Generation, Transmission & Distribution

1. 0. Generation of Electricity: The modern age lining cannot be thought of without the electricity. Generation of electricity is nothing but conversion of some other form of energy like potential energy, kinetic energy, chemical energy, heat energy, atomic energy etc to electricity. There are many ways of generating electricity conventional and non-conventional ways. The conventional sources are fossil fuels, water, atomic energy from radioactive elements etc. The non-conventional sources are solar energy, wind energy, Tidal energy, Biomass etc. Here we shall discuss some specific conventional sources of generation of electricity.

a) Thermal Generation: ***Working***: The coal fired steam power station basically works on Rankin cycle. Steam is produced in the boiler by burning coal with small amount of diesel. The steam after passing through the super heater impinges the steam turbine blades at different stages and lastly condensed in a condenser and the condensate is fed back to the boiler. The steam turbine drives the alternator which produces electricity. Large thermal power stations are generally situated near by coal mines as well as reliable water source.

Thermal efficiency: It is defined as

$$\eta_{Th} = \frac{\text{Heat equivalent of mechanical energy transmitted to turbine shaft}}{\text{Heat of coal combustion}}$$

The thermal efficiency of modern steam power station is about 30%. IT may be noted that more than 50% of total heat of combustion is lost in condenser and other heat losses occur in flue gases, radiation, ash etc.

Advantages: i) The power grade coal used in thermal generation is quite cheap compared to other fuel. ii) Land requirement is much less compared to hydro power plant of same capacity hence rehabilitation and resettlement (RR) problem is negligible iii) Cost of generation is cheaper compared to other fossil fuel power generation iv) Capital cost is less compared to other generating station v) The gestation period is much less compared to a hydro power station vi) It can be established at any place where land and water is available by transporting coal by rail or sea way (ship).

Disadvantage: i) It pollutes the atmosphere heavily with smoke, fumes, fly ash etc, ii) it adds to the atmospheric temperature in and around plant area iii) The running charge is quite high compared to hydro electric power.

Running cost of power station:The running cost of a power station is the recurring cost for generation of electricity. It includes fuel and lubricant cost, operation cost spare-part cost etc. .

Selection of site for Thermal power station:

i) *Fuel and water*: The ideal site is around coal mine area where reliable source of water is available so that transportation cost of coal is the minimum. In case the site is away from coal mines it must be ensured that it is near a rail head

ii) *Cost and type of land*: Cheap barren land is preferred. The soil bearing capacity must be adequate to take the load of heavy equipments and there should be scope for future expansion

iii) *Transportation facility*: As far as possible the site should be near by a rail head with good all weather road communication for transportation of heavy equipments

iv) *Away from populated area:* The plant site must be away from populated area so that the heat and pollutants emitted from the plant do not affect the inhabitants

v) *Away from aerodrome*: The site should be away from existing or proposed site for air field

vi) *Facility for ash disposal*: Adequate barren fallow land should be available for ash disposal.

Schematic arrangement and functions of various components: The schematic arrangement of thermal power station is shown in the figure given bellow.

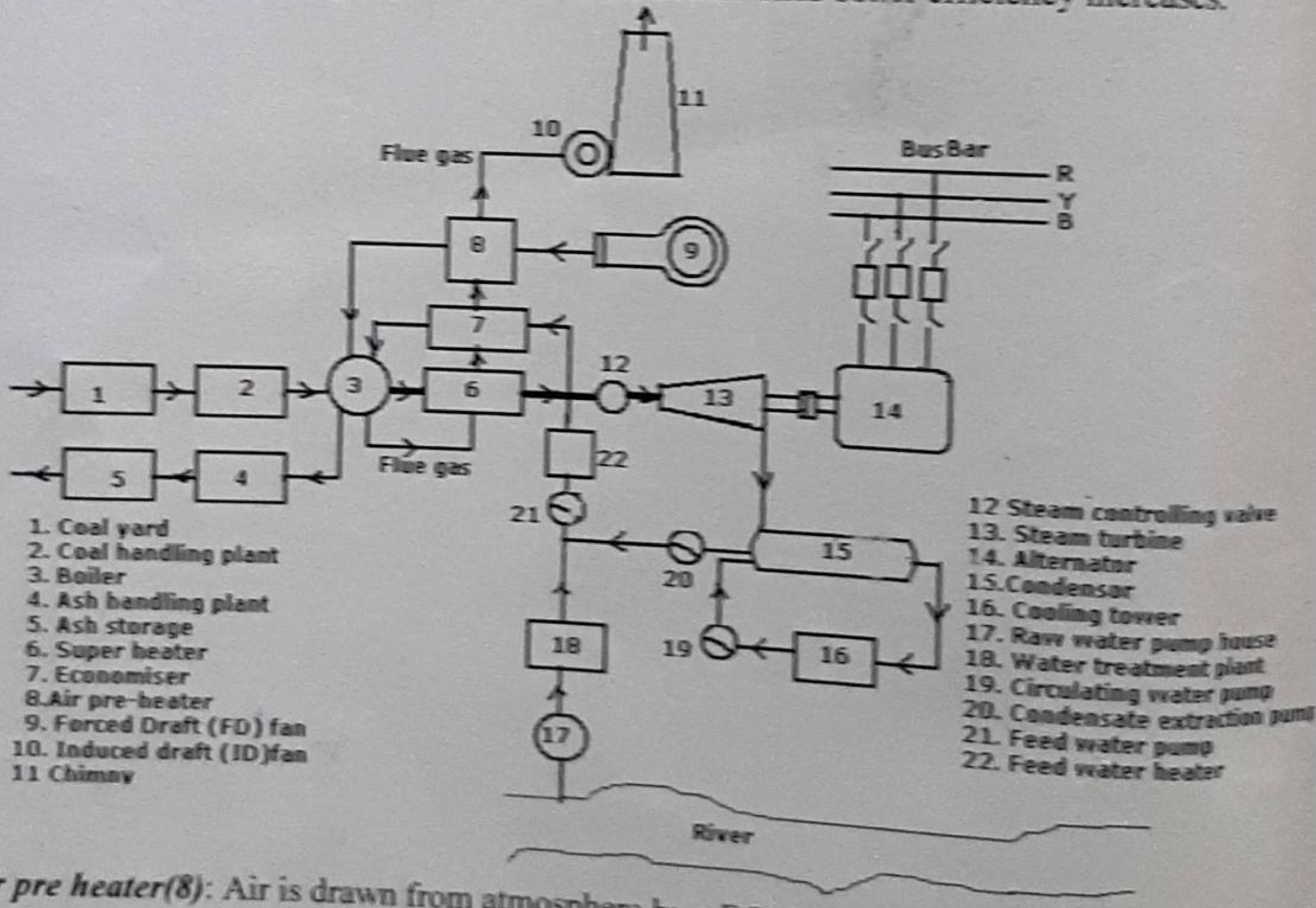
Coal handling plant (1 & 2): The coal from coal yard is crushes in primary and secondary crusher in the coal handling plant and pulverized coal is fed by conveyer belt to the boiler hearth along with preheated air and little diesel oil spay for complete combustion.

Boiler (3).: The heat from the coal burning raises steam at high temperature and pressure. In order to utilize the heat in flue gas it is passed through super heater, economizer and air pre heater and lastly forced through the chimney and dispersed at a height.

Ash handling (4 &5). The bottom ash is taken to ash dumping area. But the fine ash (Fly ash) is collected from the electro-static precipitator and made slurry by mixing water in ash handling plant and pumped to the ash pond through pipeline.

