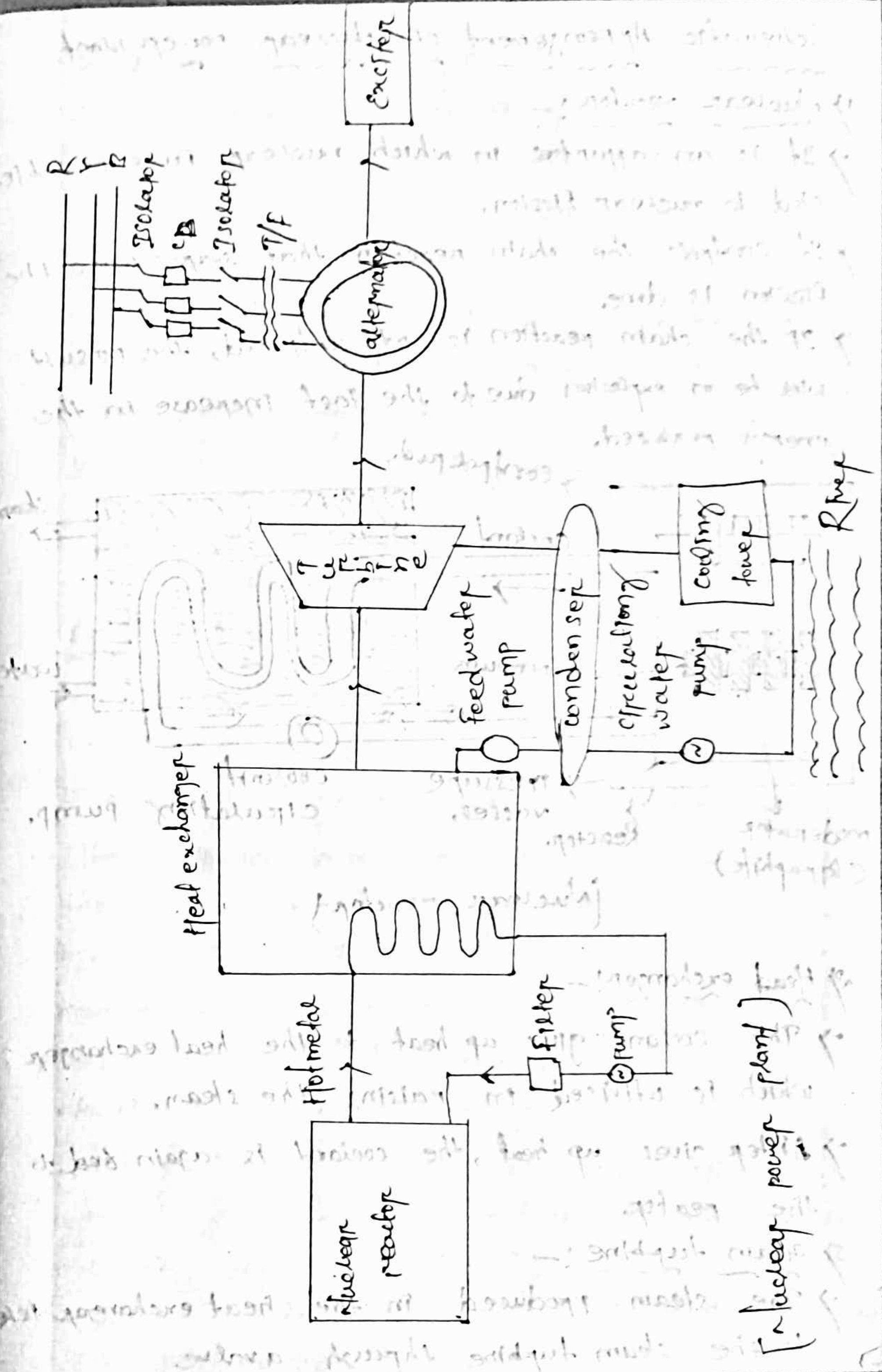
-> The capital cost is very high compare to others plant.

-> The fission by products are generally cause of dangerous amount of pollution.

-> The disposal of by products which are very dangerous is a big problem. They have to be dispored in a deep trance or in a sea away from the sea snow.

Selection sites :—

-> Availability of water
-> Transport facility
-> Distance from populated area
-> Disposal of water

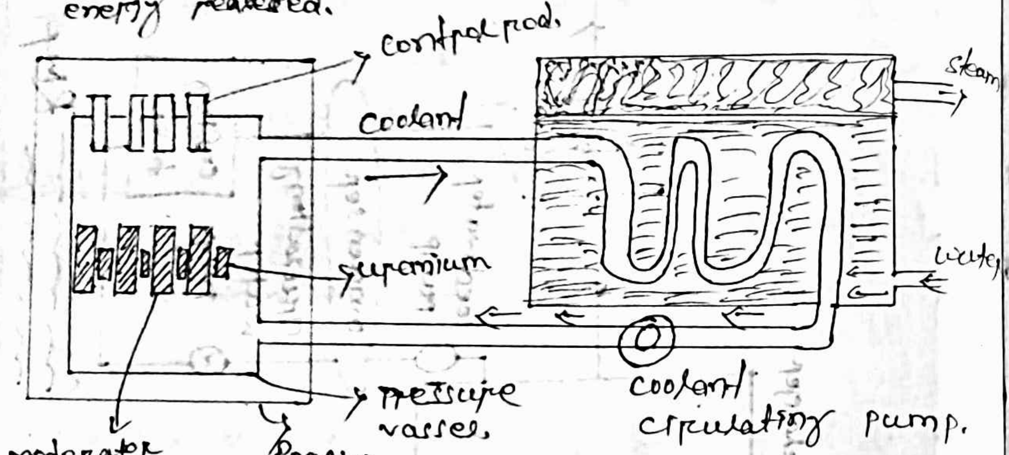


[Nuclear power plant]

Schematic Arrangement of Nuclear power plant

1) Nuclear reactor :-

- It is an apparatus in which nuclear fuel is subjected to nuclear fission.
- It controls the chain reaction that starts once the fission is done.
- If the chain reaction is not controlled, the result will be an explosion due to the fast increase in the energy released.



[Nuclear reactor]

2) Heat exchanger :-

- The coolant gives up heat to the heat exchanger which is utilised in raising the steam.
- After gives up heat, the coolant is again fed to the reactor.

3) Steam turbine :-

- The steam produced in the heat exchanger is fed to the steam turbine through a valve.
- After doing a useful work in the turbine, the steam is exhausted to condenser.
- The condenser condenses the steam which is fed to the heat exchanger through feed water pump.

4) Alternator :-

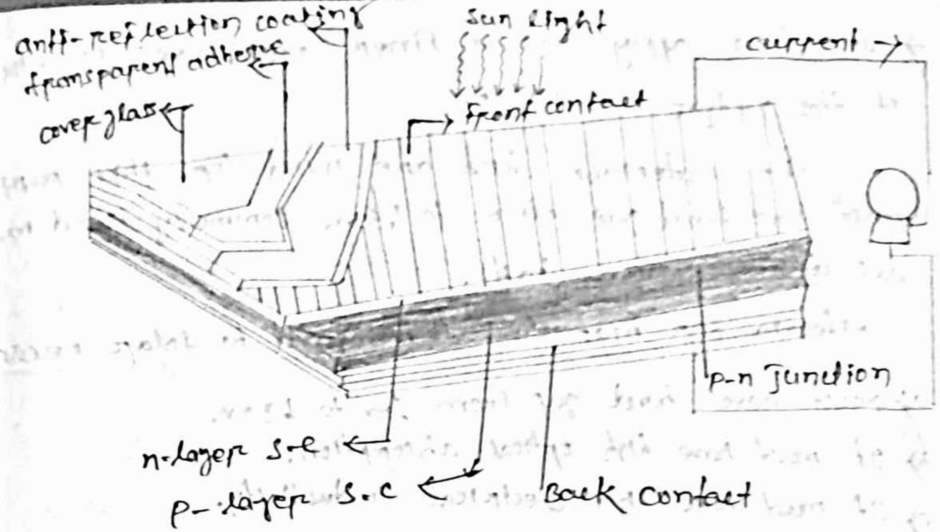
- The steam turbine drives the alternator which converts mechanical energy in to electrical energy.
- The output from the alternator is delivered to the bus-bars through transformer, ckt breakers and isolators.

Solar energy :-

Def^n -> Solar energy is the transformation of heat that comes from the sun.

- Conversion of light energy in electrical energy is based on a phenomenon of called photovolatic cells
- When semiconductor materials are exposed to light, the some of the photons of light ray are absorved by the s.c crystal which causes a significant number of free electrons in the crystal.
- This is the the basic reason for producing electricity due to photovolatic effect.
- photovolatic cell is the basic unit of the system where the photovolatic effect is utilised to produce electricity from light energy.
- Silicon is the most widely used s.c material for constructing the photovolatic cell.

- The silicon atoms has four valence electrons.
- In a solid crystal, each silicon atom shares each of it's four valance electrons with another nearest silicon atom hence creating covalent bonds between them.
- In this way, silicon crystal gets a tetrahedral lattice structure.
- While light ray strikes on any materials some portion of the light is reflected, some portion is transmitted through the material and rest is absorbed by the materials.
- If the intensity of incident light is high enough, sufficient no. of photons are absorbed by the crystal and these photons, in turn excite some of the electrons of covalent bonds.
- These excites electrons then get sufficient energy to migrate from valence band to conduction band.
- As the energy level of these electrons is in the conduction band, they leave from the covalent bond leaving a hole in the bond behind each removed electron.
- These are called free electrons move randomly inside the crystal structure of the silicon.
- These free electrons and holes have a vital role in creating electricity in photovoltaic cell.
- These electrons and holes are hence called light-generated electrons and holes respectively.



Solar cell working principle and construction :-

- A solar cell (also known as photovoltaic cell/piece) is defined as an electrical device that convert light energy into electrical energy through the photovoltaic effect.
- A solar cell is basically a p-n junction diode, solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics such as current, voltage/resistance vary when exposed to light.
- Individual solar cells can be combined to form modules commonly known as solar planets.
- A solar cell is basically a junction diode, although it's construction is little bit different from conventional p-n junction diodes.
- A very thin layer p-type sc is grown on a relatively thicker n-type s.c .

-> we then apply a few finer electrodes on the top of the p-type s.c layer.

The materials which are used for this purpose must have band gap close to 1.5ev. Commonly used materials are- silicon, GaAs.

Criteria for materials to be used to solar cells:-

a) Must have band gap from 1ev to 1.8ev.
b) It must have high optical absorption.
c) It must have high electrical conductivity.
d) The raw material must be available in abundance and the cost of the material must be low.

Advantages of solar cell:-

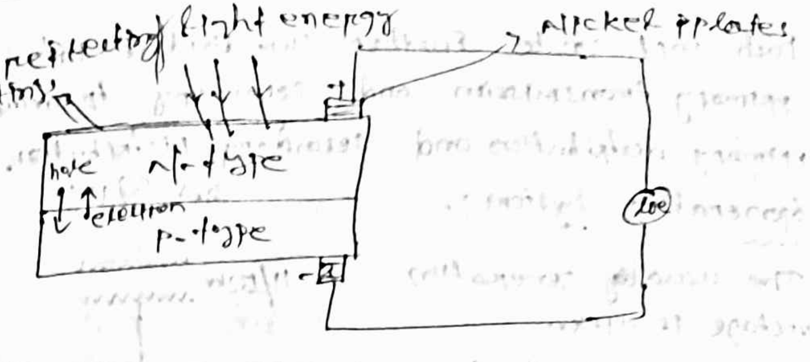
1) No pollution associated with it.
2) It must last for a long time.
3) No maintence cost.

Disadvanges of solar cell:-

1) It has high cost of installation.
2) It has low efficiency
3) During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

Uses of solar generation systems:-

a) It may be used to charge batteries.
b) used in light meters.
c) It is used to power calculators and wrist watches.
d) It can be used in spacecraft to provide electrical energy.



ch-2 Transmission of electric power Dt 28-04-21

Electric supply system:-

-> The conveyance of electric power from a power station to consumers permises known as electric power supply system.

-> An electric supply system consists of three principle components viz, the power station, the transsion lines and the distribution lines.

-> The electric supply system can be broadly calassified into, (i) d.c or a.c system (ii) overhead/underground system.

-> The underground system is more expensive than the overhead system.

-> The overhead system is mostly adopted for transmission and distribution of electric power.

Typical a.c power supply scheme:-

-> The large n/w of conductors between the power station and the consumers can be broadly divided into two parts i.e transmission system and Distribution system.

- Each part can be further sub-divided into two — primary transmission and secondary transmission and primary distribution and secondary Distribution.

i) Generating system :-

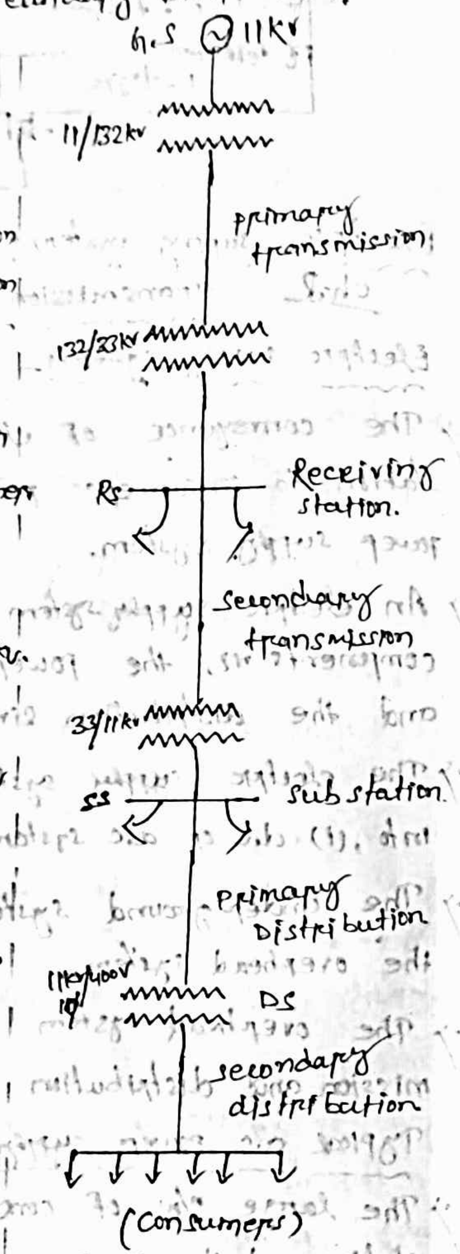
- The usually generation voltage is 11kv.
- For economy in the transmission of electric power, the generation voltage (i.e 11kv) is stepped up to 132 kv (or more) at the generating station with the help of 3-phase transformer.
- Generally the primary transmission is carried at 66 kv, 132 kv, 220 kv or 400kv.

ii) Primary transmission

- The electric power at 132 kv is transmitted by 3-phase, 3wire overhead system to the out-skirts of the city.
- This forms the primary transmission.

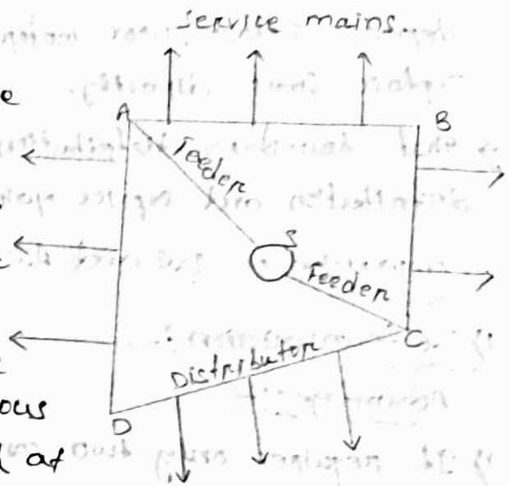
iii) Secondary transmission :-

- The primary transmission line terminates at the receiving station (RS) which usually lies at the out-skirts of the city.



[Electric supply system]

- At the receiving station, the voltage is reduced to 33 kv by step-down transformers.
- From this station, electric power is transmitted at 33 kv by 3-phase, 3-wire overhead system, to various substations (SS) located at the strategic points in the city.
- This forms the secondary transmission.



iv) Primary Distribution :-

- The secondary transmission line terminals at the sub-station (SS) where voltage is reduced from 33 kv to 11 kv, 3-phase, 3-wire.
- The 11kv lines run along the important road sides of the city. This forms the primary distribution.

v) secondary distribution :-

- The electric power from primary distribution line (11kv) is delivered to distribution sub-station.
- These sub-stations are located near the consumers localities and step-down the voltage to 400v, 3-phase, 4-wire for secondary distribution.
- The voltage betⁿ any two phases is 400v and betⁿ any phase and neutral is 230v.
- The single-phase residential lighting load is connected between any one phase and neutral.

whereas 3-phase, 400V motor load is connected across 3-phase lines directly.

→ That secondary distribution system consists of feeders, distribution and service mains.

Comparision of D.C and A.C transmission

1) D.C transmission :-

Advantages :-

i) It requires only two conductors as compared to three for a.c. transmission.

ii) There is no inductance, capacitance, phase displacement and surge problems in d.c transmission.

iii) Due to the absence of inductance, the voltage drop in a d.c transmission line is less than the a.c. line for the same load and sending end voltage. For this reason a d.c transmission line has better voltage regulation.

iv) There is no skin effect in a d.c system. Therefore, entire cross-sections of the line conductor is utilised.

v) A d.c line has less corona loss and reduced interference with communication ckts.

Dis advantages :-

i) Electric power cannot be generated at high d.c voltage due to communication problems.

ii) The d.c voltage cannot be stepped up for transmission of power at high voltages.

2) A.C transmission :-

Advantages :-

i) The power can be generated at high voltages.

ii) The maintenance of a.c sub-stations is easy and cheaper.

iii) The a.c voltage can be stepped up / stepped down by transformers with ease and efficiency. This permits to transmit power at high voltages and distribute it at safe potentials.

Dis advantages :-

i) An a.c line requires more copper than a d.c line.

ii) The construction of a.c transmission line is more complicated than d.c transmission line.

iii) Due to skin effect in the a.c system, the effective resistance of the line is increased.

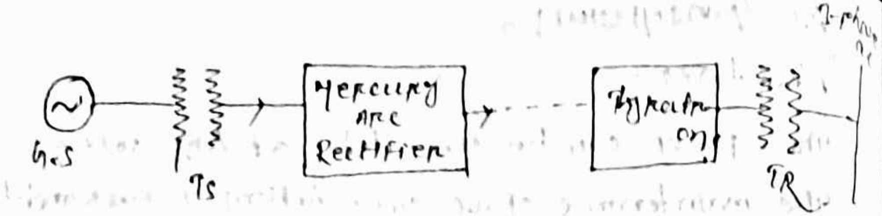
iv) An a.c line have capacitance. Therefore, there is a continuous loss of power due to charging current even when the line is open.

Conclusion :-

→ From the above comparision, it is clear that high voltage d.c transmission is superior to high voltage ac transmission.

→ Although at present transmission of electric power is carried by a.c there is an increasing interest in d.c transmission.

→ The introduction of mercury arc rectifiers and thyratrons have made it possible to convert a.c into d.c and vice-versa easily and efficiently.



-> The a.c power at high voltage is fed to the mercury arc rectifiers which convert ac into d.c.

-> The transmission of electric power is carried at high d.c voltage.

-> At the receiving end, d.c is converted into a ac with the help of thyratrons.

-> The ac supply is stepped down to low voltage by receiving end transformer T_R for distribution.

Voltage regulation:-

-> When a transmission line is carrying current, there is a voltage drop in the line due to resistance and inductance of the line.

-> The result is that receiving end voltage (V_R) of the line is generally less than the sending end voltage (V_S).

-> The voltage drop ($V_S - V_R$) in the line is expressed as a percentage of receiving end voltage V_R and is called voltage Regulation.

The difference in voltage at the receiving end of a transmission line between conditions of no load and full load is called voltage regulation and is expressed as a percentage of the receiving end voltage.

% age voltage Regulation = $\frac{V_S - V_R}{V_R} \times 100$

Transmission efficiency:-

-> The power obtained at the receiving end of a transmission line is generally less than the sending end power due to losses in the line resistance.

The ratio of receiving end power to the sending end power of a transmission line is known as the transmission efficiency of the line i.e,

% age transmission efficiency = $\frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$

$= \frac{V_R I_R \cos\phi_R}{V_S I_S \cos\phi_S} \times 100$

Various systems of power Transmission:-

1) D.C system
a) DC two-wire
b) D.C two-wire midpoint earthed.
c) D.C - three-wire.

2) Single-phase A.C system
a) single phase two-wire,
b) single-phase two-wire with mid point earthed.
c) single-phase three-wire

3) Two phase A.C system:-
a) Two-phase four wire
b) Two phase three wire,

4) Three-phase AC system:-
a) Three phase three wire.
b) Three phase four wire,

While comparing the amount of conductor material required in various system, the proper comparision shall be on the basis of equal max stress on the *dielectric. These are two cases.

a) **When transmission is by overhead system:—**

→ In the overhead system, the max. disruptive stress exists between the conductor and the earth.

→ Therefore, the comparision of the system in this case has to be made on the basis of max. voltage betn conductor and earth.

b) **When transmission is by underground system:—**

→ In the underground system, the chief stress on the insulation is between conductors.

→ Therefore, the comparision of the systems in this case should be made on the basis of max. potential difference betn conductors.

Elements of transmission line:—

For reasons associated with economy, transmission of electric power is done at high voltage by 3-phase, 3-wire overhead system.

The principal elements of a high-voltage transmission line are:—

1) **Conductors:—**

→ Usually three for a single-ckt line and six for double-ckt line. The usual material is aluminium reinforced with steel.

2) **Step-up and step-down transformers:—**

→ At the sending and receiving ends respectively. The use of transformers permits to be transmitted at high efficiency.

3) **Line Insulators:—**

→ which mechanically support the line conductors and isolate them electrically from the ground.

4) **Support:—**

→ Which are generally steel towers and provide support to the conductors.

5) **Protective devices:—**

→ Such as ground wires, lightning arresters, ckt breakers, relays ect. They ensure the satisfactory service of the transmission line.

6) **Voltage regulating devices:—**

→ Which maintain the voltage at the receiving end within permissible limits.

Economics of power transmission:—

→ While designing any scheme of power transmission, the engineer must have before him the commercial aspect of the work entrusted to him.

→ He must design the various parts of transmission scheme in a way that max economy is achieved.

The following two fundamental economic principles which closely influence the electrical design of a transmission line will be discussed:—

1) Economic choice of conductor size
2) Economic choice of transmission voltage

1) Economic choice of conductor size.

-> The cost of conductor material is generally a very considerable part of the total cost of a transmission.

-> Therefore, the determination of proper size of conductor for the line is of vital importance.

-> The most economical area of conductor is that for which the total annual cost of transmission line is minimum.

-> This is known as Kelvin's law after lord Kelvin who 1st stated it in 1881.

-> The total annual cost of transmission line can be divided broadly into two parts viz, annual charge on capital outlay and annual cost of energy wasted in the conductor.

1) Annual charge on capital outlay :-

-> This is on account of interest and depreciation on the capital cost of complete installation of transmission line.

-> In case of overhead system, it will be the annual interest and depreciation on the capital cost of conductors, supports and insulators and the cost of their erection.

-> Now, for an overhead line, insulator cost is constant, the conductor cost is proportional to the area of x-section and the cost of supports and their erection is partly constant and partly proportional to area of x-section of the conductors.

-> Therefore, annual charge on an overhead transmission line can be expressed as :-

$$\text{Annual Charge} = P_1 + P_2 a \quad \text{—— (1)}$$

where, P_1 and P_2 are constants and a is the area of x-section of the conductor.

II) Annual cost of energy wasted :-

-> This is on account of energy lost mainly in the conductor due to I^2R losses.

-> Assuming a constant current in the conductor throughout the year, the energy lost in the conductor is proportional to resistance.

-> As resistance is inversely proportional to the area of x-section of the conductor, therefore, the energy lost in the conductor is inversely proportional to area of x-section.

-> Thus, the annual cost of energy wasted in an overhead transmission line can be expressed as.

$$\text{Annual cost of energy wasted} = P_3/a \quad \text{—— (2)}$$

where P_3 is constant.

$$\text{Total annual cost, } C = \exp(1) + \exp(2)$$

$$= (P_1 + P_2 a) + P_3/a$$

$$\therefore \quad C = P_1 + P_2 a + P_3/a \quad \text{—— (3)}$$

In exp(3) only area of x-section 'a' is variable. Therefore, the total annual cost of transmission line will be minimum if differentiation of C w.r.t a is zero i.e $\frac{d}{da}(C) = 0$

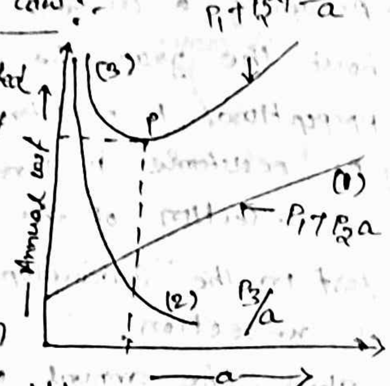
$$\Rightarrow \frac{d}{da}(P_1 + P_2 a + P_3/a) = 0$$

$$\Rightarrow P_2 - \frac{P_3}{a^2} = 0 \Rightarrow P_2 = \frac{P_3}{a^2} \Rightarrow P_2 a = P_3/a$$

i.e variable part of annual charge = Annual cost of energy wasted

-> Therefore kelvin's law can also be stated in another way i.e the most economical area of conductor is that for which the variable part of annual charge is equal to the cost of energy losses per year

Graphical illustration of kelvin's law :-



-> kelvin's law can also be illustrated graphically by ploting annual cost against x-sectional area 'a' of the conductor.

-> In the diagram, the straight line (1) shows the relation betn the annual charge (P_1+P_2a) and the area of x-section 'a' of the conductor.

-> Similarly, the rectangular hyperbola (2) gives the relation betn annual cost of energy wasted and x-sectional area 'a'.

-> By adding the ordinates of curves (1) and (2), the curve (3) is obtained.

-> This latter curve shows the relation between total annual cost ($P_1+P_2a+P_3/a$) of transmission line and area of x-section a.

-> The lowest point on the curve (i.e point P) represents the most economical area of x-section.

Limitations of kelvin's law :-

Although theoretically kelvin's law holds good, there is often considerable difficulty in applying it to a proposed scheme of power transmission. In practice, the limitations of this law are:-

1) It is not easy to estimate the energy loss in the line without actual load curves, which are not available at the time of estimation.

2) The assumption that annual cost on account of interest & depreciation on the capital outlay is in the form P_1+P_2a is strictly not true. For instance, in cables neither the cost of cable dielectric and sheath nor the cost of laying vary in this manner.

3) This law does not take into account several physical factors like safe current density, mechanical strength, corona loss etc.

4) The conductor size determined by this law may not always be practicable one because it may be too small for the safe carrying of necessary current.

5) Interest and depreciation on the capital cannot be determined accurately.

Economic choice of transmission voltage:-

-> If transmission voltage is increased, the volume of conductor material required is reduced.

-> This decreases the expenditure on the conductor material.

-> It may appear advisable to use the highest possible transmission voltage in order to reduce expenditure on conductors to a minimum.

- However, it may be remembered that as the transmission voltage is increased, the cost of insulating the conductors, cost of transformers, switchgear and other terminal apparatus also increases.
- Therefore, for every transmission line, there is optimum transmission voltage, beyond which there is nothing to be gained in the matter of economy.
- The transmission voltage for which the cost of conductors, cost of insulators, transformers, switchgear and other terminal apparatus is minimum is called economical transmission voltage.

We choose some standard transmission voltage and work out the following costs:-

i) Transformers:- at the generating and receiving ends of transmission line for a given power, this cost increases slowly with the increase in transmission voltage.

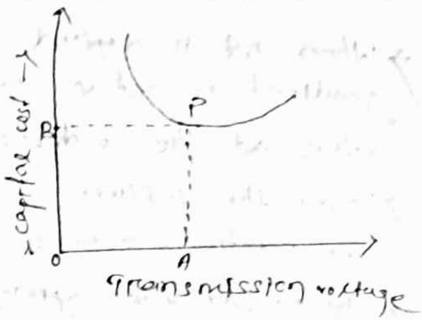
ii) Switchgear:- This cost also increases with the increase in transmission voltage.

iii) Lightning arrester:- This cost increases rapidly with the increase in transmission voltage.

iv) Insulation and supports:- This cost increases sharply with the increase in transmission voltage.

v) Conductor:- This cost decreases with the increase in transmission voltage.

The sum of all above costs gives the total cost of transmission for the voltage considered.



- The lowest point (P) on the curve gives the economical transmission voltage.
- Thus, in the present case, OA is the optimum transmission voltage.
- This method of finding the economical transmission voltage is rarely used in practice as different costs cannot be determined with a fair of accuracy.

Corona:-

- When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low.
- However, when the applied voltage exceeds a certain value called critical disruptive voltage, the conductors are surround by a faint violet glow called Corona.
- The phenomenon of corona is accompanied by a hissing sound, production of ozone, power loss and Radio Interference.
- The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona.

Theory of corona formation:- Some ionisation is always present in air due to cosmic rays, ultra violet radiations and radioactivity.

- Therefore, under normal conditions, the air around the conductors contains some ionised particles and neutral molecules.

- When P.d is applied betⁿ the conductors, potential gradient is set up in the air which will have max value at the conductors surfaces.
- Under the influence of potential gradient, the existing free electrons acquire greater velocities.
- The greater the applied voltage, the greater the potential gradient and more is the velocity of free electrons.
- This produces another ion and one or more free electrons which in turn are accelerated untile they colide with other neutral molecules, thus producing other ions.
- Thus, the process of ionisation is commulative. The result of this ionisation is that either corona is formed or spark place betⁿ the conductors.

Factors affecting corona

i) **Atmosphere:-** In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltages as comapared to fair weather.

ii) **Conductor size;** The corona effect depends up on the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage.

iii) **spacing betⁿ conductors :-** If the spacing betⁿ the conductors is made very large as compared to their diameters, there may not be any corona effect.

iv) **Line voltage :-** The line voltage greatly affects corona. If it is low, there is no change in the condition of air sorrounding the conductors and hence no corona is formed.

Advantages of corona :-

i) Due to corona formation, the air surrounding the conductors becomes conducting and hence virtual diameter of the conductors is increased. The increased diameter reduces of electrostatic stresses betⁿ the condⁿ.

ii) Corona reduces the effects of transients produced by surges.

Dis advantages:-

i) Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

ii) Ozone is produced by corona and may cause corrosion of the conductors due to chemical action.

iii) The current drawn by the line due to corona is non-sinusoidal and hence non-sinusoidal voltage drop occurs in the line. This may cause inductive interference with neighbouring communication lines.

Methods of Reducing corona effect :-

The corona effects can be reducede by the following methods:-

i) **By increasing conductor size:-**
By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that ACSR conductors which have a larger cross-sectional area are used in transmission lines.

ii) **By increasing conductor spacing :-** By increasing the spacing betⁿ conductors, the voltage at which corona occurs is raised and hence effects can be eliminated. However spacing can not be increased too much otherwise the cost of supporting structures may increase to a considerable extent.

ch 3. **Overhead lines** Dt - 12-05-21

Main components of overhead lines :-

-> An overhead line may be used to transmit or distribute electric power.

-> The successful operation of an overhead line depends to a great extent upon the mechanical design of the line.

-> While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most probable weather conditions.

In general, the main components of an overhead line are :-

i) Conductors :- Which carry electric power from the sending end station to the receiving end station.

ii) Supports :- Which may be poles or towers and keep the conductors at a suitable level above the ground.

iii) Insulators :- which are attached to supports and insulate the conductors from the ground.

iv) Cross arms :- Which provide support to the insulators.

v) Miscellaneous items :- Such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Conductors materials :-

-> The conductor is one of the important items as most of the capital outlay is invested for it.

-> Therefore, proper choice of material and size of the conductor is of considerable importance.

-> The conductor material used for transmission and distribution of electric power should have the following properties :-

i) High electrical conductivity.

ii) High tensile strength in order to withstand mechanical stresses.

iii) low cost so that it can be used for long distances.

iv) low specific gravity so that weight per unit volume is small.

All above requirements are not found in a single material. Therefore, while selecting a conductor material for a particular case, a compromise is made betn the cost and the required electrical and mechanical properties.

The most commonly used conductor materials for overhead lines are copper, aluminium, steel-cored aluminium, galvanised steel and cadmium copper.

-> The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and local conditions.

-> In standard conductors, there is generally one central wire and round this successive layers of wires containing 6, 12, 18, 24, ... wires. Thus, if there are n layers, the total no. of individual wires is $3n(n+1)+1$.

1) Copper:-

-> Copper has high current density i.e the current carrying capacity of copper per unit of x-sectional area is quite large.

-> This leads to two advantages, Firstly, smaller x-sectional area of conductor is required and secondary, the area offered by the conductor to wind loads is reduced.

-> Moreover, this metal is quite homogeneous, durable and has high scrap value.

-> However, due to it's higher cost and non-availability it is rarely used for these purposes. Now-a-days the trend is to use aluminium in place of copper.

2) Aluminium:-

-> Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength.

i) The conductivity of aluminium is 60% that of copper. The smaller conductivity of aluminium means that for any particular transmission efficiency, the x-sectional area of conductor must be larger in aluminium than in copper. For the same resistance, the diameter of aluminium conductor is about 1.26 times the diameter of copper conductor.

ii) The specific gravity of aluminium (2.71 gm/cc) is lower than that of copper (8.9 gm/cc). Therefore, an aluminium conductor has almost one-half the weight of equivalent copper conductor. For this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.

iii) Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.

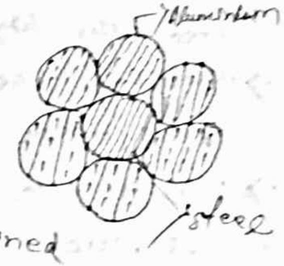
iv) Considering the combined properties of cost, conductivity, tensile strength, weight etc., aluminium has an edge over copper. Therefore, it is being widely used as a conductor material.

3) Steel Cored aluminium:-

-> Due to low tensile strength, aluminium conductors produce greater sag.

-> This prohibits their use for larger spans and makes them unsuitable for long distance transmission.

-> In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanised steel wires.



-> The composite conductor thus obtained is known as steel cored aluminium and is abbreviated as A.C.S.R (aluminium conductor steel reinforced).

-> Steel-cored aluminium conductor consists of central core of galvanised steel wires surrounded by a number of aluminium strands.

-> Usually, diameter of both steel and aluminium wire is the same.

-> The x-section of the two metals are generally in the ratio of 1:6 but can be modified to 1:4 in order to get more tensile strength for the conductor.

The steel cored aluminium conductors have the following advantages:—

i) The reinforcement with steel increases the tensile strength, steel cored aluminium conductors will produce smaller sag and hence longer spans can be used.

ii) Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.

4) **Galvanised steel**:—

-> Steel has very tensile strength. Therefore, galvanised steel conductors can be used for extremely long spans or for short line sections exposed to abnormally high stresses due to climatic conditions.

-> They have been found very suitable in rural areas where cheapness is the main consideration.

-> Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance.

5) **Cadmium copper**:—

-> The conductor material now being employed in certain cases is copper alloyed with cadmium.

-> An addition of 1% or 2% cadmium to copper increases the tensile strength by about 50% and the conductivity is only reduced by 15% below that of pure copper.

-> Therefore, cadmium copper conductor can be useful for exceptionally long spans.

-> However, due to high cost of cadmium, such conductors will be economical only for lines of small x-section

Line supports:—

-> The supporting structures for overhead line conductors are various types of poles and towers called line supports.

-> In general, the line supports should have the following properties:-

i) High mechanical strength to withstand the weight of conductors and wind loads etc.

ii) Light in weight without the loss of mechanical strength.

iii) Cheap in cost and economical to maintain.

iv) Longer life.

v) Easy accessibility of conductors for maintenance.

-> The line supports used for transmission and distribution of electric power are of various types including wooden poles, steel poles, R.C.C poles & lattice steel towers.

1) **Wooden poles**:—

-> These are made of seasoned wood (sal or chir) and are suitable for lines of moderate x-sectional area and of relatively shorter spans, say up to 50m.

-> Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition.

-> Double pole structures of the 'A' or 'H' type are often used (see fig 8.2) to obtain a higher transverse strength than could be economically provided by means of single poles.

The main objections to wooden supports are:-

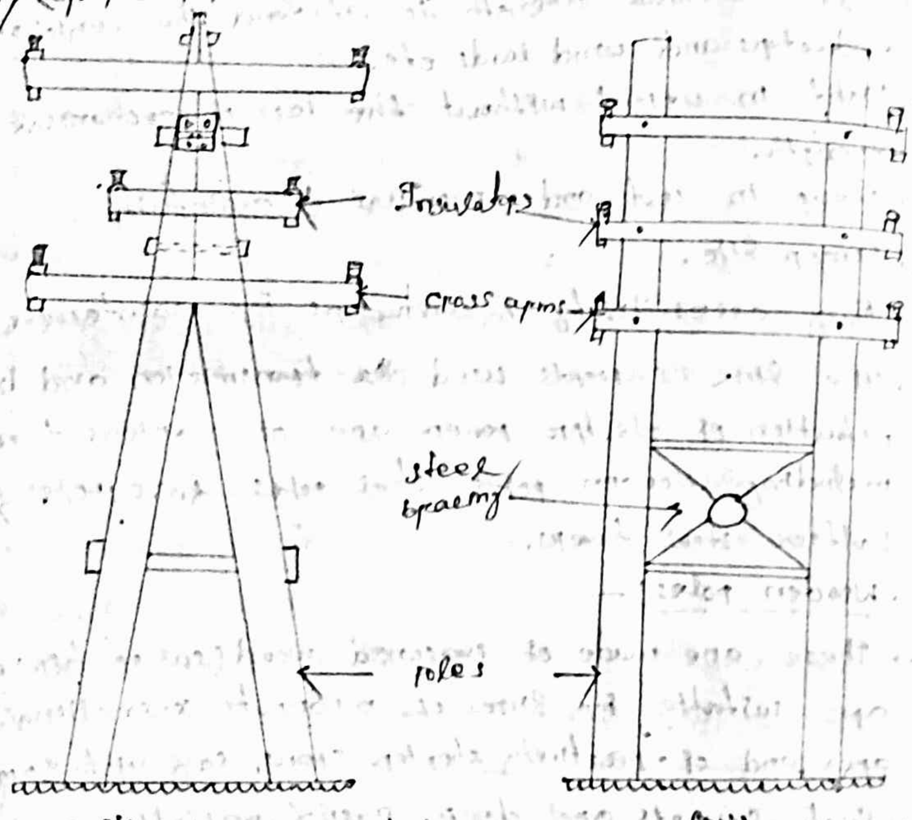
i) Tendency to rot below the ground level.

ii) Comparatively smaller life (20-25 years)

iii) Cannot be used for voltages higher than 20kV.

iv) Less mechanical strength.

-> Require periodical inspection.



(wooden poles)

2) Steel poles:-

-> The steel poles are often used as a substitute for wooden poles.