Super heater(6) : The wet steam from the boiler passes through the super heater where it becomes superheated and dry by extracting heat from hot flue gases and thus increase the overall efficiency. The superheating process avoids too much condensation at the last stage of the turbine (13) so that blade corrosion is minimized.

Economizer (7): Feed water is fed to the economizer and gets further heated by absorbing heat partly from hot flue gas and then fed to the boiler. Thus boiler efficiency increases.



Air pre heater(8): Air is drawn from atmosphere by a F.D fan (9) and fed to the air pre-heater where the temperature of the air increases by deriving heat from the flue gas and then fed to the hearth for coal burning. This increases the efficiency of the boiler.

ID fan(10 & chimney(11): It creates negative draft in the chimney so that the flue gas is ultimately forced through chimney (11) and dispersed to the atmosphere at sufficient height to minimize its environmental effects.

Main valve (12): The main valve controls the dry and super heated steam coming from super heater to the turbine.

Steam turbine (13): The steam turbine has high pressure and low pressure stages. When the super heated steam passes over the blades of the turbine the heat energy is converted to mechanical energy so that it rotates the generator coupled to it. In the last stage the steam is exhausted to the condenser.

Alternator (14): It is driven by the steam turbine and converts the mechanical energy to electrical energy. The electrical energy is delivered to the bus bar through transformer, isolator and circuit breaker.

Condenser (15): In the last stage the steam turbine exhausts the steam to the condenser. The condenser serves two purposes. i) it creates a very low pressure at the exhaust of the turbine effecting expansion of the steam in the prime mover to a very low pressure which helps in converting heat energy of steam into mechanical energy, ii) The condensed steam is used as feed water to boiler.

Cooling tower(16): The steam exhausted to the condenser. After condensation the hot water is passed through the cooling tower where it is cooled and pumped back to the condenser.

Feed water: The condensate from the condenser is used as feed water to the boiler in a closed cycle. But in the process some water is lost due to leakage, steam pressure relief valve release. Hence make-up water is pumped from the de-mineralized water tank of water treatment plant and heated up by water heaters (22) before it is fed to the boiler.

Water treatment plant and pump house (17& 18): Water is pumped from the nearby natural water source and treated in the water treatment plant for uses like service water, portable water, boiler feed water etc of the plant.

Units of energy:

Type	Unit	Explanation
Mechanical	Newton-meter or joule	One Newton force displaced by 1m distance.
Electrical	Watt-second or joule	1A current flows for 1second between two point with 1V potential difference between them.l
Heat	i) Calorie ii) BTU iii) CHU	Heat required to raise the temperature of 1gm of water by 1^0C Heat required to raise the temperature of 1lb of water by 1^0F Heat required to raise the temperature of 1lb of water by 1^0C

Inter relationship: 1 kWh = 36 x 10^5 Joules; 1 Cal =4.18 Joules; 1 BTU =1053 Joules, and 1 CHU = 1896 Joules.

b) Hydro power project:

Technology: The potential energy of huge mass of water at a height is converted to kinetic energy by regulated discharge falling through the height through a series of water conductor system. Major hydro electric projects are located in hilly areas away from load centre because of availability of head. In the hilly area rivers are narrow and have rocky beds so that it can be dammed to form reservoirs in the gorges up-stream. If H is the head (difference of level between tail race and reservoir water level) in meters, Q is the rate of discharge in m^3 to the turbine through water conductor system and η_0 is overall efficiency of the plant then power potential P is given by P = 9.81 x Q x H x η_0 KW. Depending on the nature of geography and hydro logy different schemes like Dam based, dam toe, run of river power plant can be adopted. On the basis of head also the hydro power plants can be classified as high head, medium head and low head plants. Depending on the head, head variation, and discharge the type of turbine is to be selected. The following table gives type of turbine and their head range.

Group	Type	Head range (m)
Impulse turbine	Pelton wheel: Single jet Double jet four jet	 100-2000 100-1500 100-1000
Reaction turbine	Francis	30-100
	Kaplan & Bulb	8- 75

Advantages:

i) It is a clean energy as no smoke or ash is produced.

ii) It needs no fuel. The potential energy of water is used for energy conversion.

iii) The cost of generation is the least compared to other methods of production of electricity.

iv) Hydro power plant is simple in construction and requires less maintenance compared to thermal power plant.

v) Unlike thermal stations hydro power stations are cool and clean.

vi) Unlike thermal power stations the hydro power stations are very flexible so far as operation is concerned. It can be started and stopped as and when required within no time.

vii) Hydro power plants with storage are suitable for peak load operation where as thermal or nuclear power plants run as base load stations.

viii) Hydro power plants are robust and have longer life compared to Thermal power plants.

ix) Hydro power plants can be planned as multipurpose projects with irrigation and flood control provision.

x) For operation hydro plants require less man power compared to thermal power plants.

xi) The reservoir sites of hydro power plants are now a days are being developed as eco-tourism sites with boating and fishing facilities.

Disadvantages:

i) Huge capital cost is involved for development of a hydro power plant

ii) Projects over rain-fed rives suffer in draught years.

iii) Huge amount of land which includes forest land and agricultural land is submerged to create the reservoir. This affects the environmental balance.

iv) Due to vast submergence rehabilitation and resettlement (RR) problem becomes more acute.

v) The huge amount of water impounded over a limited area in the reservoir exerts huge hydro static pressure over the limited area.

vi) Experienced and skilled personnel are required for construction as well as operation of the plant.

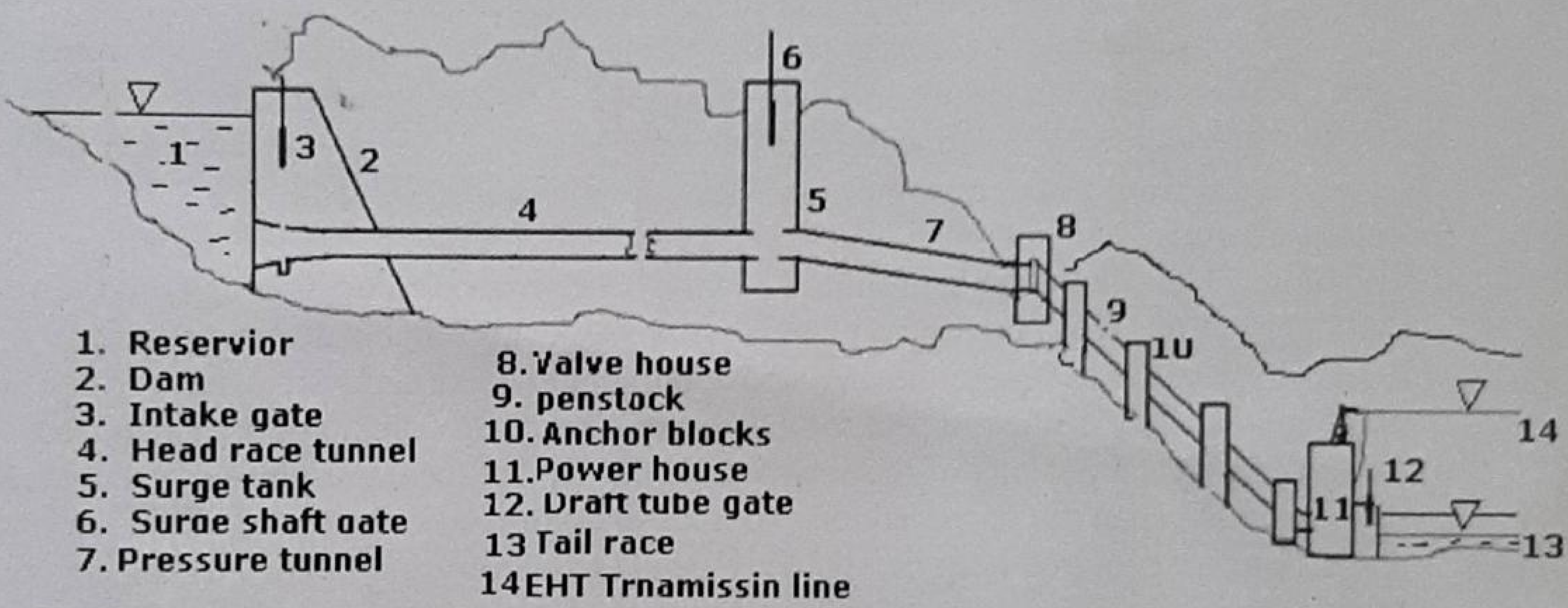
vii) It requires high cost of transmission as the sites of the projects are in hilly areas far away from load centers.