-> They possess greater mechanical strength, longer life and permit longer spans to be used.

-> Such poles are generally used for distribution purposes in the cities. This type of support is need to be galvanised or painted in order to prolong its life.

-> The steel poles are of three types viz., (i) rail poles (ii) Tubular poles and (iii) rolled steel joints.

3) RCC Poles:-

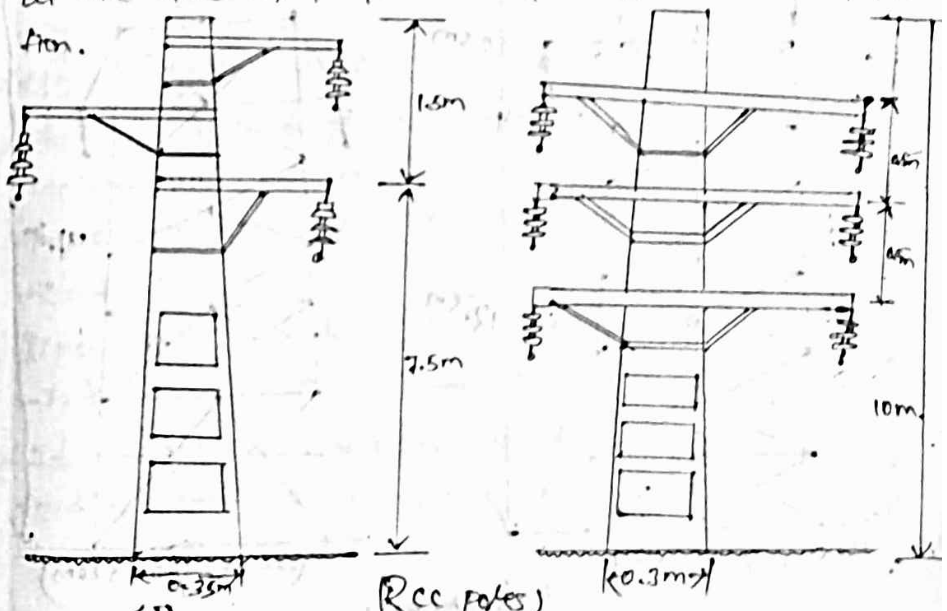
-> The reinforced concrete poles have become very popular as line supports in recent years.

-> They have greater mechanical strength, longer life and permit spans than steel poles.

-> Moreover, they give good outlook, require little maintenance and have good insulating properties.

-> The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight.

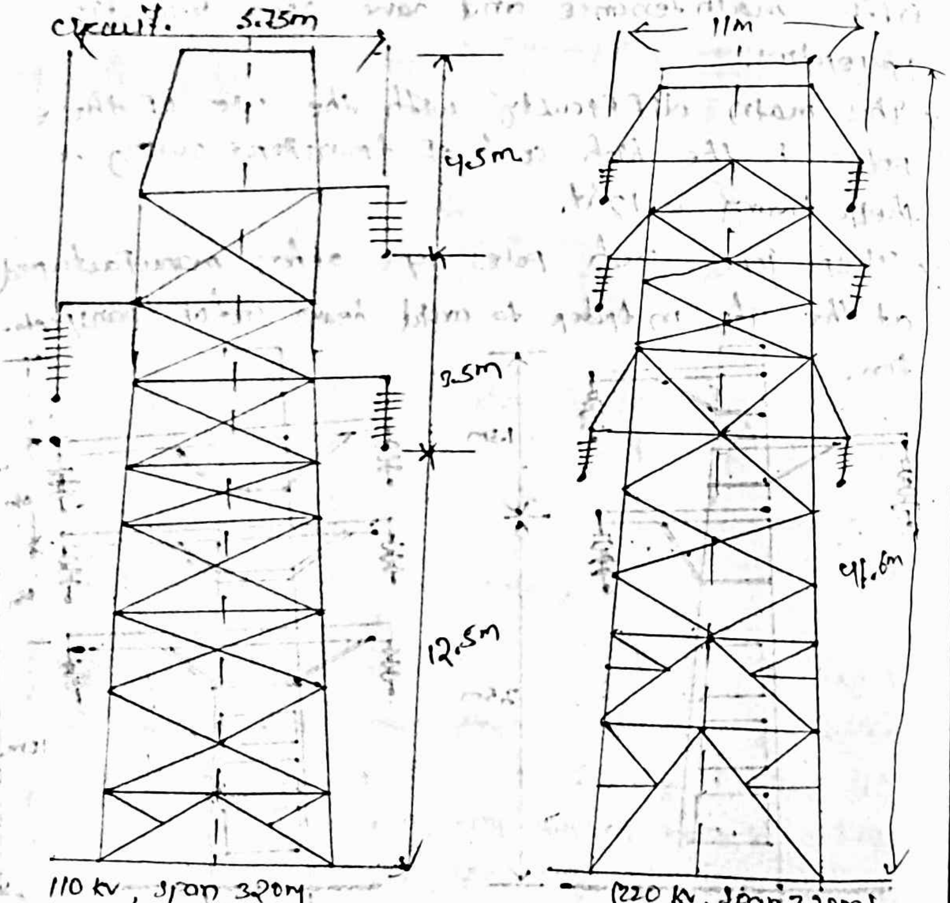
-> Therefore such poles are often manufactured at the site in order to avoid heavy cost of transportation.



(RCC poles)

4) steel towers :-

- In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say upto 11 kV.
- Tower footing are usually grounded by driving rods into the earth. This minimums the obtaining through as each tower acts as a lightning conductor.
- The double ckt has the advantage that it ensures continuity of supply.
- If case there is breakdown of one ckt, the continuity of supply can be maintained by other circuit.



(steel towers)

Insulators :-

- The overhead line conductors should be supported on the poles/towers in such a way that currents from conductors do not flow to earth through supports i.e, line conductors must be properly insulated from supports.
- This is achieved by securing line conductors to supports with the help of insulators.
- The insulators provide necessary insulation betn line conductors and supports and thus prevent any leakage current from conductors to earth.

i) High mechanical strength in order to withstand conductor load, wind load etc.

ii) High electrical resistance of insulator material in order to avoid leakage currents to earth.

iii) High relative permittivity of insulator material in order that dielectric strength is high.

iv) The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.

v) High ratio of puncture strength to flashover.

- The most commonly used material for insulators of overhead line is porcelain but glass, steatite and special composition materials are also used to a limited extent.
- Porcelain is produced by firing at a high temp^r^ a mixture of kaolin, feldspar and quartz.
- It is stronger mechanically than glass, gives less trouble from leakage and is less effected by changes of temperature.

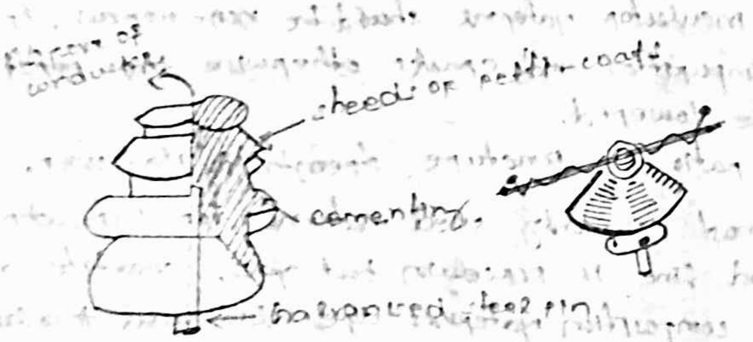
Types of Insulators :-

There are several types of insulators but the most commonly used are pin type, suspension type, strain insulators and shackle insulators.

1) Pin type insulators :-

The pin type insulator is secured to the cross arm on the pole.

- There is a groove on the upper end of the insulator for housing the conductor.
- The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.
- Pin type insulators are used for transmission and distribution of electric power at voltages up to 33 kv.
- Beyond operating voltage of 33 kv, the pin type insulators become too bulky and hence uneconomical.

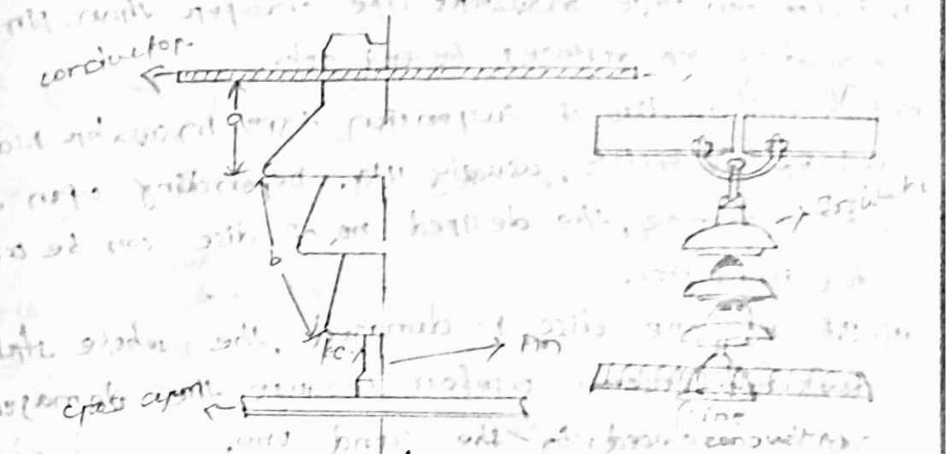


Cause of insulator failure :-

- Insulators are required to withstand both mechanical and electrical stresses.
- The latter type is primarily due to line voltage and may cause the breakdown of the insulator.
- The electrical breakdown of the insulator can occur either by flash-over or puncture.
- In flash over, an arc occurs between the line conductor and insulator pin (i.e earth) and the discharge jumps across the air gaps.

The ratio of puncture strength to flash over voltage is known as safety factor i.e,

$$\text{Safety Factor of insulator} = \frac{\text{Puncture strength}}{\text{Flash-over voltage}}$$



2) Suspension Type Insulator :-

- The cost of pin type insulator increases rapidly as the working voltage is increased.
- Therefore, this type of insulator is not economical beyond 33 kv. for high voltages (> 33 kv).
- They consist of a number of porcelain discs connected in series by metal links in the form of a string.
- The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower.

-> Each unit or disc is designed for low voltage, say 11kv.

-> They no. of discs in series would obviously depend upon the working voltage.

-> For instance, if the working voltage is 66kv, then six discs in series will be provided on the string.

Advantages :-

i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33kv.

ii) Each unit or disc of suspension type insulator is designed for low voltage, usually 11kv. Depending upon the working voltage, the desired no. of disc can be connected in series.

iii) If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

iv) The suspension arrangement provides greater flexibility to the line.

v) The suspension type insulators are generally used with steel towers.

3) Strain Insulators :-

-> When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension.

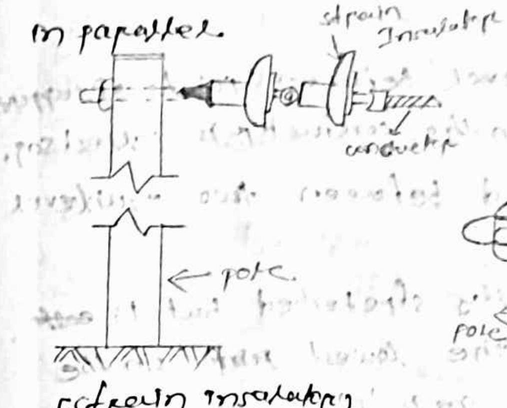
-> In order to relieve the line of excessive tension, strain insulators are used.

-> For low voltage lines (< 11kv), shackle insulators are used as strain insulators.

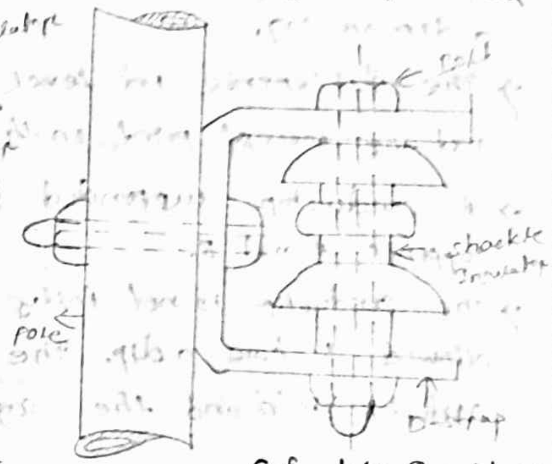
-> However for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators.

-> The disc of strain insulators are used in the vertical plane.

-> When the tension in lines is exceedingly high, as at long river spans, two or more strings are used in parallel.



(strain insulator)



(Shackle Insulator)

4) Shackle Insulators :-

-> In early days, the shackle insulator were used as strain insulators :

-> But now a days, they are frequently used for low voltage distribution lines.

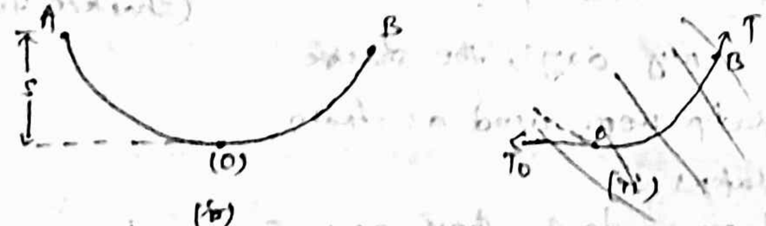
-> Such insulators can be used either in a horizontal position or in a vertical position.

-> They can be directly fixed to the pole with a bolt or to the cross arm.

-> The conductor in the groove is fixed with a soft binding wire.

Sag overhead lines :-

- If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension.
- In order to permit safe in the conductors, they are not fully stretched but are allowed to have a dip or sag.
- The difference in level between points of supports and the lowest point on the conductor is called sag.
- A conductor suspended between two equilevel supports A and B.
- The conductor is not fully stretched but is allowed to have a dip. The lowest point on the conductor is 'O' and the sag is 's'.



Conductor sag and tension :-

- This is an important consideration in the mechanical design of overhead lines.
- The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level.
- It is also desirable that tension in the conductor should be low to avoid the mechanical failure of conductor and to permit the use of less strong supports.
- Low conductor tension and min. sag are not possible. It is because low sag means a tight wire and high tension, whereas a low tension means a loose wire and increased sag.

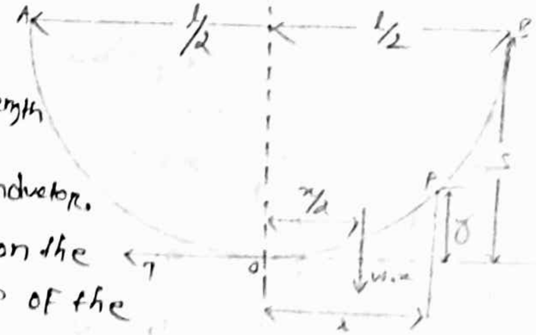
Therefore, in actual practice, a compromise is made between the two.

Calculation of sag :-

i) When supports are at equal levels :-

Consider a conductor between 'O' at the lowest point.

Let, l = Length of span.
w = weight per unit length of conductor.
T = Tension in the conductor.



Consider a point 'P' on the conductor (OP = x) OP of the conductor are:

I) The weight wx of conductor acting at a distance $x/2$ from O.

II) The tension 'T' acting at O:

Equating the moments of above two forces about point O, we get,

$$Ty = wx \times \frac{x}{2}$$

$$\Rightarrow y = \frac{wx^2}{2T}$$

The max. dis (sag) is represented by the value of 'y' at either of the supports A and B. At support A, $x = l/2$ and $y = s$

$$\therefore \text{sag};\ s = \frac{w(l/2)^2}{2T} = \frac{wl^2}{8T}$$

ii) When supports are at unequal levels :-

→ In hilly areas, we generally come across conductors suspended bet^n supports at unequal levels.

→ Figure shows, a conductor suspended bet^n two supports A and B which are at different levels.

→ The lowest point on the conductor is O;

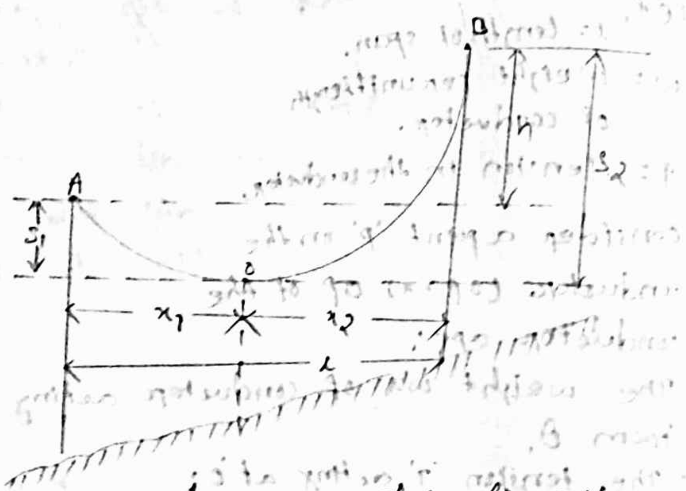
Let, l = span length

h = Difference in levels bet^n two supports

x_1 = Distance of support at lower level (i.e, A) from O

x_2 = Distance of support at higher level (i.e, B) from O

T = Tension in the conductor.



If w is the weight per unit length of the conductor, then sag $S_1 = \frac{w x_1^2}{2T}$

and sag $S_2 = \frac{w x_2^2}{2T}$

Also, $x_1 + x_2 = l$ ——— (I)

$y = \frac{wx^2}{2T}$

At support A, $x = x_1$ and $y = S_1$

$S_1 = \frac{w x_1^2}{2T}$

Now, $S_2 - S_1 = \frac{w}{2T}[x_2^2 - x_1^2]$

$= \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$

$\therefore S_2 - S_1 = \frac{wl}{2T}(x_2 - x_1)$

But, $S_2 - S_1 = h$

$h = \frac{wl}{2T}(x_2 - x_1)$

(or) $x_2 - x_1 = \frac{2Th}{wl}$ ——— (2)

Solving eqns. (I) and (II) we get,

$x_1 = \frac{l}{2} - \frac{Th}{wl}$

$x_2 = \frac{l}{2} + \frac{Th}{wl}$

Having found x_1 and x_2 values of S_1 and S_2 can be easily calculated.

Effect of wind and ice loading :-

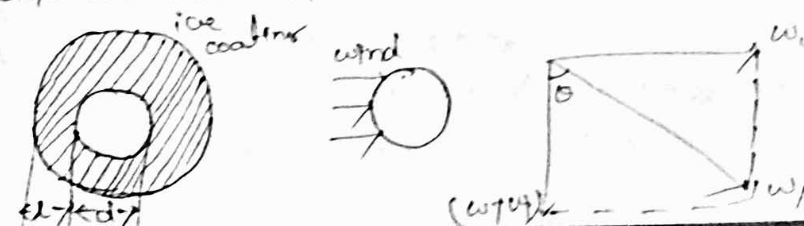
→ The above formula for sag are true only in still air and at normal temperature when the conductor is acted by its weight only.

→ However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure.

→ The weight of ice acts vertically downwards i.e in the same direction as the weight of conductor.

→ The force due to the wind is assumed to act horizontally i.e at right angle to the projected surface of the conductor.

→ Hence, the total force on the conductor is the vector sum of horizontal and vertical forces.