Schematic arrangement and features: The schematic arrangements differ for different categories of hydro electric plants such as away from dam power plats. Dam toe power plants, Run-off-river Plants, Pump storage plants etc. However a typical lay-out of conventional high head away from dam power plant with Francis turbine is shown bellow

Featur 's

i) *Dam & Reservoir*. A dam is built on the course of the river to impound water to build up the storage and create head. Depending on the location, geological conditions, height of the dam etc, the type of dam is decided. Dam may be of masonry, concrete, rock filled, earth dam or composite dam. The reservoir may have more than one dam and some dykes. In order to release excess flood water to the river downstream, the dam must have some spill ways and sluice gates. At the intake of water release for power trash racks and floating booms are provided to prevent entry of derbies and floating trash.

ii) *Intake gate*: an intake gate is provided in the intake structure to facilitate maintenance of the head race tunnel and to handle emergency situations. The gate is opera rated by a motor driven hoist.



iii) *Head race tunnel*: Since the H.E projects are in hilly area open contour channel may nor be possible to convey water from the reservoir to the surge tank. So in most cases the head race is a free flow horse shoe type tunnel. Some time the head race may be combination of tunnel and open channel depending geography and geology.

iv) *Surge tank*: In case of long water conducting system using closed conduit a surge tank is a must to release water hammer pressure in the pressure conduit due to sudden load throw off. The surge tank also acts as a mini reservoir to regulate the immediate water demand of the turbines. It is a long circular tank open at the top. In order to reduce the height more than one expansion chambers are provided. It should be located as close to the power house as possible. Electrically operated gates are provided to block water to the pressure tunnel to facilitate maintenance.

v) *Pressure tunnel:* The portion of the conduit between surge tank and the valve house is pressure tunnel. It is circular in shape. There may be more than one pressure tunnel.

vi) *Valve house:* The pressure tunnel ends at valve house. Each pressure tunnel may be bi-furcated or trifurcated depending on number of generating units before entry to the valve house. The valve house houses butterfly valves and its auxiliaries and local control system for each penstock. The valves facilitate maintenance of penstock and turbines by stopping water to the turbine.

vii) *Penstock* The special steel pipe laid from the valve house to the turbine inlet valve is the penstock This feed water to the turbine as per demand under full pressure. Number of penstocks are normally equal to number of turbines.

viii) *Power house*: The power house housed the turbines, alternators, their auxiliaries and control protection including service bay and control room.

ix) *Draft tube*: The water finally discharged from the turbine runner to the tail race pond through elbow shape draft tube in case of reaction turbines. Negative head is to be maintained over the exit of the draft tube by maintaining specified water head over it in the tail pond. At the exit there is a gate which lowered for maintenance of the turbine.

x) *Tail pond and tailrace*: The turbine discharges trough draft tube to the tail pond from where water is conveyed by a tail race channel to be finally released either to the same river or some other river depending upon the location of the power house (inter basin transfer). Alternatively the tail race water can be used for irrigation by constructing a barrage and taking canal system from the barrage. Excess water, if any is left to the river through gate in provided in the barrage:

xi) *Generation and transmission*: The turbine drives the alternator which converts the mechanical energy to electrical energy. Usually the generation is at 11kV which is stepped up by unit transformers to 220 kV or 132 kV and transmitted to the switch yard from where transmission lines goes out to load centers.

Selection of site:

i) *Hydrology*: The catchment area should be large to give good run-off though out the year so that the river on which the hydro plant is proposed yields reliable discharge to form a reservoir. In order to design the dam and appurtenant works and also to asses hydro electric potential the daily discharge data for a long period not less than 50 years is required.

ii) *Geography* i)The geology of the site should be such that there must be sufficient level difference between the proposed reservoir site and the power plant site with in reasonable distance to get required head ii) The river should be narrow and flanked by hill on both banks at the dam site to reduce the length of the dam iii) The reservoir area should be clear of reserve forest, historical monuments, rare flora and fauna etc iv)The reservoir area should not contain fertile agriculture and is thinly populated .

iii) *Geology*: The geology of the area should be sound and devoid of fault lines.

iv) *Communication facilities*: Reasonable road communication to the site should be available which can be developed during construction: There should be a rail head within few kilo meters so that heavy equipments can be transported.

Nuclear Power Station: In this power plant nuclear energy is converted into electrical energy. $Uranium^{235}$ and $Thorium^{232}$ are subjected to nuclear fission process in a atomic reactor. The heat energy released in the process is utilized in raising steam at high temperature and pressure which runs a steam turbine and the turbine drives a generator which produces electricity. The fuel efficiency of the plant is very high compared to a conventional thermal power station. So far as energy is produced 1kg of Uranium is equivalent to 4500 tons of coal. But the recovery of nuclear fuels is difficult and expensive. The spent fuel and waste from the nuclear plant are radioactive in nature. They emit harmful radiation. Radioactive elements are isotopes of uranium, thorium etc having short life. Uranium and Thorium in form of rare earth are found in small quantities in the sand of some beaches. After purification they are made fuel sticks under strict protection and precaution.

Advantages: i) The amount of fuel required is small. Therefore there is considerable saving in transportat on cost.

iii) It requires less space compared to conventional power stations.

iv) The running cost is small due to requirement of small quantity of fuel for production of bulk electrical energy.

v) Can be located near to load center reducing the cost of transmission.

vi) Nuclear power plants are very economical for production of bulk electric power

vii) The plants are very clean due to no dust and ash problem.

viii) Considering the worldwide deposit of nuclear fuel, such plants can sustain thousands of years.

Disadvantages: i) The fuel used id expensive and is difficult to recover.

ii) The capital cost is very high compared to coal based thermal powe station.

iii) Setting-up of the plant and its operation and maintenance requires highly technical knowhow.

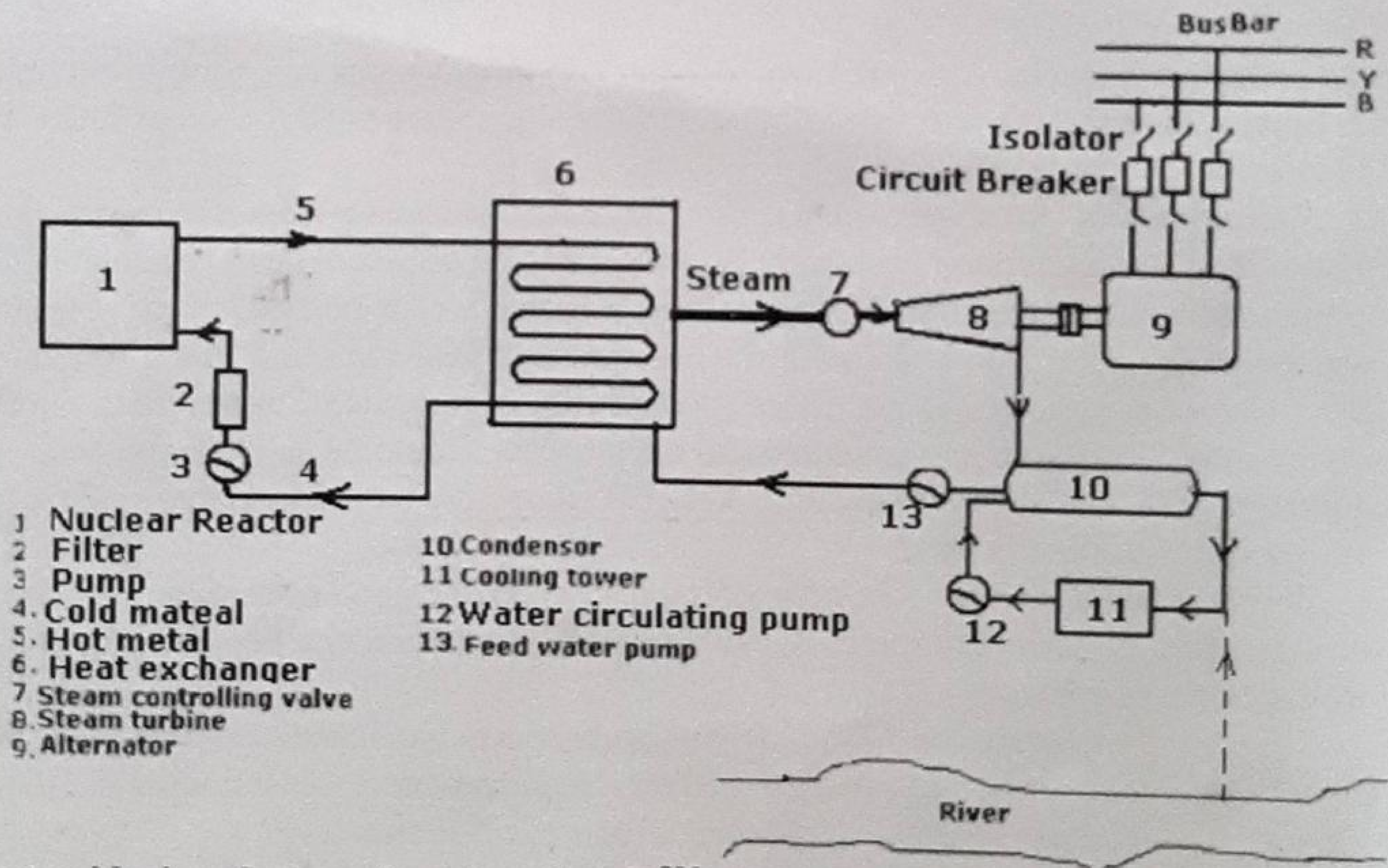
iv.) The fission by products are radioactive and may cause dangerous amount of radio active radiations.

v) High salary of specially trained personnel increases the cost of maintenance.

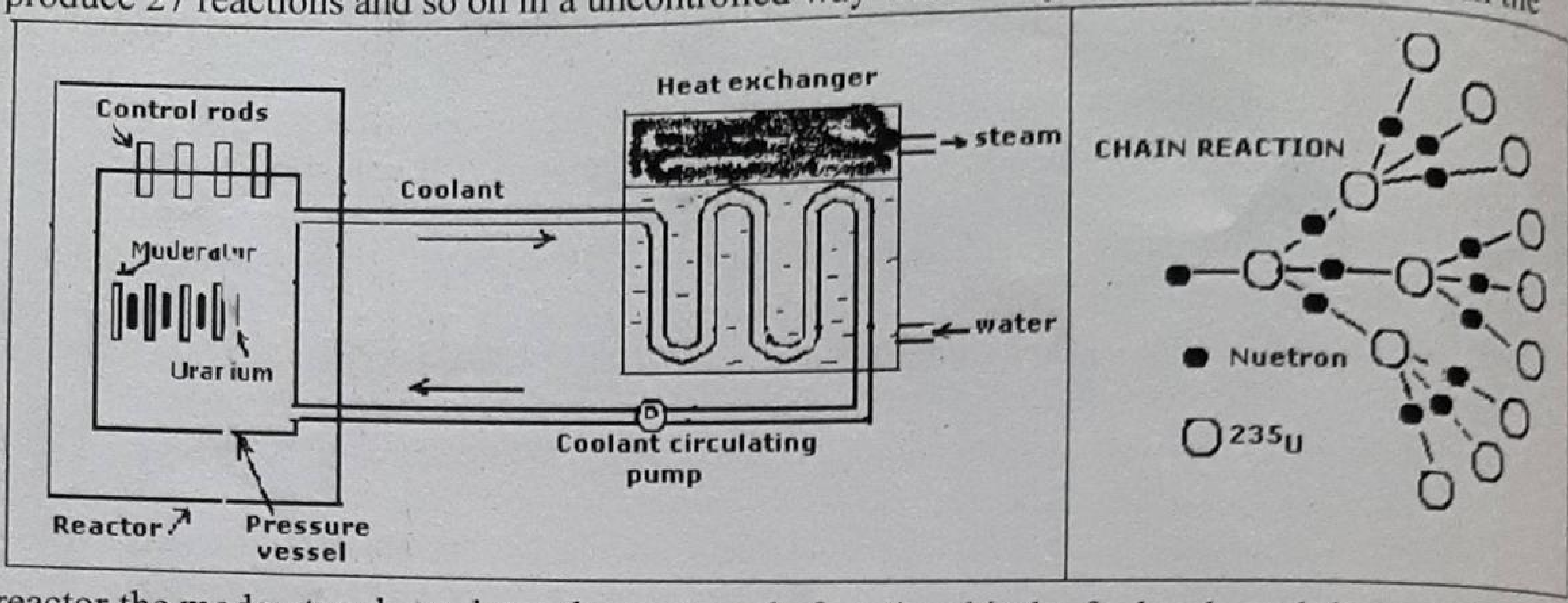
vi) The nuclear power plants can run only as base plants. They are not suited for varying loads.

vii) The byproducts being radioactive posed problem for disposal. They are either to be disposed in a deep trench or in deep sea away from the shore.

Schematic arrangement: The schematic arrangement is shown bellow.



Nuclear Reactor: Nuclear fission of uranium fuel (U^{235}) takes place inside the reactor. It is a cylindrical pressure vessel and houses uranium fuel rods, graphite rods as moderators and cadmium rods as control rods. Controlled chain reaction takes place inside the reactor and huge amount of energy is released by fission of uranium fuel. Chain reaction means a series of individual reactions in which a reaction of first product produces a second reaction, the product of second reaction produces a third and so on. U^{235} nucleus when hit by a slow moving neutron under goes the reaction:- $^{235}_{92}U + ^{1}_{0}n = ^{139}_{56}Ba + ^{64}_{36}Kr + 3\,^{1}_{0}n$. Each of three neutrons produced in the produced in the reaction, thus produce nine subsequent reactions. These nine reactions, in turn produce 27 reactions and so on in a uncontrolled way which may result in explosion. So in the



reactor the moderator slows down the neutrons before they hit the fuel rods and the cadmium control rods absorb the neutrons and controls the number of neutrons bu pushing the rods up and down as per requirement.