Total weight of conductor per unit length is,

where, $W_t = \sqrt{(w + w_i)^2 + (w_w)^2}$

w: weight of conductor per unit length

= conductor material density × volume per unit length

W_i: weight of ice per unit length

= density of ice × volume of ice per unit length

= density of ice × $\frac{\pi}{4}[(d+2t)^2 - d^2] \times 1$

= density of ice × $\frac{\pi}{4} t (d+t)^{\pi}$

W_w = wind force per unit length

= wind pressure per unit area × projected area per unit length

= wind pressure × [(d + 2t) × 1]

When the conductor has wind and ice loading also, the following points may be noted:-

i) The conductor sets itself in a plane at an angle 'θ' to the vertical where, $\tan\theta = \frac{W_w}{w + w_i}$

ii) The sag in the conductor is given by,

$$S = \frac{W_t l^2}{2T}$$

Hence, 'S' represents the slant in a direction making an angle θ to the vertical. If no specific mention is made in the problem, then slant sag is calculated by using the above formula.

iii) The vertical sag = S cos θ

Prob-1

A 132 kV transmission line has the following data:
wt. of conductor = 680 kg/km ; length of span = 260 m
ultimate strength = 3100 kg, safety factor = 2.
Calculate the height above ground at which the conductor should be supported. Ground clearance required is 10 metres.

Sol^n Given that,

wt. of conductor (w) = 680 kg/km = 0.68 kg

length of span (l) = 260 m

ultimate strength = 3100 kg

safety factor = 2

Tension, $T = \frac{\text{ultimate strength}}{\text{safety factor}} = \frac{3100}{2} = 1550$

$\therefore$ sag $= \frac{wl^2}{8T} = \frac{0.68 \times (260)^2}{8 \times 1550} = 3.70$ m

$\therefore$ conductor should be supported at a height of, 10 + 3.7 = 13.7 m

2) A transmission line has a span of 150 m between level supports. The conductor has a cross-sectional area of 2 cm². The tension in the conductor is 2000 kg. If the sp. gravity of the conductor material is 9.9 gm/cm³ and wind pressure is 1.5 kg/m length. Calculate the sag, what is the vertical sag?

G.T. Transmission line has a span (l) = 150 m

Tension in the conductor (T) = 2000 kg

wind pressure (W_w) = 1.5 kg/m

weight of conductor/m length =,

w = sp. gravity × volume of 1 m conductor

= 9.9 × 2 × 100 = 1980 gm = 1.98 kg

Total wt. of 1m length of conductor is,

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1.98)^2 + (1.5)^2} = 2.48\,kg$$

$$\therefore \text{sag}, S = \frac{w_t l^2}{8T} = \frac{2.48 \times (150)^2}{8 \times 2000} = 3.48\,m$$

This is the value of slant sag in a direction making an angle 'θ' with the vertical.

Referring to the value of θ is given by,

$$\tan\theta = \frac{w_w}{w} = \frac{1.5}{1.98} = 0.76$$

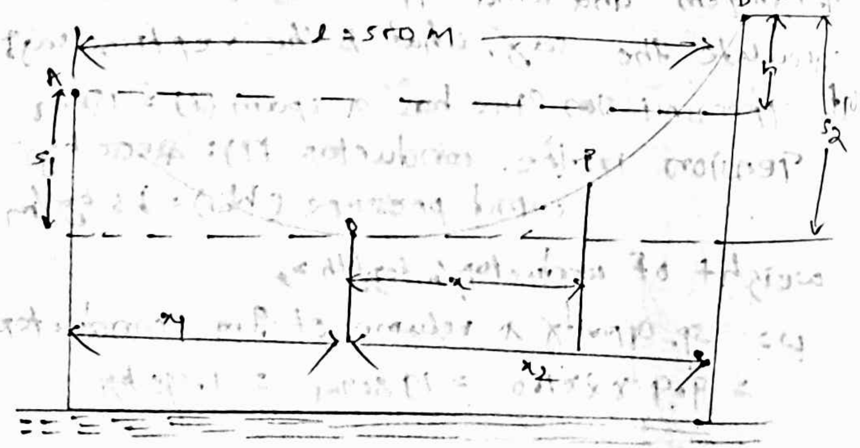
$$\theta = \tan^{-1}(0.76) = 37.23^\circ$$

$$\therefore \text{vertical sag} = S\cos\theta$$

$$= 3.48\cos 37.23 = 2.77\,m$$

3) The towers of height 30m and 90m respectively support a transmission line conductor at water crossing. The horizontal distance between the towers is 500m. If the tension in the conductor is 1600 kg, find the min. clearance of the conductor and water and clearance mid way between the supports. Weight of conductor is 1.5 kg/m. Bases of the towers can be considered be at water level.

Sol^n $x_1 + x_2 = 5000m$



G.t. $H_1 = 30m$, $H_2 = 90m$

Tension (T) 1600 kg

wt. of conductor (w) = 1.5 kg/m

length (l) = 500m

$h = h_2 - h_1 = 60\,m$.

$$S_1 = \frac{w x_1^2}{2T} \text{ and } S_2 = \frac{w x_2^2}{2T}$$

$$\Rightarrow h = S_2 - S_1 = \frac{w x_2^2}{2T} - \frac{w x_1^2}{2T}$$

$$60 = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$\therefore x_2 - x_1 = \frac{60 \times 2 \times 1600}{1.5 \times 500} = \frac{2Th}{wl}$$

$$\Rightarrow x_1 = \frac{l}{2} - \frac{Th}{wl} = \frac{500}{2} - \frac{1600 \times 60}{1.5 \times 500} = 122\,m$$

$$x_2 = \frac{l}{2} + \frac{Th}{wl} = \frac{500}{2} + \frac{1600 \times 60}{1.5 \times 500} = 375\,m$$

$$\text{Now, } S_1 = \frac{w x_1^2}{2T} = \frac{1.5 \times (122)^2}{2 \times 1600} = 7\,m.$$

Clearance of the lowest point 'O' from water level,

$= 30 - 7 = 23\,m$

Let the mid-point 'P' be at a distance x from the lowest point 'O'.

Clearly, $x = 250 - x_1 = 250 - 122 = 128\,m$

$$\text{sag at mid point P, } S_{mid} = \frac{w x^2}{2T} = \frac{1.5 \times (128)^2}{2 \times 1600}$$

$= 7.68\,m$

Clearance of mid-point 'P' from water level

$= 23 + 7.68$

$= 30.68\,m.$

4) An overhead transmission line conductor having parabolic configuration weights 1925 kg per metre length. The area of x-section of the conductor is $2.2 cm^2$ and the ultimate strength is 8000 kg/cm². The supports are 600 m apart having 15 m difference of levels. Calculate the sag from the taller of the two supports which must be allowed so that the factor of safety shall be 5. Assume that ice-load is 1 kg per metre run and there is no wind pressure.

sol^n Given that,

$l = 600m$, $w_i = 1kg$; $h = 15m$

$w = 1.925 kg$, Tension (T) = $\frac{8000 \times 2.2}{5} = 3520 kg$

Total weight of 1m length of conductor is,

$w_t = w + w_i = 1.925 + 1 = 2.925 kg$

Let, the lowest point 'O' of the conductor be at a distance x_1 from the support at lower level and at a distance x_2 from the support at higher level.

Clearly, $x_1 + x_2 = 600m$

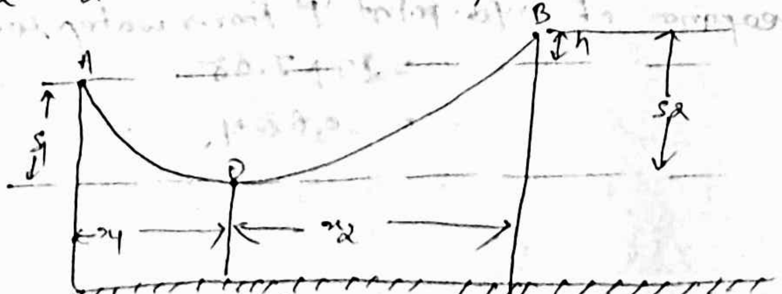
Now, $h = S_2 - S_1 = \frac{w_t x_2^2}{2T} - \frac{w_t x_1^2}{2T}$

$\Rightarrow 15 = \frac{w_t}{2T}(x_2 + x_1)(x_2 - x_1)$

$\Rightarrow x_2 - x_1 = \frac{2Th}{w_t l}$

$\Rightarrow x_1 = \frac{l}{2} - \frac{Th}{w_t l} = \frac{600}{2} - \frac{3520 \times 15}{2.925 \times 600} = 270m.$

$x_2 = \frac{l}{2} + \frac{Th}{w_t l} = \frac{600}{2} + \frac{3520 \times 15}{2.925 \times 600} = 330m$



Sag from the taller of the two towers B,

$S_2 = \frac{w_t x_2^2}{2T} = \frac{2.925 \times (330)^2}{2 \times 3520} = 45.24m$

Classification of overhead lines! –

A transmission line has three constants R, L & C distributed uniformly along the whole length of the line.

→ The resistance & inductance form the series impedance.

→ The capacitance existing bet^n conductors for 1-phase line or from a conductor to neutral for a 3-phase line forms a shunt path throughout the length of the line.

→ Therefore, capacitance effects introduce complications in transmission line calculations.

→ Depending upon the manner in which capacitance is taken into account, the overhead transmission lines are classified as:-

1) Short transmission lines! – When the length of an overhead transmission line is up to about 50 km and the line voltage is comparatively low (<20 kV), it is usually considered as a short transmission line. Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected.

2) Medium transmission lines! – When the length of an overhead transmission line is about 50-150 km and the line voltage is moderately high (>20 kV < 100 kV), it is considered as a medium transmission line. Due to sufficient length and voltage of the line, the capacitance effects are taken into account.

3) Long transmission lines! – When the length of an overhead transmission line is more than 150 km and line voltage is very high (>100 kV), it is considered as a long transmission line.

ch-4 performance of short & medium lines Dt-2.8.21

performance of single phase short transmission lines

- As stated earlier, the effects of line capacitance are neglected for a short transmission line.
- Therefore while studying the performance of such a line, only resistance and inductance of the line are taken in to account.
- The equivalent ckt of a single phase short transmission line is shown in fig.
- There the total line resistance and inductance are shown as concentrated or lumped instead of being distributed.

The ckt is a simple a.c series ckt,

Let, I = Load current

R = loop resistance i.e resistance of both conductors

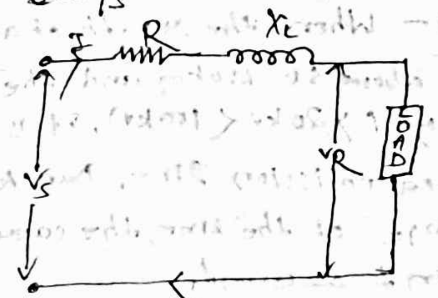
X_L = loop reactance

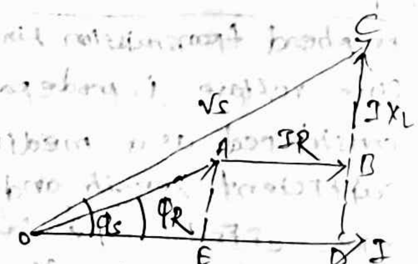
V_R = Receiving end voltage

$\cos\phi_R$ = Receiving end power factor (lagging)

V_S = sending end voltage

$\cos\phi_S$ = sending end power factor





$$(OC)^2 = (OD)^2 + (DC)^2$$

$$V_S^2 = (OE+ED)^2 + (DB+BC)^2$$

$$= (V_R\cos\phi_R + IR)^2 + (V_R\sin\phi_R + IX_L)^2$$

$$\therefore V_S = \sqrt{(V_R\cos\phi_R + IR)^2 + (V_R\sin\phi_R + IX_L)^2}$$

i) % age voltage regulation: $\frac{V_S - V_R}{V_R} \times 100$

ii) Sending end p.f, $\cos\phi_S = \frac{OD}{OC} = \frac{V_R\cos\phi_R + IR}{V_S}$

iii) power delivered $= V_R I_R \cos\phi_R$

Line losses $= I^2R$

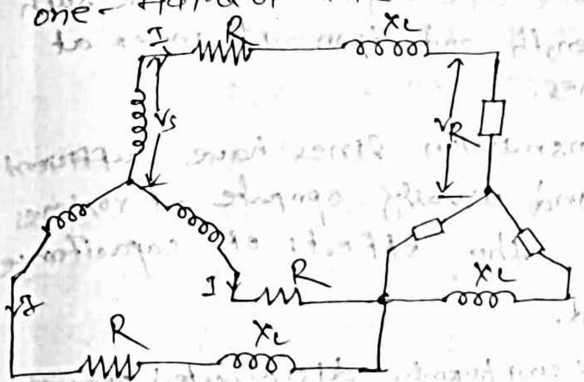
power sent out $= V_R I_R \cos\phi_R + I^2R$

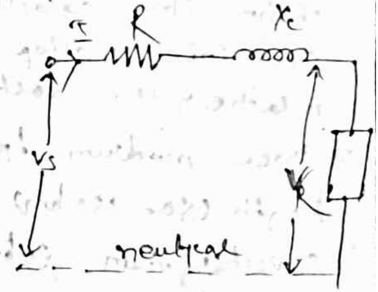
% age transmission efficiency $= \frac{\text{power delivered}}{\text{power sent out}} \times 100$

$$= \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I^2R} \times 100$$

Three-phase short transmission lines:-

- For reasons associated with economy, transmission of electric power is done by 3-phase system.
- This system may be regarded a consisting of three single phase units, each wire transmitting one-third of the total power.





- There fore, expression for regulation, efficiency etc derived for a single phase line can also be applied to a 3-phase system.
- Since only one phase is considered, phase values of 3-phase system should be taken.
- Thus V_S and V_R are the phase voltages, whereas R and X_L are the resistance and inductive reactance perphase respectively.

1) Effect of Regulation

% age voltage Regulation: $\frac{IR\cos\phi_R - IX_L\sin\phi_R}{V_R} \times 100$ (for lagging)

% age voltage Regulation: $\frac{IR\cos\phi_R + IX_L\sin\phi_R}{V_R}$ (for leading)

2) Effect on transmission efficiency:-

$P = V_R * I\cos\phi_R$ (for 1 phase line)

$\therefore I = \frac{P}{V_R\cos\phi_R}$

$P = 3V_R I\cos\phi_R$ (for 3 phase line)

$\therefore I = \frac{P}{3V_R\cos\phi_R}$

Medium transmission lines:-

→ In short transmission line calculations, the effects of the line capacitance are neglected because such lines have smaller length and transmit power at relatively low voltages.

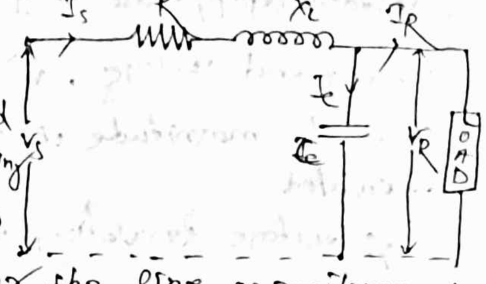
→ Since medium transmission lines have sufficient length (50-150 km) and usually operate at voltage greater than 20 kV, the effects of capacitance can not be neglected.

→ The capacitance is uniformly distributed over the entire of the line.

→ The most commonly used methods (known as localised capacitance methods) for the solution of medium transmission lines are:-

1) End condenser method.
2) Nominal T method.
3) Nominal π method.

1) End condenser method:-



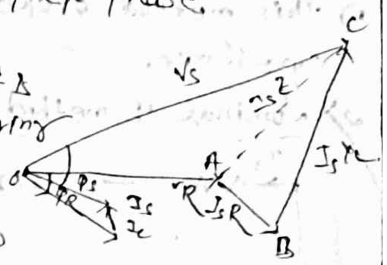
→ In this method, the capacitance of the line is lumped or concentrated at the receiving (or) load end as shown in fig.

→ This method of localising the line capacitance at the load end overestimates the effects of capacitance.

→ One phase of the 3-phase transmission line is shown at fit & more convenient to work in phase instead of line-to-line values.

Let, I_R = load current per phase;
R = Resistance per phase
X_L = Inductive reactance per phase
C = capacitance per phase
$\cos\phi_R$ = Receiving end power factor (lagging)
V_s = sending end voltages per phase.

The phasor diagram for the ckt is shown in fig. Taking the receiving end voltage $\vec{V_R}$ as the reference phase we have, $\vec{V_R} = V_R + j0$



load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

capacitive current $\vec{I_C} = j\vec{V_R}\omega C = j2\pi f C\vec{V_R}$

The sending end current $\vec{I_s}$ is the phase sum of load current $\vec{I_R}$ and capacitive current $\vec{I_C}$ i.e.

$\vec{I_s} = \vec{I_R} + \vec{I_C}$

$= I_R(\cos\phi_R - j\sin\phi_R) + j2\pi f C V_R$

$= I_R\cos\phi_R + j(-I_R\sin\phi_R + 2\pi f C V_R)$

voltage drop/phase $= \vec{I_s} \vec{Z} = \vec{I_s}(R + jX_L)$

Sending end voltage, $\vec{V_s} = \vec{V_R} + \vec{I_s}\vec{Z} = \vec{V_R} + \vec{I_s}(R + jX_L)$

Thus the magnitude of sending end voltage V_s can be calculated.

% voltage Regulation $= \frac{V_s - V_R}{V_R} \times 100$

% voltage transmission efficiency $= \frac{\text{power delivered/phase}}{\text{power delivered/phase} + \text{losses/phase}} \times 100$

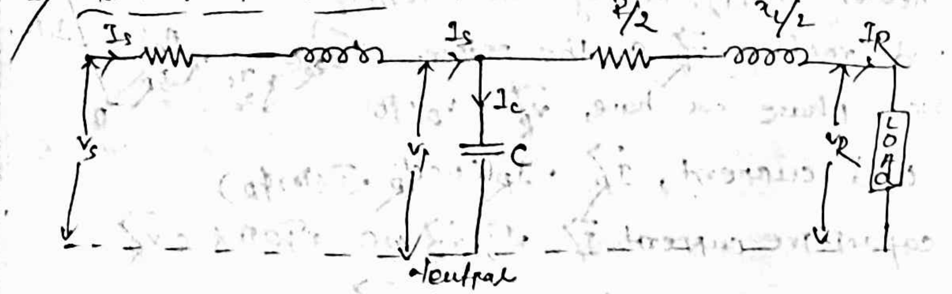
$= \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I_s^2 R} \times 100$

Limitations:— Although end condenser method for the solution of medium lines is simple to work out calculations, yet it has the following drawbacks:—

i) There is a considerable error (about 10%) in calculations because the distributed capacitance has been assumed to be lumped or concentrated.

ii) This method overestimates the effects of the line capacitance.

2) Nominal T method:—



→ The whole line capacitance is assumed to be concentrated at the middle point of the line and half the line resistance and reactance are lumped on its either side.

→ Therefore, in this arrangement, full charging current flows over half the line.

→ One phase of 3-phase transmission line is shown as it is advantageous to work in phase instead of line-to-line values.

Let, I_R = load current per phase

R = Resistance per phase

C = capacitance per phase

V_s = sending end voltage/phase

X_L = Inductive reactance per phase

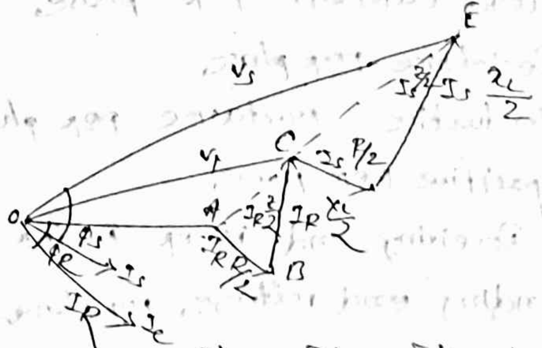
$\cos\phi_R$ = Receiving end power factor lagging

V_1 = voltage across capacitor C.