Heat exchanger: The sodium in liquid form is used as coolant. Hot coolant gives up heat to the heat exchanger and then pumped to the reactor in a closed cycle.

The arrangement of Turbine, Alternator, Condenser, Cooling tower etc is same as those of thermal power station.

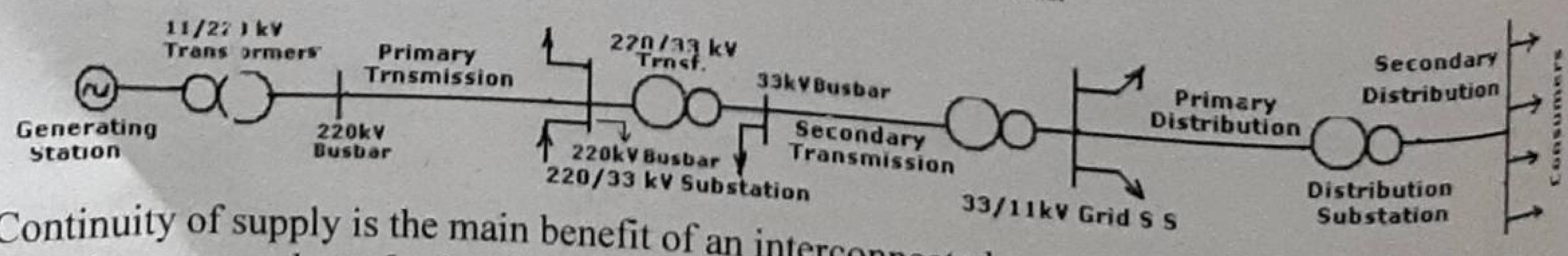
Site selection criteria: i) *Availability of water*- As ample water is required for cooling and at the time of disaster, the site should be nearby a water source with sufficient water availability for the whole year.

ii) *Spent fuel and waste disposal facility*: Spent fuel and waste from a atomic power plant are radio active and hazardous for health. So they are to be buried in deep trenches or disposed in deep sea away from the shore. Either sufficient barren/waste land should be available for in-land location or the plant is to be located in a deserted area near sea shore.

iii) *Away from populated area*: There is possibility of radioactive radiation in the atmosphere surrounding the atomic power station. So the location should be sufficiently away from populated area. Off course to avoid leaking of radioactive radiation to atmosphere of to undr ground water a dome is used.

iv. *Transportation facility*: The area selected should have good communication facility for transportation of heavy equipments and personnel during construction and erection and subsequently operation.

2.1 Layout of transmission and distribution scheme. The interconnected liking network from generating station to the consumer to convey electric power is transmission and distribution scheme. A single line schematic diagram of the system is shown.



Continuity of supply is the main benefit of an interconnected system. Once a power plant pulls out other power plants feed to the system.

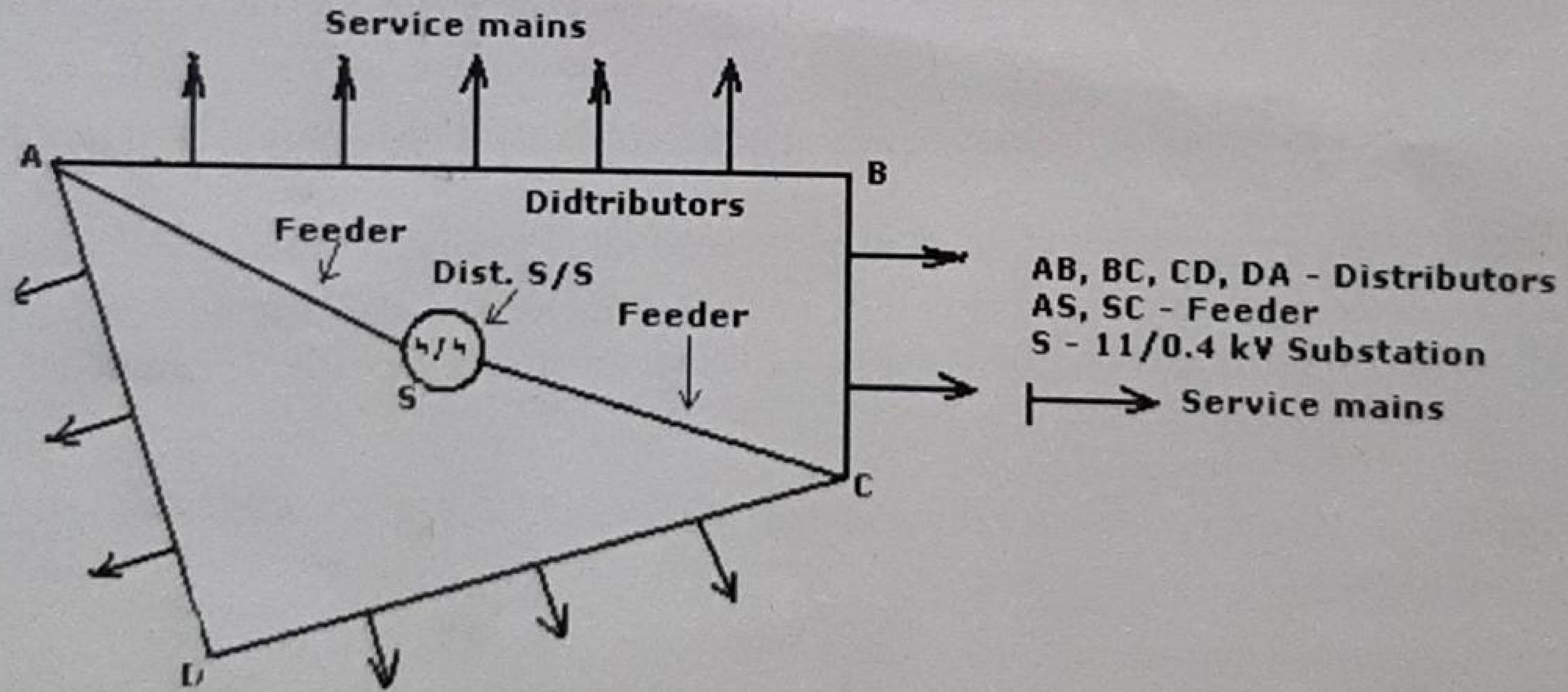
i) *Generating station*: In the generating stations several 3-Φ Alternators operate in parallel. The usual generating voltage is 11 kV which is stepped up by a 3Φ or three 1-Φ step-up transformers known as unit trans formers at the generating station either to 66 kV, 132 kV, 220 kV or 400 kV depending on the amount of power to be transmitted and the distance to be transmitted.

ii) *Primary Transmission*: The portion of 3-Φ three wire 132 kV or 220 kV transmission line starting from the generating station and ending in a grid substation at the load center (usually outskirts of a city) is known as primary transmission. At the load center the the primary transmission voltage is stepped down to 33 kV by a 132/33 kV or 220/33 kV 3-Φ transformer for secondary transmission.

iii) *Secondary transmission*: From the grid substation 33 kV, 3-Φ, three wire overhead lines are drawn to the various 33/11 kV substations at strategic locations around the city. This forms the secondary transmission.

iv) *Primary distribution*: , 3-Φ, three wire 11kV lines emerging from 11 kV bus-bar at 33/11 kV substation run along important road sides of the city. The distribution network at 11 kV forms the primary distribution. The consumers whose demand is more than 50 kW are generally supplied at 11kV to be handled at their own substation.

v) *Secondary distribution*: Power is delivered by 11 kV line to the distribution substations located near a group of consumers' locality. 11 kV is stepped down to 0.4 kV for secondary distribution at , 3-Φ, 4-wire. The residential consumers who require power at 1-Φ are given supply at 220V between any phase and the neutral. The 3-Φ consumers are given 3-Φ, 4-wire connection. The secondary distribution system includes feeders, distributors and service mains as shown.



2.2. Voltage regulation and efficiency of transmission:

i) Voltage regulation is defined as drop in voltages between sending end and the receiving end as a percentage of receiving end voltage. Mathematically

% Regulation $= \frac{|V_S| - |V_R|}{|V_R|}$ x 100, where $|V_S|$ absolute value of sending end voltage and $|V_R|$ is absolute value of receiving end voltage. As per Indian electricity rules the voltage at receiving end should be within ± 10% of declared voltage. Voltage regulation for trans mission system is ± 4% and that of distribution is ± 6%. Large variation of voltage affects electric motors, lights whose efficiency becomes poor at low voltages. Sudden change in voltage may trip the breaker interrupting power to hospitals and other emergency services.

ii) Efficiency: efficiency is given by the ratio output to input. Again output is input less losses. In order that efficiency should be high the transmission losses are to be reduced. The economic design of the system as a whole should be to minimize over all annual cost. The loss can be reduced by taking care of the power factor for the system. The consumers having loads of low power factor are to be penalized unless they take steps to improve their power factor.

2.3.1. Kelvin' law for economic size of the conductor: For a overhead transmission line the cost of conductor generally constitutes a major part of transmission line. Therefore determination of proper size of the conductor is very important. As per Kelvin's law 'The most economical cross section of the conductor is that for which the total annual cost of transmission line is minimum.' The annual cost of transmission line consists of two parts: i) Annual charge on capital investment and ii) annual cost of energy lost in the conductor.

i) Annual charge on Capital: The annual charge is the interest and depreciation on capital investment which includes cost of conductor, supports and insulator besides their erection. The insulator cost is almost constant. Support cost is partly constant and partly varies directly with X-section of the conductor. Capital investment on conductor varies directly with cross section of the conductor. So we can write the annual charge C_1 in the form $C_1 = P_1 + P_2 a$ where P_1 and P_2 are constants and a is the X-section of the conductor.

ii) Annual cost of energy wasted. The major loss in the transmission line is the I^2R loss in the conductor. Resistance of conductor is inversely proportional to the X-section of the conductor. Therefore, the annual energy loss, hence the cost of annual energy loss is inversely proportional to cross sectional area of the conductor a. If C_2 is the annual cost of energy lost, then $C_2 = \frac{P_3}{a}$, where P_3 is another constant. So, the total annual cost $C = C_1 + C_2 = P_1 + P_2 a + \frac{P_3}{a}$. C to be minimum, $\frac{dC}{da} = 0$ or $\frac{d(P_1 + P_2 a + \frac{P_3}{a})}{da} = 0$ or $P_2 - \frac{P_3}{a^2} = 0$ or $P_2 a = \frac{P_3}{a}$. That is variable part of annual charge is equal to the cost of annual energy loss. From this the Kelvin's law can be redefined as 'The most economical cross section of the conductor is that for which the variable part of annual charge is equal to the cost of annual energy loss'.

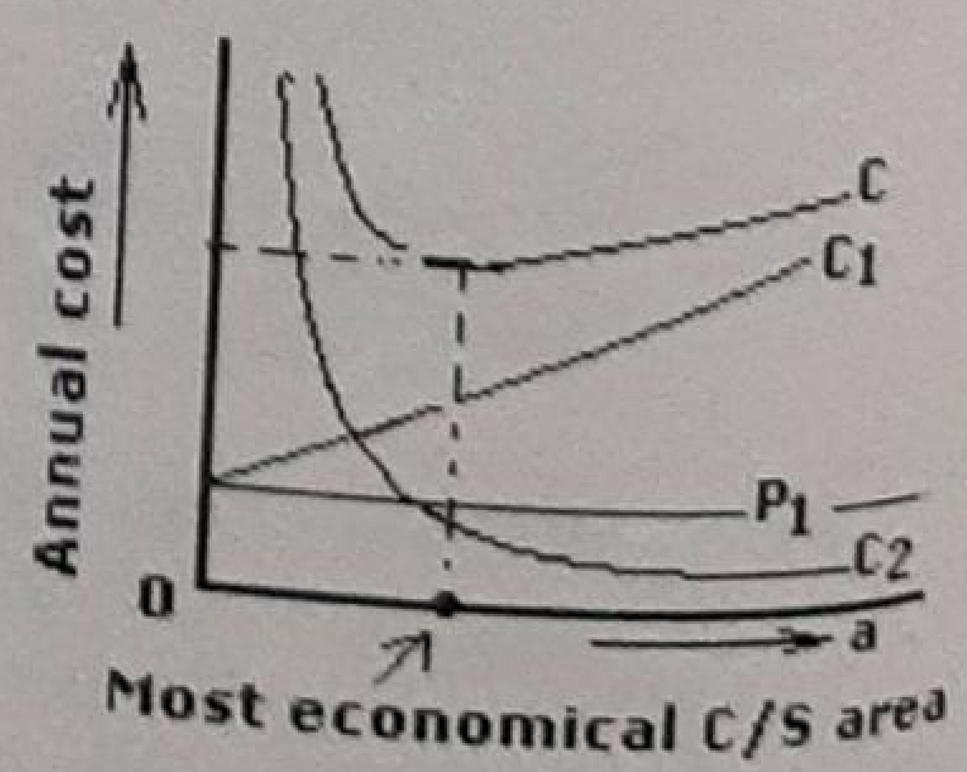
2.3.2 Graphical representation of Kelvin's Law:

a) Annual charge $C_1 = P_1 + P_2 a$. C_1 vrs. a is a straight line.

b) Annual cost of energy wasted $C_2 = \frac{P_3}{a}$. So C_2 vrs a is a rectangular hyperbola.

c) total cost $C = C_1 + C_2 = P_1 + P_2 a + \frac{P_3}{a}$

All the three graphs are shown in the given figure. The lowest point on curve C represent the most economical X-section of the conductor.



2.3.3 Limitations of Kelvin's Law:

i) In absence of operating load curve it is not easy to estimate the annual energy loss at the planning and estimating stage.

ii) The assumption that annual charge on account of depreciation and interest on the capital investment is in the form $C_1 = P_1 + P_2 a$ is strictly speaking not true. In case of cable neither the cost of the dielectric and sheath nor the cost of laying vary in this manner. The loss in insulation dielectric is not accounted for.

iii) The law does not take care of safe current density, mechanical strength, corona loss etc

iv) The conductor size determined by this law may not always be practicable one to carry the necessary current safely.

v) Interest and depreciation on capital outlay cannot be accurately determined.

2.4 Explain corona and corona loss on transmission line:

2.4.1 Corona: When the potential applied between two conductors exceeds a certain value called 'critical disruptive voltage the conductors are surrounded by a faint violet glow called corona. The phenomenon of corona is accompanied by hissing sound , production of ozone, power loss and radio interference. So corona can be defined as ' the phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona. IF the conductors are polished and smooth the glow will appear uniform otherwise the rough points will appear brighter. In d.c line the positive wire has uniform glow while the negative wire has spotty glow.