The phase diagram for the ckt is shown in. Taking the receiving end voltage $\vec{V_R}$ as the reference phasor we have,

Receiving end voltage $\vec{V_R} = V_R + j0$

Load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$



voltage across C, $\vec{V_1} = \vec{V_R} + \vec{I_R}\vec{Z}/2$

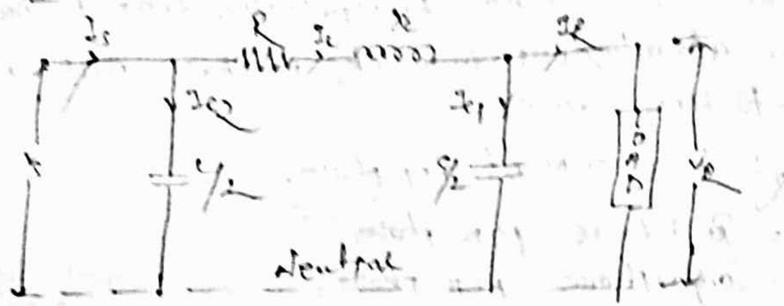
$= V_R + I_R(\cos\phi_R - j\sin\phi_R)\left(\frac{R}{2} + j\frac{X_L}{2}\right)$

capacitive current $\vec{I_C} = j\omega C\vec{V_1} = j2\pi fC\vec{V_1}$

sending end current $\vec{I_s} = \vec{I_R} + \vec{I_C}$

sending end voltage $\vec{V_s} = \vec{V_1} + \vec{I_s}\frac{\vec{Z}}{2} = \vec{V_1} + \vec{I_s}\left(\frac{R}{2} + j\frac{X_L}{2}\right)$

3) Nominal π method :-



- capacitance of each conductor i.e. line to neutral is divided into two halves; one half being lumped at the sending end and the other half at the receiving end as shown in fig.
- It is obvious that capacitance at the sending end has no effect on the line drop.
- However, its charging current must be added to line current in order to obtain the total sending end current.

let, I_R = load current per phase.

R = Resistance per phase.

X_L = Inductive reactance per phase.

C = capacitive per phase.

$\cos\phi_R$ = Receiving end power factor lagging.

V_S = sending end voltage per phase

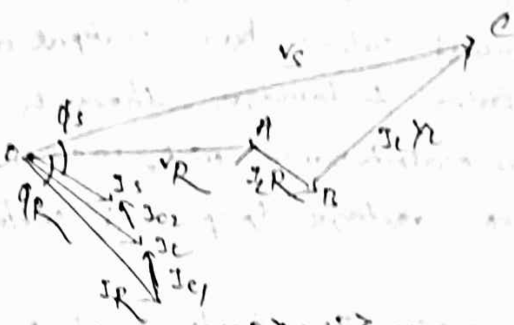
The phasor diagram for the ckt is shown. Taking the receiving end voltage as the reference phase, we have,

$$\vec{V_R} = V_R + j0$$

load current $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

charging current at load end is

$$\vec{I_{C_1}} = j\omega(C/2)\vec{V_R} = j\pi fC\vec{V_R}$$



Line current, $\vec{I_L} = \vec{I_R} + \vec{I_{C_1}}$

sending end voltage $\vec{V_S} = \vec{V_R} + \vec{I_L}\vec{Z} = \vec{V_R} + \vec{I_L}(R+jX_L)$

charging current at the sending end is,

$$\vec{I_{C_2}} = j\omega(C/2)\vec{V_S} = j\pi fC\vec{V_S}$$

∴ sending end current, $\vec{I_S} = \vec{I_L} + \vec{I_{C_2}}$

ch-7 underground cables Dt- 14-06-2021

Introduction :-

→ Electric power can be transmitted or distributed either by overhead system or by underground cables.

→ The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chances of faults, smaller voltage drop and better general appearance.

→ However, their major draw back is that they have greater installation cost and introduce insulation problems at high voltages compared with the equivalent overhead system.

→ For this reason, underground cables are employed where it is impracticable to use overhead lines.

underground cables:-

→ An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

In general, a cable must fulfil the following necessary requirements:-

i) The conductor used in cables should be tinned stranded copper or aluminium of high conductivity.

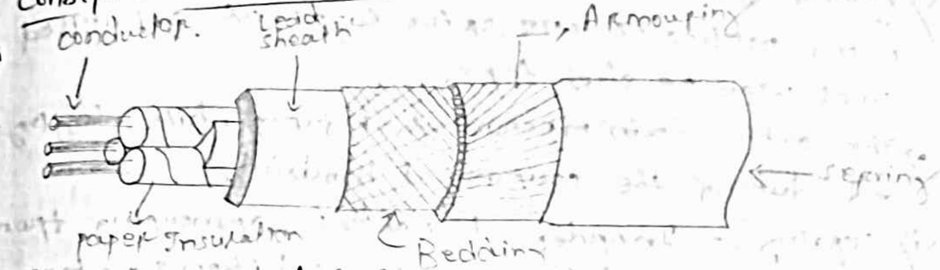
ii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.

iii) The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.

iv) The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

v) The materials used in the manufacture of cables should be such that there is complete chemical and physical stability throughout.

Construction of cables



(Construction of cable)

i) Cores of conductors:- A cable may have one or more than one core (conductor) depending up on the type of service for which it is intended.

→ The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

ii) Insulation:- Each core or conductor is provided with a suitable thickness of insulation the thickness of layer depending up on the voltage to be withstood by the cable.

→ The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound.

iii) Metallic sheath:- In order to protect the cable from moisture, gases or other damaging liquids in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation.

iv) **Bedding:**— Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape.

→ The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

v) **Armouring:**— Over the bedding, armouring is provided which consists of one or two layers of galvanised steel wire or steel tape.

→ The cable from mechanical injury while laying it and during the course of handling.

vi) **Serving:**— In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring. This is known as serving.

Insulating materials for cables:—

The proper choice of insulating material for cables is of considerable importance.

→ In general, the insulating materials used in cables should have the following properties:—

i) High insulation resistance to avoid leakage current.

ii) High mechanical strength to withstand the mechanical handling of cables.

iii) High dielectric strength to avoid electrical break down of the cables.

iv) Non-hygroscopic

v) Non-inflammable

vi) Low cost so as to take the underground system a viable proposition.

vii) Unaffected by acids and alkalies to avoid any chemical action.

The principal insulating materials used in cables are rubber, vulcanised india rubber, impregnated paper, varnished cambric and polyvinylchloride.

i) **Rubber:**— Rubber may be obtained from milky sap of tropical trees or it may be produced from oil products.

→ It has relative permittivity varying betn 2 and 3, dielectric strength is about 30kV/mm and resistivity of insulation is 10^{17} Ω cm.

→ It suffers from some major drawbacks viz, readily absorbs moisture, max safe temperature is low (about 38°C), soft and liable to damage due to rough handling and ages when exposed to light.

→ Therefore, pure rubber cannot be used as an insulating material.

2) **Vulcanised India Rubber:**— It is prepared by mixing pure rubber with mineral material such as zinc oxide, red lead etc and 3 to 5% of sulphur.

→ Vulcanised India rubber has greater mechanical strength, durability and wear resistant property than pure rubber.

→ Its main drawback is that sulphur reacts very quickly with copper and for this reason, cables using VIR insulation have tinned copper conductor.

→ The VIR insulation is generally used for low and moderate voltage cables.

3) Impregnated paper:—

→ It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinic or napthenic material.

→ It is because it has the advantages of low cost, low capacitance, high dielectric strength and high insulation resistance.

→ The only disadvantage is that paper is hygroscopic and even if it is impregnated with suitable compound, it absorbs moisture and thus lowers the insulation resistance of the cable.

→ For this reason, paper insulated cables are always provided with some protective covering.

4) Varnished cambric:— It is a cotton impregnated and coated with varnish.

→ This type of insulation is also known as empire tape.

→ As the varnished cambric is hygroscopic, therefore such cables are always provided with metalic sheath.

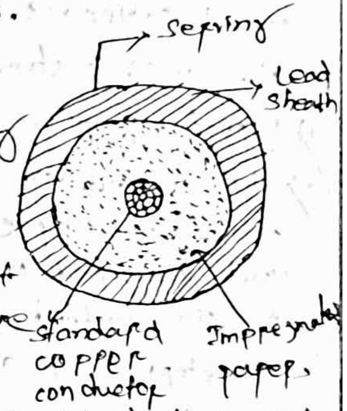
→ Its dielectric strength is about 4 kV/mm and permittivity is 2.5 to 3.8.

5) Polyvinyl chloride (PVC):— The insulating material is a synthetic compound. It is obtained from the polymerisation of acetylene and is in the form of white powder.

→ Polyvinyl chloride has high insulation resistance, good dielectric strength and mechanical toughness over a wide range of temperatures.

→ This type of insulation is preferred over VIR in extreme enviromental conditions such as in cement factory or chemical factory.

→ As the mechanical properties of PVC are not so good as those of rubber, therefore, PVC insulated cables are generally used for low and medium domestic lights and power installations.



Classification of cables:—

→ Cables for underground service may be classified in two ways according to (i) the type of insulating material used in their manufacture (ii) the voltage for which they are manufactured.

→ According to which cables can be divided into the following groups:—

i) Low-tension (L.T) cables – up to 1000 V.

ii) High-tension (H.T) cables – up to 11,000 V

→ A cable may have one or more than one core depending upon the type of service for which it is intended.

→ It may be (i) single-core (ii) two-core (iii) Three-core (iv) Four-core etc.

→ For a 3-phase service, either 3-single core cables or three core cable can be used depending upon the operating voltage and load demand.

→ The constructional details of a single-core low tension cable

→ It consists of one circular core of conductor tinned stranded copper (or aluminium) insulated by layers of impregnated paper.

→ The principle advantages of single-core cables simple construction and availability of larger copper section.

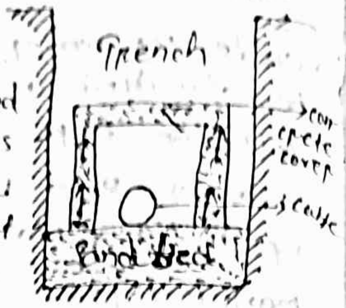
Laying of underground cables:—

-> There are three main methods of laying underground cables viz, direct laying, drawing system and the solid system.

i) Direct laying:—

-> This method of laying underground cables is simple and cheap and is much favoured in modern practices.

-> In this method, a trench of about 1.5 meter deep and 45cm wide is dug.



-> The trench is covered with a layer of fine sand (of about 10cm thickness) and the cable is laid over this sand bed.

-> The sand prevents the entry of moisture from the ground and thus protects the cable from decay.

-> After the cable has been laid in the trench it is covered with another layer of sand of about 10 cm thickness.

-> The trench is than covered with bricks and other materials in order to protect the cable from mechanical injury.

Advantages:—

i) It is a simple and less costly method.

ii) It gives best conditions for dissipating the heat generated in the cables.

iii) It is a clean and safe method as the cable is invisible and free from external disturbances.

Disadvantages:—

i) The extension of load is possible only by a completely new excavation which may cost as much as the original work.

ii) The alterations in the cable network will be made easily

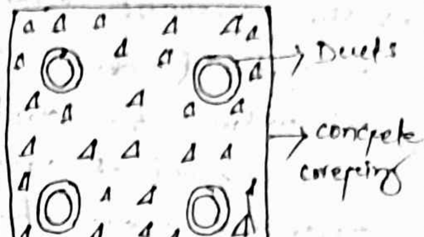
iii) The maintenance cost is very high

iv) Localisation of fault is difficult.

This method of laying cables is used in open areas where excavation can be done conveniently and at low cost.

ii) Drawing systems:—

-> In this method, conduit or duct of glazed stone or cast iron or concrete are laid in the ground with manholes at the suitable positions along the cable route.



-> The cables are then pulled into position from man holes.

-> Three of the ducts carry transmission cables and the fourth duct carries relay protection connection, pilot wires.

-> Care must be taken that where the duct line changes direction; depts, dips and offsets be made with a very long radius or it will be difficult to pull a large cable between the man holes.

-> The cables to be laid in this way need not be armoured but must be provided with serving hessian and jute in order to protect them when being pulled into the ducts.

Advantages—

i) Repairs, alterations or additions to the cable can be made without opening the ground.

ii) As the cables are not armoured, therefore, joints become simpler and maintenance cost is reduced considerably.

iii) There are very less chances of fault occurrence due to strong mechanical protection provided by the system.

Disadvantages:—

i) The initial cost is very high.

ii) The current carrying capacity of the cables is reduced due to the close grouping of cables and unfavourable conditions for dissipation of heat.

This method of cable laying is suitable for congested areas where excavation is expensive and inconvenient, for once the conduits have been laid, repairs or alterations can be made without opening the ground.

This method is generally used for short length cable routes such as in workshops, road crossings, where frequent digging is costlier or impossible.

3) Solid system:—

→ In this method of laying, the cable is laid in open pipes or troughs dug out in earth along the cable route.

→ After the cable is laid in position, the troughing is filled with a bituminous or asphaltic compound and covered over.

→ Cables in this manner are usually plain lead covered because troughing affords good mechanical protection.

Disadvantages:—

i) It is more expensive than direct laid system.

ii) It requires skilled labour and favourable weather conditions.

iii) Due to poor heat dissipation facilities, the current carrying capacity of the cable is reduced.

In view of these disadvantages, this method of laying cables is rarely used now-a-days.

Types of cables faults:—

→ Cables are generally laid directly in the ground or in ducts in the underground distribution system. For this reason, there are little chances of faults in underground cables.

The following are the faults most likely to occur in underground cables:—

i) Open-circuit-fault:— When there is a break in the conductor of a cable, it is called open ckt fault.

→ The open-ckt fault can be checked by a megger.

→ For this purpose, the three conductors of the 3-core cable at the far end are shorted and earthed.

→ The megger will indicate zero resistance in the ckt of the conductor that is not broken.

→ However, if the conductor is broken, the megger will indicate infinite resistance in its ckt.

ii) Short-ckt-fault:— When two conductors of a multi core cable come in electrical contact with each other due to insulation failure, it is called a short-ckt fault.

→ Again we can seek the help of a megger to check this fault. For this purpose, the two terminals of the megger are connected to any two conductors.

- If the megger gives zero reading, it indicates short-ckt fault bet^n these conductors.

iii) **Earth fault**:- When the conductor of a cable comes in contact with earth, it is called earth fault or ground fault.

- To identify this fault, one terminal of the megger is connected to the conductor and the other terminal connected to earth.

- If the megger indicates zero reading, it means the conductor is earthed.

Loop Tests for location of Faults in underground cables

However, two popular methods known as loop tests are:

i) murray loop test

ii) varley loop test.

These simple tests can be used to locate the earth fault or short-ckt fault in underground cables provided that a sound cable runs along the faulty cable.

Both these tests employ the principle of wheatstone bridge for fault location.

- **murray loop test**

The murray loop test is the most common and accurate method of locating earth fault or short-ckt fault in underground cables.

i) **Earth fault**:- The ckt diagram for locating the earth fault by murray loop test.

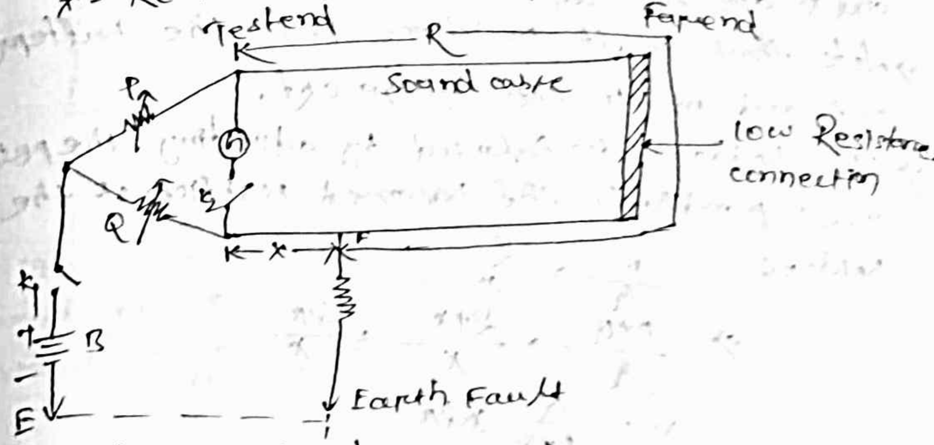
- Here AB is the sound cable and CD is the faulty cable; the earth fault occurring at point F.

- The far end D of the faulty cable is joined to the far end B of the sound cable through a low resistance link.

- Two variable resistance P and Q are joined to ends A and C respectively and serve as the ratio arms of the Wheatstone bridge.

Let, R = Resistance of the conductor loop up to the fault from the test

X = Resistance of the other length of the loop



Note that, P, Q, R and X are the four arms of the Wheatstone bridge. The resistance P and Q are varied till the galvanometer indicates zero deflection.

In the balanced position of the bridge, we have

$$\frac{P}{Q} = \frac{R}{X}$$

$$\frac{P}{Q} + 1 = \frac{R}{X} + 1$$

$$(or)\quad \frac{P+Q}{Q} = \frac{R+X}{X}$$

If 'r' is the resistance of each cable, then $R+X = 2r$

$$\therefore \frac{P+Q}{Q} = \frac{2r}{X}$$

$$(or)\quad X = \frac{Q}{P+Q} \times 2r$$

If l is the length of each cable in meters, then resistance per metre length of cable $= \frac{r}{l}$

∴ Distance of fault point from test end is,

$$d = \frac{x}{r/l} = \frac{Q}{P+Q} \times 2R \times \frac{l}{r}$$

$$= \frac{Q}{P+Q} \times 2l$$

$$d = \frac{Q}{P+Q} \times (\text{loop length})\ ^{*}\text{meters.}$$

ii) **short-ckt fault:**– The ckt diagram for locating the short ckt fault by murray loop test. Again P, Q, R and x are the four arms of the bridge.

→ Note that fault resistance is in the battery ckt and not in the bridge ckt.

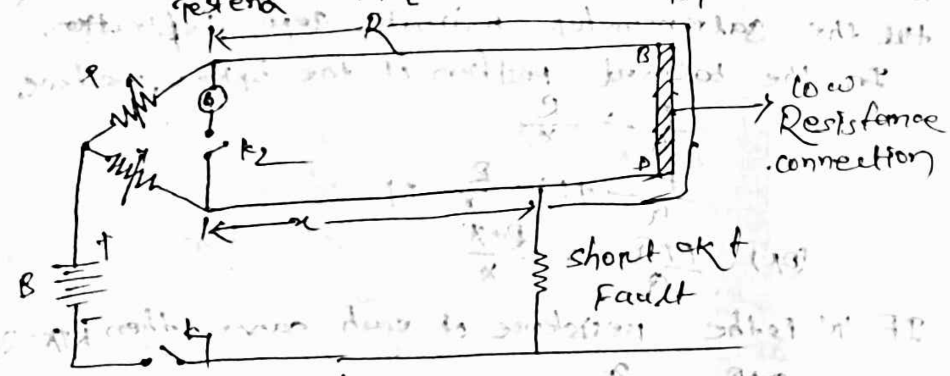
→ The bridge is balanced by adjusting the resistances P and Q. In the balanced position of the bridge:

$$\frac{P}{Q} = \frac{R}{x}$$

$$\Rightarrow \frac{P+Q}{Q} = \frac{R+x}{x} = \frac{2R}{x}$$

$$x = \frac{Q}{P+Q} \times 2R$$

$$x = \frac{Q}{P+Q} \times (\text{loop length})\ \text{meters.}$$



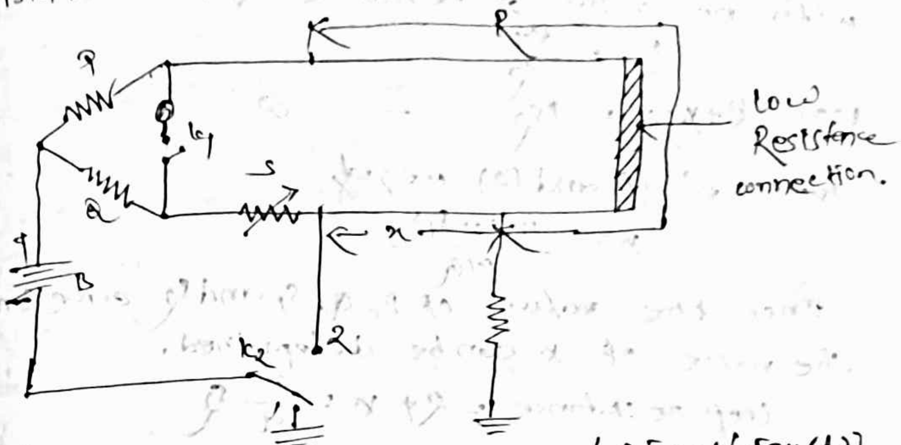
2) **Varley loop Test:**–

→ The varley loop test is also used to locate earth fault or short-ckt fault in underground cables.