2.4.2 Cause of corona formation. Some ionized particles are always present in the atmosphere. When potential difference is applied between conductors, a potential gradient is setup in the air surrounding the conductor with maximum value at conductor surface. The greater is the applied voltage more is the potential gradient and more is the velocity of the free electrons in the ionized particles near by the conductor. IF the applied voltage is such that the potential gradient is about 30 kV(peak) /cm, The velocity of free electrons becomes sufficient to strike the neutral molecules with enough force to dislodge one or more electrons which strike other neutral particles. The process of ionization becomes cumulative. The result of this ionization process either forms corona or produce spark between the conductors.

2.4.3 Factors affecting corona: a) Atmosphere: In stormy weather the number of ions present in the atmosphere is more than normal. So corona occurs at much less voltage compared to fair weather.

b) Conductor surface: Rough and irregular surface of conductor give rise to more corona because uneven surface decrease the breakdown voltage.

c) Spacing between conductors: When the spacing is very large compared to the diameter of conductor there may not be any corona because it reduces the potential gradient at the conductor surface.

d) Line voltage: The voltage greatly affects the corona. If the applied voltage is not high enough to create sufficient potential gradient at the surface of conductor to ionize the surrounding air no corona is created.

2.4.4 Important terms: *i) Potential gradient* (g) near the conductor $g = \frac{V}{r \log_e(\frac{d}{r})}$ kV/cm, where V is phase to neutral potential in kV, r is the radius of each conductor in cm and d is the spacing between them in cm.

ii) Break-down voltage of air: The break down voltage of air at 76 cm of Hg pressure and 25^0C temperature is 30 kV/cm peak or 21.2 kV/cm RMS and is denoted by g_0.

iii) *Critical disruptive voltage*: It is the minimum phase to neutral voltage at which corona occurs. If V_c is the critical disruptive voltage, then $g_0 = \frac{V_c}{r \log_e(\frac{d}{r})}$ or $V_c = g_0 r \log_e(\frac{d}{r})$ at 76 cm of Hg pressure and 25^0C temperature. If the temperature and pressure vary then g_0 varies. g_0 is proportional to air density δ. Thus the break down voltage of air at a barometric pressure b cm of

Hg and temperature t ^{0}C is given by δg_0 where δ = air density factor $=\frac{3.92b}{273+t}$, $\delta = 1$at 76 cm of Hg pressure and 25^{0}C temperature. So $V_c = g_0\delta r \log_e(\frac{d}{r})$. Correction also has to be made for surface irregularities. Taking into account the surface irregularity factor m, $V_c = mg_0\delta r \log_e(\frac{d}{r})$. Value of m for polished surface = 1, for dirty surface 0.92 to 0.98, for stranded conductors 0.80 to 0.87 and rough conductor 0.72 to 0.82.

iv) Visual critical voltage (V_0): It is the minimum phase to neutral voltage at which corona glow appears all along the line conductors. In case of parallel conductors $V_0 = mg_0\delta r[1 + \frac{0.3}{\sqrt{\delta r}}] \log_e(\frac{d}{r})$. kV/phase.

2.4.5 Power loss due to corona: Corona is always accompanied by energy loss in form of light, sound heat and chemical action. The power loss due to corona is given by

P = 242.2 $[\frac{f+25}{\delta}]\sqrt{\frac{r}{d}}\,(V - V_c)^2 \times 10^{-5}$ kW/km/phase, where f is supply frequency in Hz, V is rms phase to neutral voltage in kV, V_c is rms critical disruptive voltage per phase in kV.

2.4.6. Advantages and disadvantages of corona: i) Advantages- a). Due to corona the air surrounding the conductor becomes conducting and hence virtual diameter is increased which reduces the electrostatic stresses between the conductors b). corona reduces the effect of transients produced by surges.

ii) disadvantages: a). Corona is accompanied by energy loss hence transmission efficiency is reduced b) Ozone is produced by corona which corrodes the conductor due to oxidation c) The current drawn by the corona is non sinusoidal, hence non-sinusoidal voltage drop occurs in the line wich causes interference with the nearby communication lines.

2.4.7 Methods of reducing corona effect. i) By increasing the conductor size the voltage at which corona occurs is increases which reduces the effect of corona. For this reason ACSR conductors are used in transmission lines ii) By increasing conductor spacing: More is the spacing higher is the voltage for corona formation. But by increasing conductor spacing structures will be very costly.

3.0 Overhead lines:

3.0.1 Components of a O.H line: i) Conductor: Carry electric power from one place to other. ii) Line supports: They support the conductors to provide required ground clearance, iii) Insulators They are fixed to the cross arms and hold the conductors so that proper insulation is provided between conductor and earth, iv) Cross arms: Insulators are fixed to the cross arms and provide requisite spacing between conductors, v) Earth wire & Lightening arresters: Protect against lightening surges vi) Miscellaneous items: Danger boards, Anti-climbing wires, spacers, guarding etc as per requirement.

3.1 Types of supports, size and spacing of conductor.

3.1.1 Desirable properties: *i) High mechanical strength, ii)Light weight without loss of strength iii) Low cost and economical to maintain, iv) Long life, v) Easy accessibility of conductors for maintenance, vi) Able to provide required ground clearance.*

3.1.2 Types of supports:

a) Wooden poles. Wooden poles can be used for short spans up to 50m. They tend to rot bellow ground. They are no more in use due to scarcity of wood, forest conservation. Large scale felling of trees causes environmental degradation.

Hg and temperature t ^{0}C is given by δg_0 where δ = air density factor $= \frac{3.92b}{273+t}$, $\delta = 1$ at 76 cm of Hg pressure and 25^{0}C temperature. So $V_c = g_0 \delta r \log_e(\frac{d}{r})$. Correction also has to be made for surface irregularities. Taking into account the surface irregularity factor m, $V_c = mg_0 \delta r \log_e(\frac{d}{r})$. Value of m for polished surface = 1, for dirty surface 0.92 to 0.98, for stranded conductors 0.80 to 0.87 and rough conductor 0.72 to 0.82.

iv) Visual critical voltage (V_0): It is the minimum phase to neutral voltage at which corona glow appears all alo. g the line conductors. In case of parallel conductors $V_0 = mg_0 \delta r[1 + \frac{0.3}{\sqrt{\delta r}}] \log_e(\frac{d}{r})$. kV/phase.

2.4.5 Power loss due to corona: Corona is always accompanied by energy loss in form of light, sound heat and chemical action. The power loss due to corona is given by

P = 242.2 $[\frac{f+25}{\delta}]\sqrt{\frac{r}{d}}\,(V - V_c)^2 \times 10^{-5}$ kW/km/phase, where f is supply frequency in Hz, V is rms phase to neutral voltage in kV, V_c is rms critical disruptive voltage per phase in kV.

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b.) Steel poles R.S joists, rails and tubular poles are used for Lt and HT lines up to 33 kV. They have good mec hanical strength and are used for longer spans. Tubular poles are galvanized but RS joists and rai poles are periodically painted.

c) Rein forced cement concrete (R.C.C) poles: They have good mechanical strength and long life. They are good looking and maintenance free. They are used for 400 V up to 66 kV single circuit and double circuit lines. Due to heavy weight transportation poses problems.

d) Pre-stresses concrete (P.S.C) poles: They have the similar properties as those of RCC poles. But of less strength. Breakage is observed during transportation. They are used for primary and secondary distribution lines.

e) Galvanized steel towers: For EHT (66kV to 400 kV) transmission lines lattice galvanized towers are used. There are various types of towers. Y- types, H- types are used for voltages 400 kV and above.

f) Double pole structures: In the straight run of lines (0.4 kV to 33 kV) normally single poles are used. But where the line deviates, double pole structure is used. Double poles are also used in case of 11/0.4 kV pole mounted substations. Two poles with straight and cross bracings at suitable height make a double pole structure.