→ This test also employes wheatstone bridge principle.

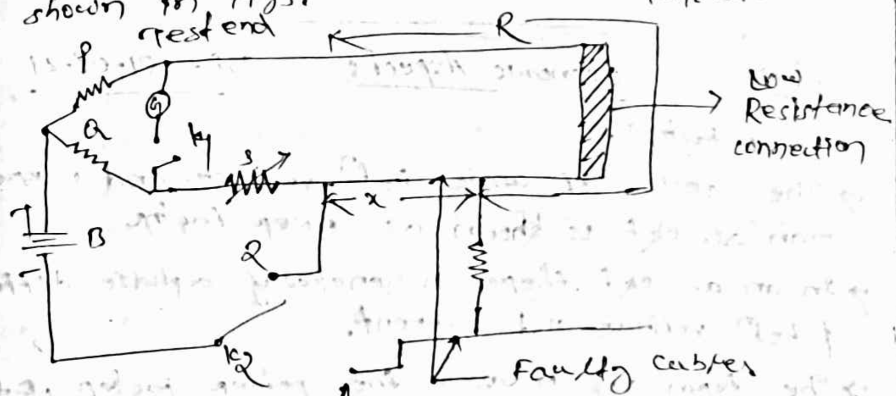
→ It differs from murray loop test in that here the ratio arms P and Q are fixed resistance.

→ Balance is obtained by adjusting the variable resistance S.



[Varley loop Test (Earth fault)]

The connection diagram for locating the earth fault and short-ckt fault by varley loop test are shown in Figs.



Varley loop Test (short ckt Test)

For earth fault or short-ckt fault, the key K_2 is first thrown to position 1. The variable resistance 'S' is varied till the bridge is balanced for resistance value of S_1. Then

$$\frac{P}{Q} = \frac{R}{x+S_1}$$

(or) $$\frac{P+Q}{Q} = \frac{R+x+S_1}{x+S_1} \Rightarrow x = \frac{Q(R+x) - PS_1}{P+Q} \quad \text{—①}$$

Now key k_2 is thrown to position 2 (for earth fault or short-ckt fault) and bridge is balanced with new value of resistance S_2. Then,

$$\frac{P}{Q} = \frac{R+X}{S_2}$$

(or) $(R+X)Q = PS_2$ —— ②

From eqⁿ ① and ② we get,

$$X = \frac{P(S_2 - S_1)}{P+Q}$$

Since the values of P, Q, S_1 and S_2 are known the value of x can be determined.

Loop resistance = $R + X = \frac{P}{Q} S_2$

If 'r' is the resistance of the cable per metre length, then, Distance of Fault from the test end is, $d = \frac{x}{r}$ metres.

Ch-8   **Economic Aspects**   DT - 21-06-21

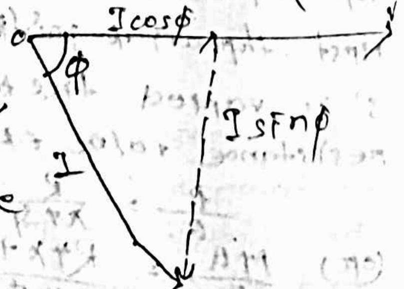
Power Factor:-

→ The cosine of angle betⁿ voltage and current in an a.c. ckt is known as power factor.

→ In an a.c ckt, there is generally a phase difference φ betⁿ voltage and current.

→ The term cosφ is called the power factor of the ckt.

→ If the ckt is inductive, the current lags behind the voltage and the power factor is referred to as lagging.



→ However, in a capacitive ckt, current leads the voltage and power factor is said to be leading.

→ Consider an inductive ckt taking a lagging current I from supply voltage V; the angle of lag being φ. The phasor diagram of the ckt is shown in fig.

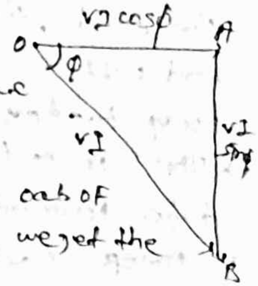
→ The ckt current I can be resolved into two perpendicular components, namely;

a) I cosφ in phase with V.

b) I sinφ 90° out of phase with V.

b) **power triangle:-**

→ The analysis of power factor can also be made in terms of power drawn by the a.c ckt.



→ If each side of the current triangle OAB of Fig. is multiplied by voltage V, then we get the power triangle OAB.

OA = VI cosφ and represents the active power in watts or kW.

AB = VI sinφ and represents the reactive power in VAR or kVAR.

OB = VI and represents the apparent power in VA or kVA.

The following points may be noted from the power triangle:

i) The apparent power in an a.c ckt has two components viz; active and reactive power at right angle to each other.

$$OB^2 = OA^2 + AB^2$$

(or) (apparent power)² = (Active power)² + (Reactive power)²

$$(KVA)^2 = (KW)^2 + (KVAR)^2$$

ii) Power Factor, $\cos\phi = \frac{OA}{OB} = \frac{\text{active power}}{\text{apparent power}} = \frac{kW}{kVA}$

Thus the power factor of a ckt may also be defined as the ratio of active power to the apparent power. This is a perfectly general definition and can be applied to all cases, whatever be the wave form.

iii) The lagging reactive power is responsible for the low power factor. It is clear from the power triangle that smaller the reactive power component, the higher is the power factor of the ckt.

$KVAR = KVA \sin\phi = \frac{kW}{\cos\phi} \sin\phi$

$KVAR = kW \tan\phi$

iii) For leading currents, the power triangle becomes reversed. This fact provides a key to the power factor improvement. If a device taking leading reactive power (e.g. capacitor) is connected in parallel with the load, then the lagging reactive power of the load will be partly neutralised, thus improving the power factor of the load.

v) The power factor of a ckt can be defined in one of the following three ways:

a) Power factor = $\cos\phi$ = cosine of angle betn V and I.

b) Power factor = $\frac{R}{Z}$ = $\frac{\text{Resistance}}{\text{Impedance}}$

c) Power factor = $\frac{VI\cos\phi}{VI}$ = $\frac{\text{Active power}}{\text{Apparent power}}$

vi) The reactive power is neither consumed in the ckt nor it does any useful work. It merely flows back and forth in both directions in the ckt. A wattmeter does not measure reactive power.

Disadvantages of low power factor:-

The power factor plays an importance role in ac ckts since power consumed depends upon this factor.

$P = V_L I_L \cos\phi$ (for single phase supply)

$I_L = \frac{P}{V_L \cos\phi}$ —— (1)

$P = \sqrt{3} V_L I_L \cos\phi$ (for 3-phase supply)

$I_L = \frac{P}{\sqrt{3} V_L \cos\phi}$ —— (2)

→ It is clear from above that for fixed power & voltage, the load current is inversely proportional to the power factor.

→ lower the power factor, higher is the load current and vice-versa.

→ A power factor less than unity results in the following disadvantages:-

i) Large kVA rating of equipment:- The electrical machinery (e.g. alternators, transformers, switchgears) is always rated in kVA.

Now, $kVA = \frac{kW}{\cos\phi}$

→ It is clear that kVA rating of the equipment is inversely proportional to power factor.

→ The smaller the power factor, the larger is the kVA rating.

→ Therefore, at low power factor, the kVA rating of the equipment has to be made more, making the equipment larger and expensive.

ii) Greater conductor size:- To transmit or distribute a fixed amount of power at constant voltage, the conductor will have to carry more current at low power factor.

iii) Larger copper loss:- The large current at low power factor causes more I^2R losses in all the elements of the supply system. This results in poor efficiency.

iv) Poor voltage regulation:- The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors. The results in the decreased voltage available and the supply end.

v) Reduced handling capacity of system:- The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilisation of installed capacity.

causes of low power factor :-

low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system is lower than 0.8.

i) most of the ac motors are of induction type (1φ and 3φ induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0.2 to 0.3) and rises 0.8 or 0.9 at full load.

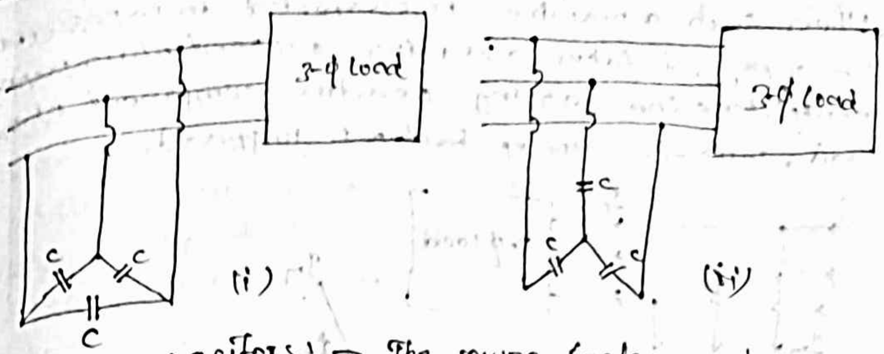
ii) Arc lamps electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

iii) The load on the power system is varying; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetisation current. This results in the decreased power factor.

power factor Improvement Equipment :-

Normally, the power factor of the whole load on a large generating station in the region of 0.8 to 0.9. This can be achieved by the following equipments:-

1) static capacitors
2) synchronous condenser
3) phase advancers.



i) static capacitors :- The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor.

-) The capacitor draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load.

Advantages :-

i) They have low losses.

ii) They require little maintenance as there are no rotating parts.

iii) They can be easily installed as they are light and required no foundation.

iv) They can work under ordinary atmospheric cond.

Disadvantages :-

i) They have short service life ranging from 8 to 10 year.

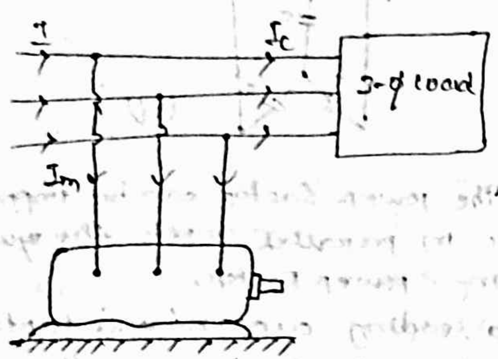
ii) They are easily damaged if the voltage exceeds the rated value.

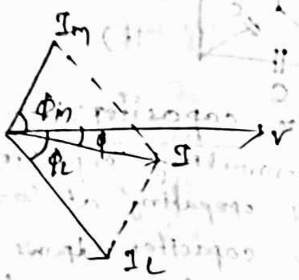
iii) Once the capacitors are damaged their repair is uneconomical.

2) Synchronous condenser :- A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor.

-) An over-excited synchronous motor running on no-load is known as synchronous condenser.

→ When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralises the lagging reactive component of the load. Thus the power factor is improved.





3-φ synchronous motor

Advantages:—

i) By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount.

ii) The motor windings have high thermal stability to short ckt currents.

iii) The faults can be removed easily.

Disadvantages:—

i) There are considerable losses in the motor.

ii) The maintenance cost is high

iii) It produces noise.

iv) Except in sizes above 500KVA, the cost is greater than that of static capacitors of the same rating.

→ As a synchronous motor has no self-starting torque therefore, an auxiliary equipment has to be provided for this purpose.

3) Phase advancers:—

→ Phase advancers are used to improve the power factor of induction motors.

→ The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags behind the supply voltage by 90°.

→ If the exciting ampere turns can be provided from some other ac source, then the stator winding will be relieved of exciting current & the power factor of the motor can be improved.

→ This job is accomplished by the phase advancer which is simply an ac exciter.

Variable load on power station:—

→ The load on a power station varies from time to time due to uncertain demands of the consumers and is known as variable load on the station.

Load curves:—

The curve showing the variation of load on the power station with respect to time is known as a load curve.

→ The load on a power station is never constant; it varies from time to time.

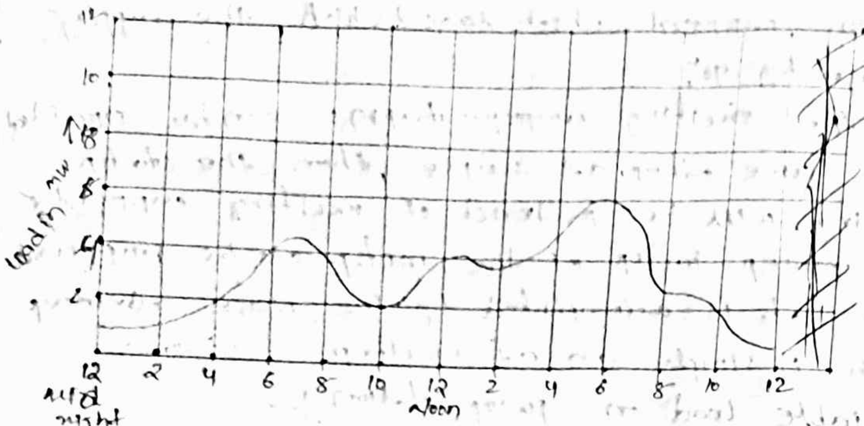
→ These load variations during the whole day (i.e. 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph.

→ The curve thus obtained is known as daily load curve as it shows the variations of load with time during the day.

→ The monthly load curve can be obtained from the daily load curves of that month.

→ For this purpose, average values of power over a month at different times of the day are calculated and then plotted on the graph.

→ The monthly load curve is generally used to fix the rates of energy.



Important terms and Factors:—

1) **Connected load:**— It is the sum of continuous ratings of all the equipment connected to supply system

2) **Maximum demand:**—
→ It is the greatest demand of load on the power station during a given period.

3) **Demand Factor:**— It is the ratio of max. demand on the power station to its connected load. i.e

$$\text{Demand Factor} = \frac{\text{Maximum demand}}{\text{connected load}}$$

4) **Average load:**— The average of loads occurring on the power station in a given period (Day or month or year) is known as average load or average demand

$$\text{Daily average load} = \frac{\text{No. of units (kWh) generated in day}}{24 \text{ hours}}$$

$$\text{monthly average load} = \frac{\text{No. of units (kWh) generated in a month}}{\text{No. of hours in a month}}$$

$$\text{Yearly average load} = \frac{\text{No. of units (kWh) generated in year}}{8760 \text{ hours}}$$

5) **Load Factor:**— The ratio of average load to the maximum demand during a given period is known as load factor i.e

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}}$$

If the plant is in operation for 'T' hours

$$\text{Load factor} = \frac{\text{Average load} \times T}{\text{Max. demand} \times T}$$

$$= \frac{\text{units generated in T hours}}{\text{Max. demand} \times T \text{ hours}}$$

6) **Diversity Factor:**— The ratio of the sum of individual max. demands to the max. demand on power station is known as diversity factor i.e

$$\text{Diversity Factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$$

7) **Plant capacity factor:**— It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period, i.e.

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}$$

$$= \frac{\text{Average demand} \times T}{\text{Plant capacity} \times T}$$

$$= \frac{\text{Average demand}}{\text{Plant capacity}}$$

Types of Loads:—
A device which taps electrical energy from the electric power system is called a load on the system.
The various types of loads on the power system are:

1) **Domestic load:**— Domestic load consists of lights, fans, refrigerators, heaters, television, small motors for pumping water etc.

ii) **Commercial load:**– Commercial load consists of lighting for shops, fans and electric appliances used in restaurant etc.

iii) **Industrial load:**– Industrial load consists of load demand by industries. The magnitude of industrial load depends upon type of industry.

iv) **Municipal load:**– Municipal load consists of street lighting, power required for water supply and draining purposes.

v) **Traction load:**– This type of load includes tram cars, trolley buses, railway etc.

vi) **Irrigation load:**– This type load is the electric power needed for pumps driven by motors to supply water to fields.

Prob: A generating station has a connected load of 43MW and a max. demand of 20MW; the units generated being 61.5×10^6 per annum. Calculate (i) the demand factor and (ii) load factor.

Sol^n

i) Demand Factor $= \frac{\text{Max. demand}}{\text{connected Load}} = \frac{20}{43} = 0.465$

ii) Average demand $= \frac{\text{units generated/annum}}{\text{Hours in a year}} = \frac{61.5 \times 10^6}{876}$
$= 7020\,kW$

∴ Load Factor $= \frac{\text{Average demand}}{\text{Max. demand}}$

$= \frac{7020}{20 \times 10^3} = 0.351$ (or) 35.1%

Types of Tariff

Dt - 29-06-21

→ The rate at which electrical energy is supplied to a consumer is known as tariff.

Objectives of tariff:–

Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit.

Therefore, a tariff should include the following items:–

i) Recovery of cost of producing electrical energy at the power station.

ii) Recovery of cost on ~~producing electri~~ the capital investment in transmission and distribution systems.

iii) Recovery of cost of operation and maintenance of supply of electrical energy e.g. metering equipment billing etc.

iv) A suitable profit on the capital investment.

Desirable characteristics of a Tariff:–

i) **Proper return:**– The tariff should be such that it ensures the proper return from each consumer.

→ In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit.

ii) **Fairness:**– The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy.

→ Thus a big consumer should be charged at a lower rate than a small consumer.

→ It is because increased energy consumption spreads the fixed charge over a greater number of units, thus reducing the overall cost of producing electrical energy.

iii) **Simplicity:**– The tariff should be simple so that an ordinary consumer can easily understand it.

iv) Reasonable profit:– The profit element in the tariff should be reasonable.
→ An electric supply company is a public utility company and generally enjoys the benefits of monopoly.

v) Attractive:– The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy.
→ Efforts should be made to fix the tariff in such away so that consumers can pay easily.

Types of Tariff

1) Simple tariff:– When there is a fixed rate per unit of energy consumed, it is called a simple tariff (or) uniform rate tariff.

Disadvantages:–
i) There is no discrimination bet? different types of consumers since every consumer has to pay equitably for the fixed charges.
ii) The cost per unit delivered is high.
iii) It does not encourage the use of electricity.

2) Flat rate tariff:– When different types of consumers are charged at different uniform per unit rates, it is called as flat rate tariff.

Disadvantages:–
i) Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.
ii) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

3) Block rate tariff:– When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates. It is called a block rate tariff.
i) The advantages of such of tariff is that the consumer gets an incentive to consume more electrical energy. This increase the load factor of the system and hence the cost of generation is reduced.
→ This type of tariff is being used for majority of residential and small consumers.

4) Two-part-tariff:– When the rate of electrical energy is charged on the basis of max. demand of the consumer and the units consumed, it is called a two-part tariff.
→ In two-part tariff, the total charge to be made from the consumer is split into two components viz, fixed charges and running charges.
→ Thus the consumer is charged at a certain amount per kW of max. demand plus a certain amount per kWh of energy consumed i.e

Total charges = Rs($b \times kW + c \times kWh$)

b = charge per kW of max. demand.
c = charge per kWh of energy consumed.

Advantages:–
i) It is easily understood by the consumers.
ii) It recovers the fixed charges which depend upon the max. demand of the consumer but are independent of the units consumed.

Disadvantages:–
i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.
ii) There is always error in assesing the max. demand of the consumer.

5) **Maximum demand tariff:-**

-> It is similar to two-part tariff with the only difference that the max. demand is actually measured by installing max. demand meter in the premises of the consumer.

-> This removes the objection of two-part tariff where the max. demand is assessed merely on the basis of the rateable value.

Prob. A consumer has a max. demand of 200 kw and 40% load factor. If the tariff is Rs. 100 per kw of max. demand plus 10 paisa kwh. Find the overall cost per kwh.

Soln units consumed/year = max. demand × L.F × Hours in a year

$= (200) \times 0.4 \times 8760$

$= 7,00,800$ kwh

Annual charges = Annual M.D charges + Annual energy charges.

$= Rs (100 \times 200 + 0.1 \times 7,00,800)$

$= Rs\ 90080$

$\therefore$ overall cost/kwh = $Rs \frac{90,080}{7,00,800} = Rs\ 0.1285$

$= 12.85$ paisa.

ch-10 **Substation** Dt - 05-07-21

-> The assembly of apparatus used to change some characteristic of electric supply is called a sub-station.

-> Sub-stations are important part of power system.

-> The continuity of supply depends to a considerable extent upon the successful operation of substations.

i) It should be located at a proper site. As far as possible, it should be located at the centre of gravity of load.

ii) It should provide safe and reliable arrangement. For safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc.

iii) It should be easily operated and maintained.

iv) It should involve minimum capital cost.

Classification of sub-stations:-

-> There are several ways of classifying sub-stations. However, the two most important ways of classifying them are according to -

1) **According to service requirement:-** A substation may be called upon to change voltage level or improve power factor or convert ac power into d.c power etc. Acc. to the service requirement, substations are classified as-

a) **Transformer substations:-** Those sub-stations which change the voltage level of electric supply are called transformer sub-stations.

b) **Switching sub-stations:-** These substations do not change the voltage level i.e incoming & outgoing lines have same voltage.

-> **Power factor correction sub-stations:-** These substations which improve the power factor of the system are called power factor correction substations.

-> Such substations are generally located at the receiving end of transmission lines.

d) Frequency changer substations:— Those sub-stations which change the supply frequency are known as frequency changer sub-stations.

e) Converting substations:— Those sub-stations which change a.c power into d.c power are called converting substations.

f) Industrial substations:— Those substations which supply power to individual industrial concerns are known as industrial sub-stations.

2) Acc. to constructional features:—

A sub-station has many components (e.g. ckt breakers, switches, fuses, instruments etc), which must be housed properly to ensure continuous and reliable service.

Acc. to constructional features, the sub-stations are classified as:-

i) Indoor sub-stations:— For voltage up to 11 kV, the equipment of the sub-station is installed indoor because of economic considerations.

-> However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages up to 66 kV.

ii) Outdoor sub-stations:— For voltage beyond 66 kV, equipment is invariably installed out door. It is because for such voltages the clearances betⁿ conductors and the space required for switches, ckt breakers and other equipment becomes so great that it is not economical to install the equipment indoor.

iii) Underground sub-stations:— In thickly populated areas, the space available for equipment and building is limited and the cost of land is high. Under such situations, the sub-station is created underground.

iv) Pole-mounted sub stations:— This is an outdoor sub-station with equipment installed overhead on H-pole or 4-pole structure.

-> It is the cheapest form of sub-stations for voltages not exceeding 11 kV (or 33 kV some cases)

Comparision betⁿ outdoor and Indoor sub-stations.

S. No.	Particular	Outdoor sub-station	Indoor substation
1.	Space Required	More	less
2.	Time required for erection	less	More
3.	Future extension	Easy	Difficult
4.	Fault location	Easier because the equipment is in full view	Difficult because the equipment is enclosed
5.	Capital cost	Low	High
6.	Operation	Difficult	Easier
7.	Possibility of fault escalation	less because greater clearances be provided	More

Transformer sub-stations:—

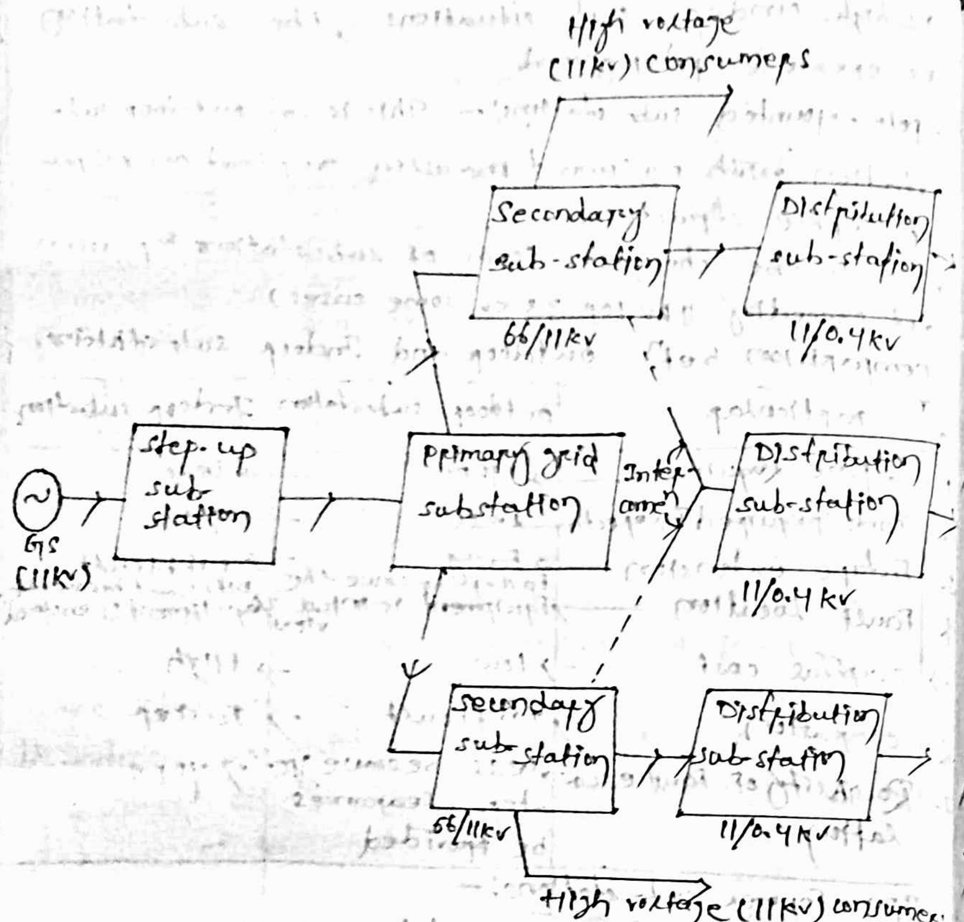
-> The majority of the sub-stations in the power system are concerned with the changing of voltage level of electric supply.

-> These are known as transformer sub-stations because transformer is the main component employed to change the voltage level.

-> Depending upon the purpose served, transformer sub-station may be classified into:-

i) Stepup substation (ii) Primary grid sub-station

iii) Secondary sub-station (iv) Distribution sub-station.



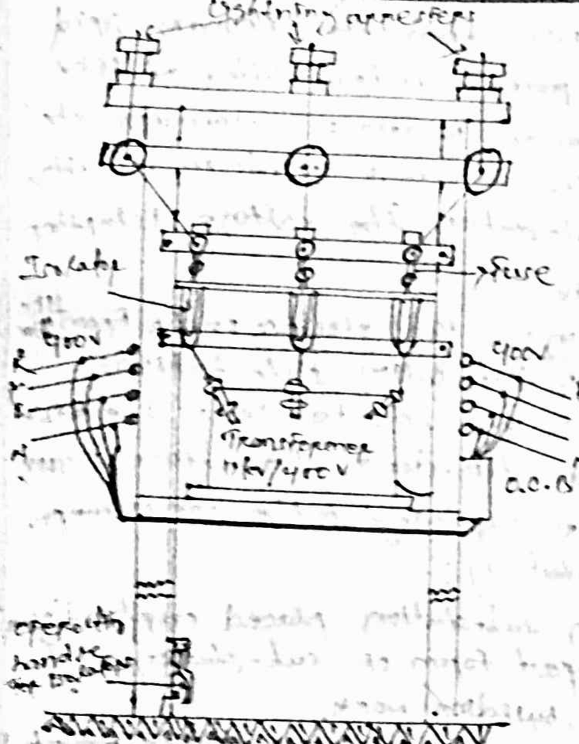
i) <u>step up substation</u> :- The generation voltage (11kv in this case) is stepped up to high voltage (220kv) to affect economy in transmission of electric power.
→ The sub-stations which accomplish this job are called stepup sub-stations.

ii) <u>Primary grid sub stations</u> :- From the step-up sub station, electric power at 220kv is transmitted by 3-phase, 3wire overhead system to the outskirts of the city.
→ Here, electric power is received by the primary grid sub-stations which reduces the voltage level to 66kv for secondary transmission.

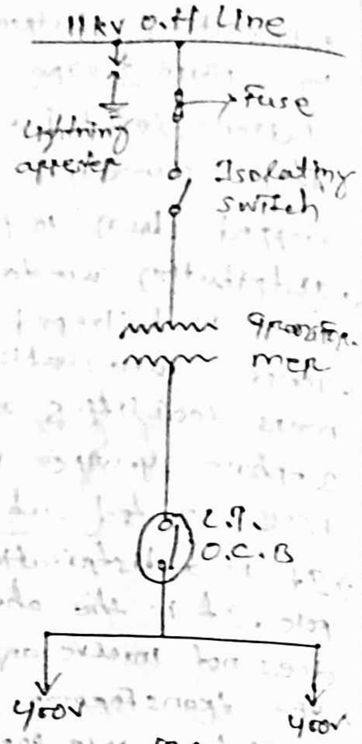
iii) <u>Secondary sub-station</u> :- From the primary grid sub-station, electric power is transmitted at 66kv by 3-phase 3-wire system to various secondary sub stations located at the strategic points in the city.
→ At a secondary sub station, the voltage is further stepped down to 11kv.

iv) <u>Distribution sub-station</u> :- The electric power from 11kv lines is delivered to distribution sub stations.
→ These sub-stations are located near the consumers localities and step-down the voltage to 400v, 3-phase, 4-wire for supplying to the consumers.

<u>Pole-mounted sub-station</u> :-
→ It is a distribution sub-station placed overhead on a pole. It is the cheapest form of sub-station as it does not involve any building work.
→ The transformer and other equipment are mounted on H-type pole (or 4-pole structure).
→ The 11kv line is connected to the transformer (11kv/400v) through gang isolator and fuse.
→ The lightning arresters are installed on the H.T side to protect the sub-station from lightning strokes.
→ The transformer steps down the voltage to 400v, 3-phase, 4-wire supply.
→ The voltage betn any two lines is 400v whereas the voltage betn any line and neutral is 230v.
→ The pole mounted sub-stations are generally used for transformer capacity up to 200kvA.
i) There should be periodical check-up of the dielectric strength of oil in the transformer & O.C.B.
ii) In case of repair of transformer or O.C.B, both gang isolator and O.C.B should be shut off.



(1)



(2)

S.No.	Circuit element	Symbol
1)	Bus bar	
2)	Single-break isolating switch	
3)	Double-break isolating switch	
4)	On load isolating switch	
5)	Isolating switch with earth blade	
6)	current transformer	
7)	potential transformer	
8)	capacitive voltage transformer	

9) oil ckt-breaker

10) Air ckt breaker with overcurrent tripping device

) Air blast ckt breaker

11) Lightning arrester (cattre gap)

12) Lightning arrester (valve type)

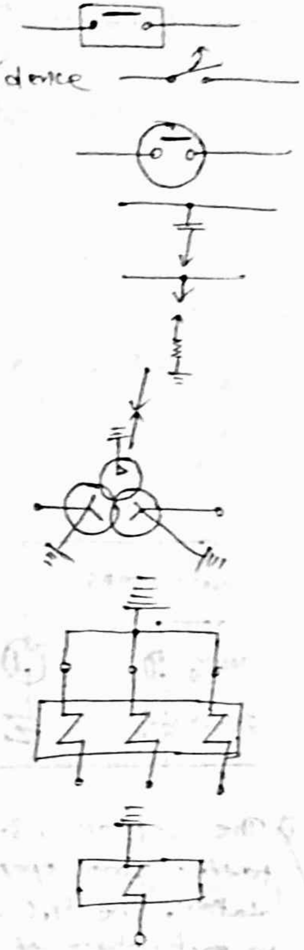
13)

14) Arcing horn

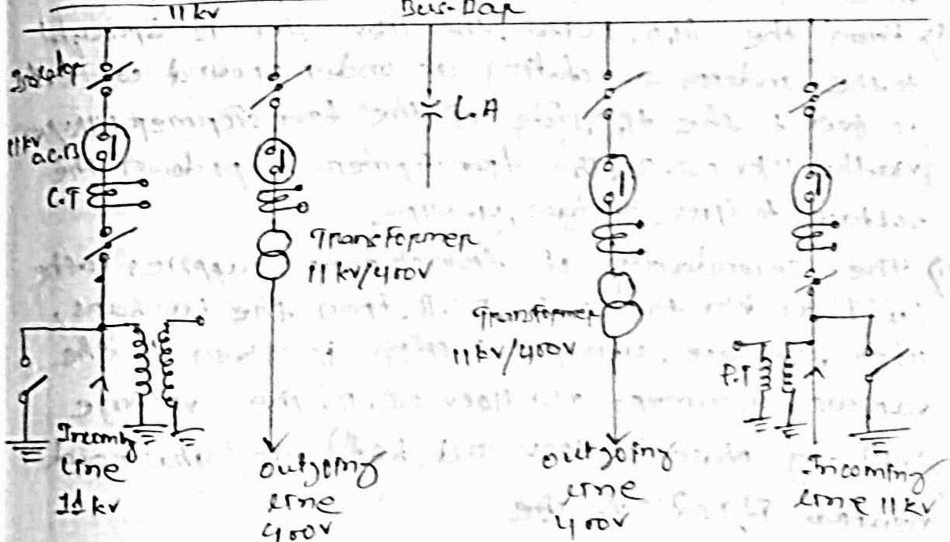
15) 3-φ power transformer

16) over current relay

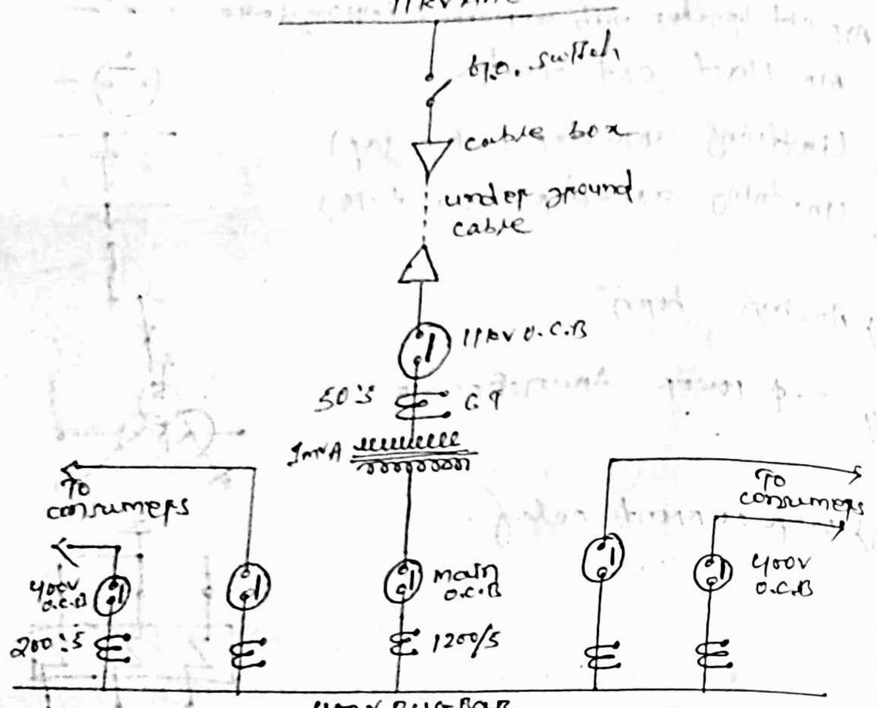
17) Earth Fault relay



Bus Bar arrangement of sub-station



Key Diagram of 11kV/400V Indoor sub-station :-



i) The 3-phase, 3-wire 11kV line is tapped and brought to the gang operating switch installed near the sub station. The G.O switch consists of isolators connected in each phase of the 3-phase line.

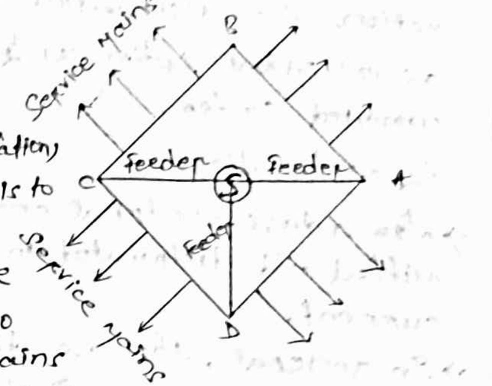
ii) From the G.O. switch, the 11kV line is brought to the indoor sub-station as underground cable. It is fed to the H.T. side of the transformer (11kV/400) via the 11kV O.C.B. The transformer steps down the voltage to 400V, 3-phase, 4-wire.

iii) The secondary of transformer supplies to the bus-bars via the main O.C.B. From the bus bars, 400V, 3-phase, 4-wire supply is given to the various consumers via 400V O.C.B. The voltage betn any phases is 400V and betn any phase and neutral it is 230V. The

ch-6 Distribution system Dt- 20-07-21

Distribution system :-

The part of power system which distributes electric power for local use is known as distribution system.



i) **Feeder** :- A feeder is a conductor the sub-station (or localised generating station) to the area where power is to be distributed.

-> Generally, no tappings are taken from the feeder so that current in it remains the same throughout.

The main consideration in the design of a feeder is the current carrying capacity.

ii) **Distributor** :- A distributor is a conductor from which tappings are taken for supply to the consumers.

-> In fig. AB, BC, CD, DA are the distributors.

-> The current through a distributor is not constant because tappings are taken at various places along its length.

-> While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ±6% of rated value at the consumers terminals.

iii) **Service mains** :- A service mains is generally a small cable which connects the distributor to the consumers terminals.

Classification of Distribution system :-

i) **Nature of current** :- According to nature of current distribution system may be classified as (a) d.c distribution system (b) a.c distribution system.

ii) Types of construction :- According to type of construction, distribution system may be classified as (a) overhead system (b) underground system.

iii) Scheme of connection :- According to scheme of connection, the distribution system may be classified as (a) radial system (b) Ring main system (c) Interconnected system.

A.C. Distribution :-

-> Now a days electrical energy is generated, transmitted and distributed in the form of alternating current.

-> In general, the a.c distribution system is the electrical system betn the step-down substation fed by the transmission system and the consumers meters.

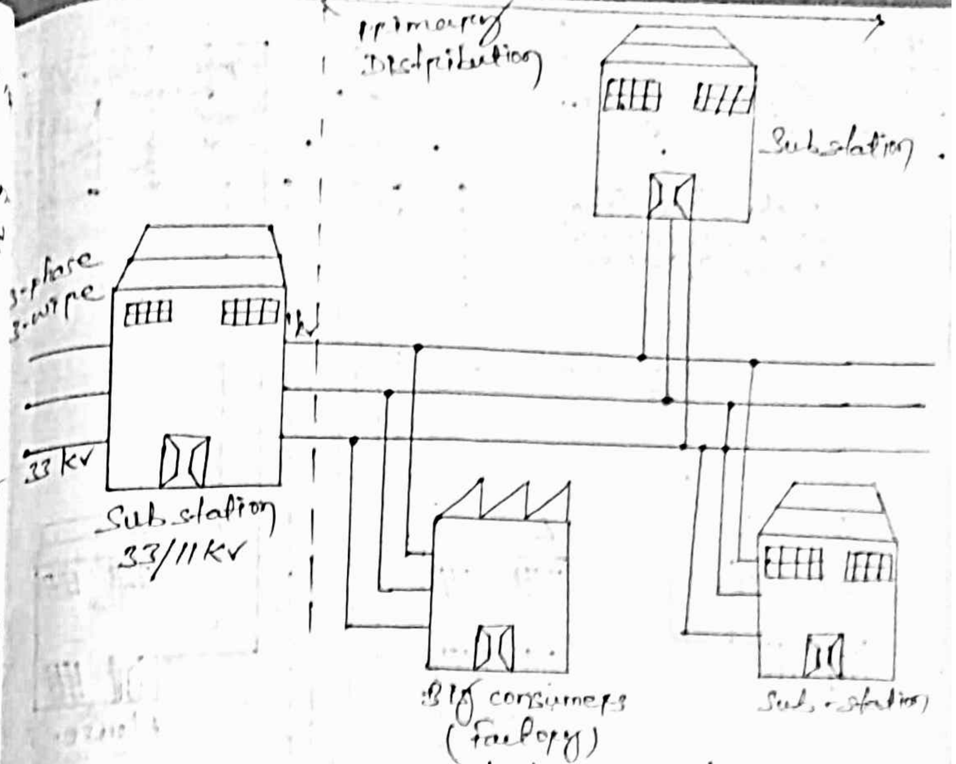
-> The a.c distribution system is classified into
i) primary distribution system.
ii) secondary distribution system.

i) primary distribution system :-

-> The a.c distribution system which operates at voltages somewhat higher than general utilisation and handles large blocks of electrical energy than the average low voltage consumer uses.

-> The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed.

-> The most commonly used primary distribution voltage 11kv 6.6kv and 3.3kv.



-> A typically primary distribution system. Electric power from the generating station is transmitted at high voltage to the substation located in or near the city.

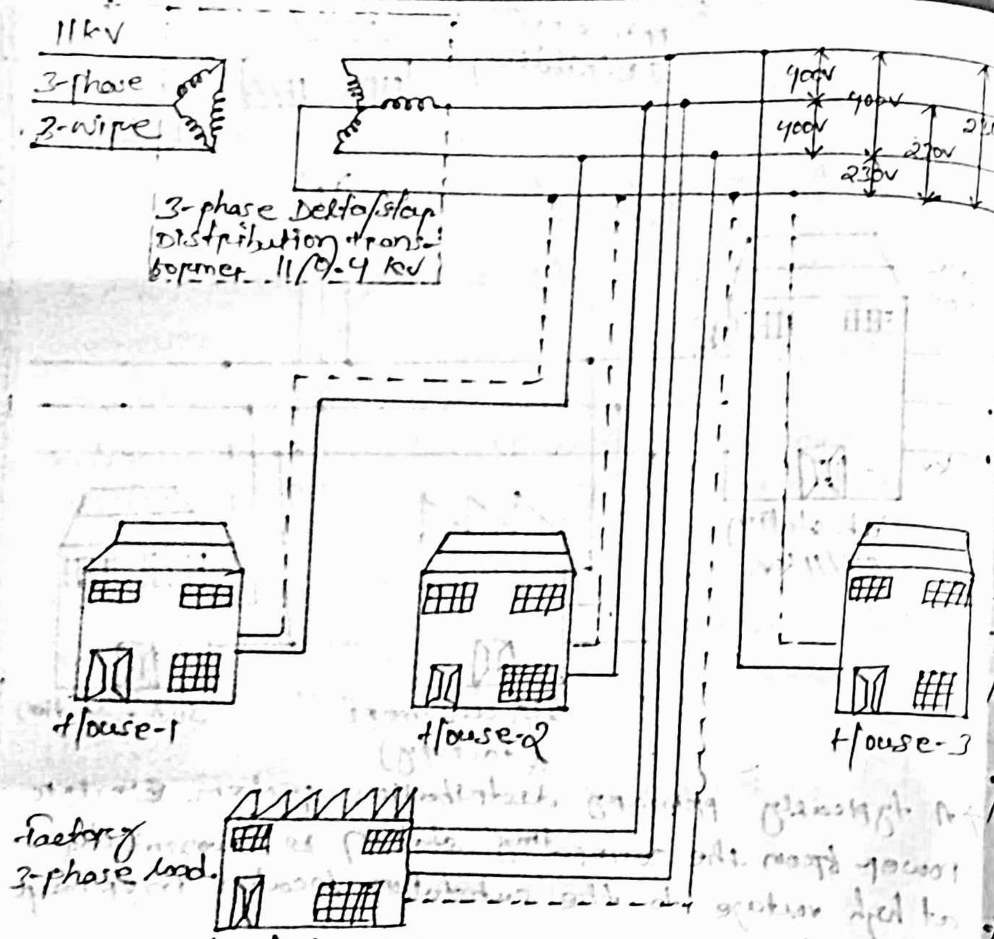
-> power is supplied to various sub-stations for distribution or to big consumers at this voltage.

ii) secondary distribution system :-

-> It is that part of a.c distribution system which includes the range of voltages at which the ultimate consumer utilises the electrical energy delivered to him.

-> The secondary distribution employs 400/230v, 3-phase, 4-wire system.

-> The single phase domestic loads are connected betn any one phase and the neutral, whereas 3-phase 400v motor loads are connected across 3-phase lines directly.



D.C. Distribution:-

→ It is a common knowledge that electric power is almost exclusively generated, transmitted and distributed as a.c.

→ However, for certain applications, d.c. supply is absolutely necessary.

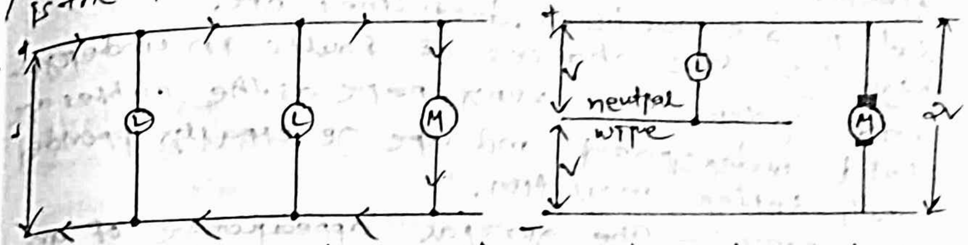
→ For instance d.c supply is required for the operation of variable speed machinery, for electrochemical work and for congested areas where storage battery reserves are necessary.

→ For this purpose, a.c power is converted into d.c power at the substation by using converting machinery e.g mercury arc rectifiers, rotary converters and motor-generator sets.

The d.c. supply from the substation may be obtained in the form of (i) 2-wire (or) (ii) 3-wire for distribution.

i) 2-wire d.c system:- As the name implies, this system of distribution consists of two wires.

→ One is the outgoing or the wire and the other is the return or -ve wire.



ii) 3-wire d.c system:- It consists of two outers and a middle or neutral wire which is earthed at the substation.

→ The voltage betn the outers is twice the voltage betn either outer and neutral.

Overhead versus underground system:-

→ The distribution system can be overhead or underground.

→ Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors.

→ The choice betn overhead and underground system depends upon a number of widely differing factors.

Therefore, it is desirable to make a comparison betn the two.

1) Public safety:- The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

i) **Initial cost:**— The underground system is more expensive due to the high cost of trenching conduit, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

ii) **Flexibility:**— The overhead system is much flexibility than the underground system. In the latter case, manholes, duct lines etc.

iv) **Faults:**— The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

v) **Appearance:**— The general appearance of an underground system is better as all the distribution lines are invisible.

vi) **Fault location and repairs:**— In general, there are little chances of faults in an underground system.

vii) **Current carrying capacity and voltage drop:**— An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section.

viii) **Useful life:**— This useful life of underground system is much longer than that of an overhead system.

ix) **Maintenance cost:**— The maintenance cost of underground system is very low as compared with that the telephone lines.

x) **Interference with communication ckts:**— An overhead system causes electromagnetic interference with the telephone line.

It is clear from the above comparison that each system has its own advantages and disadvantages.

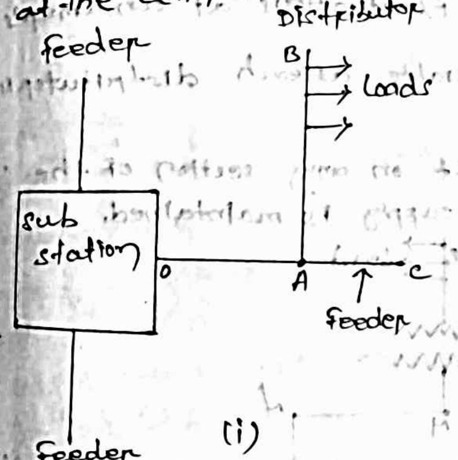
Connection schemes of Distribution system:— All distribution of electrical is done by constant voltage system. In pratice, the following distribution ckts are generally used.

i) **Radial system:**— In this system, separate feeders radiate from a single substation and feed the distributors at one end only.

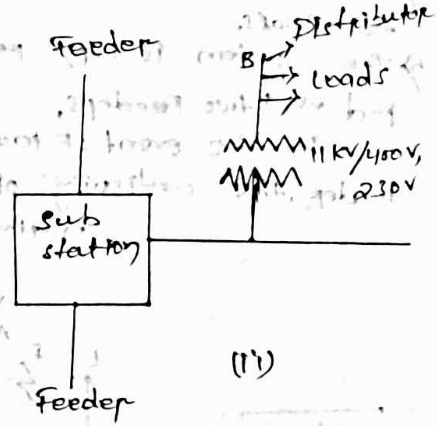
→ The below fig. shows a single line diagram of a radial system for d.c distribution where a feeder oc supplies a distributor AB at point A.

→ Obviously, the distributor is fed at one end only i.e point A is the case.

→ The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.



(i)



(ii)

→ This is the simplest distribution ckt and the lowest initial cost.

Drawbacks:—

a) The end of the distributor nearest to the feeding point will be heavily loaded.

b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes.

Due to these limitations, this system is used for short distances only.

ii) Ring main system:— In this system, the primaries of distribution transformers form a loop.

→ The loop ckt starts from the substation bus-bars, make a loop through the area to be served, and returns to the sub-station.

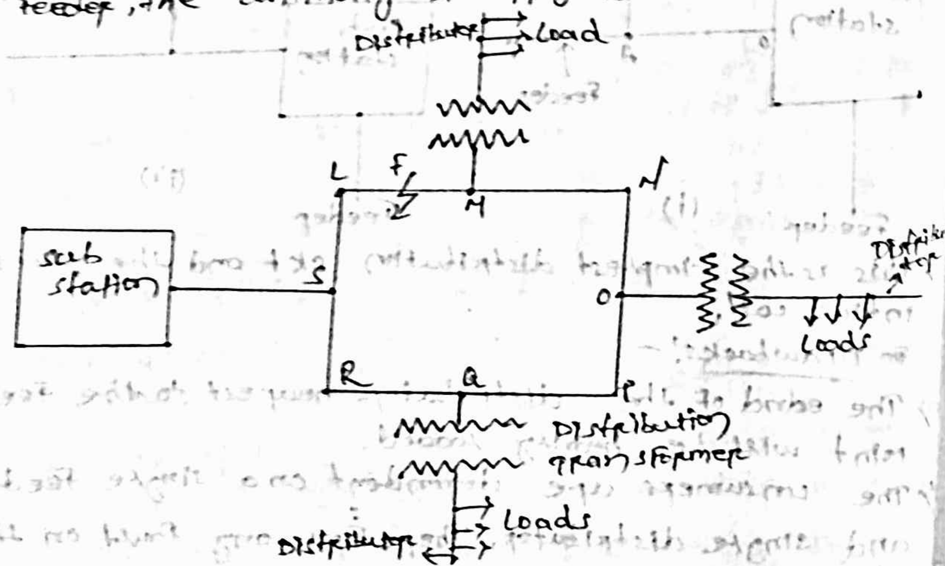
→ The fig. shows the single line diagram of ring main system for ac distribution where sub-station supplies to the closed feeder LMNOPQRS.

Advantages:—

a) There are less voltage fluctuations at consumer's terminals.

b) The system is very reliable as each distributor is fed via two feeders.

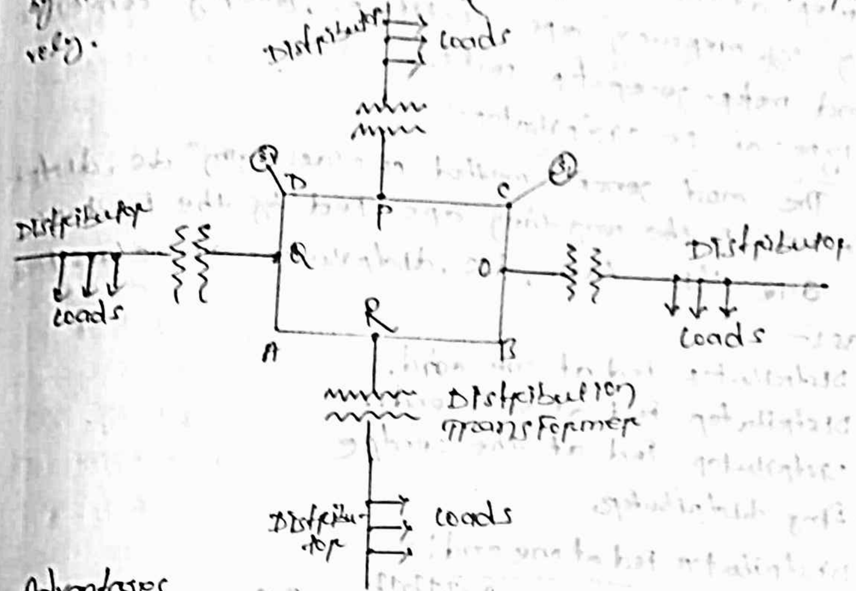
In the event of fault on any section of the feeder, the continuity of supply is maintained.



iii) Interconnected system

When the feeder ring is energized by two or more than two generating stations/sub-stations, it is called interconnected system.

→ Fig. shows the single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two substations S_1 and S_2 at points D and C respectively.



Advantages

a) It increases the service reliability.

b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.

DC Distributors:—

→ Now-a-days, electrical energy is generated, transmitted and distributed in the form of a.c as an economical proposition.

→ The transformer permits the transmission and distribution of a.c power at high voltages.

→ This has greatly reduced the current in the conductors (and hence their sizes) and the resulting line losses.

→ However, for certain applications, d.c supply is absolutely necessary.

→ For ex- dc supply is required for the operation of variable speed machinery (e.g dc motors), electro chemical work and electric traction.

→ For this purpose, a.c power is converted into d.c power at the sub-station by using converting machinery eg. mercury are rectifiers, rotary converters and motor-generator sets.

Types of DC Distributors:—

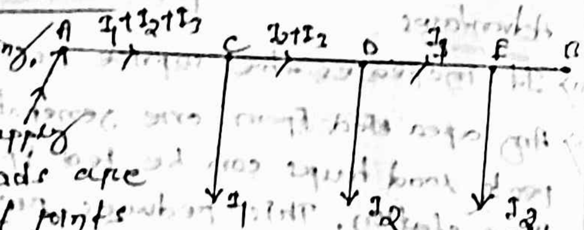
The most general method of classifying dc, distributors is the way they are fed by the feeders.

On this basis, d.c. distributors are classified as:—

i) Distributor fed at one end.
ii) Distributor fed at both ends.
iii) Distributor fed at the centre
iv) Ring distributor.

i) Distributor fed at one end:—

→ In this type of feeding, the distributor is connected to the supply at one end and loads are taken at different points along the length of the distributor.



→ Fig. shows the single line diagram of a d.c. distributor AB fed at the end A and loads I_1, I_2 and I_3 tapped off at points C, D and E respectively.

The following points are worth nothing in a singly fed distributor:

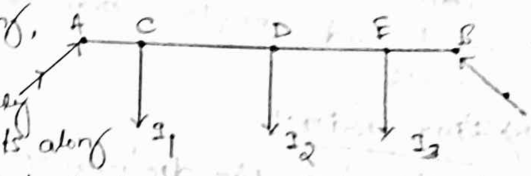
a) The current in the various sections of the distributor away from feeding point goes on decreasing. Thus current in section AC is more than the current in section CD and current in section CD is more than the current in section DE.

ii) The voltage across the loads away from the feeding point goes on decreasing. Thus in fig. the min. voltage occurs at the load point E.

iii) In case a fault occurs on any section of the distributor, the whole distributor will have to be disconnected from the supply mains. Therefore, continuity of supply is interrupted.

ii) Distributor Fed at both ends:—

→ In this type of feeding, the distributor is connected to the supply off at different points along the length of the distributor.



→ The voltage at the feeding points may or may not be equal.

→ The above figure shows a distributor AB fed at the ends A and B and loads of I_1, I_2 and I_3 tapped off at points C, D and E respectively.

→ The minimum voltage occurs at some load point and is never fixed.

→ It is shifted with the variation of load on different of load on different sections of the distributor.

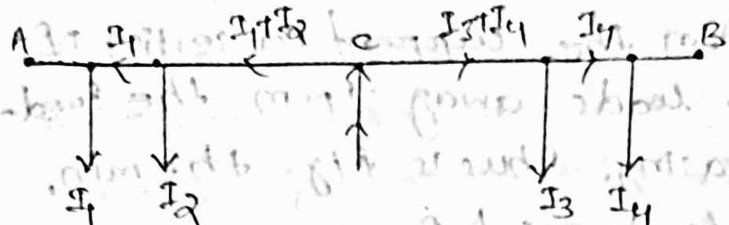
Advantages:—

a) If a fault occurs on any feeding point of the distributor, the continuity of supply is maintained from the other feeding point.

b) In case of fault on any section of the distributor, the continuity of supply is maintained from the other feeding point.

c) The area of x-section required for a doubly fed distributor is much less than that of a singly fed distributor

iii) Distributor fed at the centre:—



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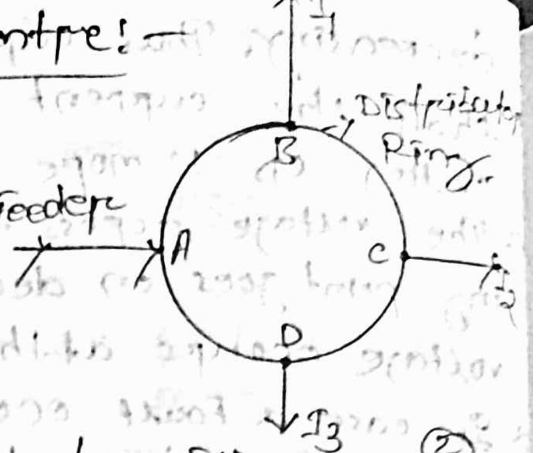

②

→ In this type of feeding, the centre of the Distributor is connected to the supply mains as shown in Fig-1. It is equivalent to two singly fed distributors, each distributor having a common feeding point and length equal to the half of the total length.

iv) Ring mains:—

→ In this type, the distributor is in the form of a closed ring as shown in Fig-2.

→ It is equivalent to a ~~single~~ straight distributor fed at both ends with equal voltages, the two ends being brought together to form a closed Ring.

→ The distributor ring may be fed at one or more than one point.