Maximum leng h of span in mtrs

Type of support	Wooden poles	Tubular	P.S.C	R.C.C	R.S. Joist/Rail	Steel tower
Span in mtrs	40-50	50-80	50 – 80	80 -100	70-120	100 -400

Ground Clearance of OH Lines

Type of O.H Line	Minimum clearance of conductor above ground (mtr.)			Vertical clearance above building if line is passing over it.(mtr.)	Horizontal clearance from the building (mtr.)
	Crossing road or public through fare	Along road or public place	At other places		
LT 440V	5.8	5.5	4.6	2.5	1.25
Up to 11 KV	6.1	5.8	5.2	3.66	1.25
Up to 33 KV	6.1	5.8	5.2	3.66	1.83
>33KV			5.2 +0.305 for every additional 33 KV.	3.66+0.305 for every additional 33 KV.	1.83+0.305 for every additional 33 KV.

3.1.3Spacing between conductors. The empirical formula commonly employed for determining the spacing of aluminum conductors is given as Spacing = $\sqrt{S} + \frac{V}{150}$ *meters* , where S is sag in mtrs. And V is the line voltage in KV. Some typical values are given in the table.

Working voltage	Spacing between conductors for:		Spacing between conductor and the supporting structure (cm)
	Vertical formation (cm)	Horizontal formation (cm)	
LT	38	46	15
6.6KV or11 KV	76	114	30.5
33KV	122	153	61
66	198	323	76
110	313	496	107

132	366	487	130

For EHT transmission lines the conductor spacing are 6.0 mtr. For 220KV, 11.5 mtr. For 400 KV and 14 mtrs for 765 KV.

3.2 Types of conductor material: *Requirement and properties-* i) High electrical conductivity, ii) High tensile strength, iii) Low cost, Low weight per unit volume.. All the above properties are not found in a single material used for OH line conductor. So a compromise is made between cost and other properties..

Commonly used conductor materials: i) Copper, ii) Aluminum, iii) cadmium –copper, iv) Galvanized steel etc. All conductors used in OH line are stranded except copper. The advantage of stranding are: a) it is flexible, b) reduced skin effect and c) due to large diameter, swing and vibration is less. If there are n number of layers of stranding then number of strands is given by 3n(n+1) + 1. Consecutive layers of wires are twisted in opposite direction.

i)Copper: Hard drawn copper is used to increase tensile strength. Copper has very good conductivity. But its cost is very high for which it is no more in use.

ii) Aluminum: It is cheap, light, has reasonably good conductivity (60% of Cu.), has low tensile strength. For same power transmission, more conductor c/s areais required for which it is subjected to more wind pressure, more sag. The support height is bigger to give required ground clearance. The light weight causes more swing and vibration for which conductor spacing is more. It has low tensile strength for which sag is more. But due to cheapness it is widely used.

iii) *ACSR (Aluminum Conductor Steel Reinforced):* The cross section ratio is in general 1:6 but it can be modified to 1:4. Steel reinforce increases the tensile strength so that it is used in EHT transmission line where span is more.

iv) Galvanized steel wire: It is cheap and its mechanical strength is more. It is used to transmit small power in rural area. The power loss is more.

v.) Cadmium copper. It is very costly and very rarely used.

3.3 Types of insulators and cross arms.

Insulators: Insulators are used to insulate the line conductors from cross arms and support body. The desirable properties are: a) High mechanical strength to withstand conductor load/tension, wind pressure etc, b) High insulation resistance to prevent leakage current to the earth, c) High dielectric strength, d) Should be non-porous, free from impurities and crack, e High ratio of puncture to flash over strength.

Materials used: a) Porcelain- Mixture of plastic clay, silica and feldspar fired at high temperature produced porcelain. It is then glazed. Porcelain insulators are most common.

b) Glass: Toughened glass insulators are used in EHV and HVDC lines due to their transparency cracks are easily detected by visual inspection.

Synthetic: They are made of silicon rubber and resin. In this type of insulator leakage current is more. They are heap and mostly used as bushings.

ii) Hardware: Insulation hardware are metallic parts made out of malleable cast iron and galvanized.

iii) Types of insulators:

a) Pin type: Mostly used in LT (220 v and 440 V) and Ht (11kV & 33kV) lines,

b) Post insulators: Used in substations and switch yard for supporting bare bus bars, jumpers, Isolating switches. They be 2, 3 or 4 piece unit for use in higher voltages.

c) Suspension Insulators: They are disc insulators. Each disc is designed for working voltage of 11 to 12 kV. A string of suspension insulators are used for various voltage levels at suspension points only. They are free to swing in any direction. They are in horizontal plain.

d) Strain insulators: They are also discs. Each disc is designed for working voltage of 11 to 12 kV. A string of strain insulators are used for various voltage levels at cut points, angle points or terminal points at the switch yard. The discs are in vertical plain.

The string efficiency = $\frac{\text{Voltage across the srting}}{\text{n x voltage across the disc nearest to the conductor.}}$

Puncture voltage: The voltage at which the insulator losses its insulating property. Puncture voltage test is a destructive test.

Flash-over voltage: It is the voltage at which flash over occurs but the insulator is not destroyed.

e) Shackle insulators. These insulators are used in LT distribution lines at dead ends or at points where the line changes direction. They are also used at cut points in very long straight run of LT line. Shackle insulator in vertical position where the LT line is run in vertical configuration.

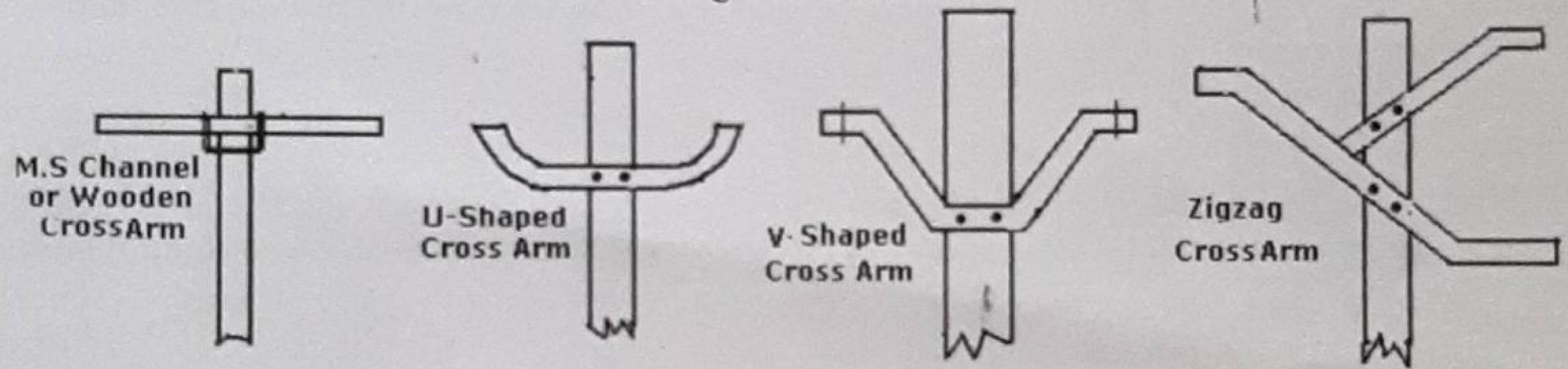
Cross arms

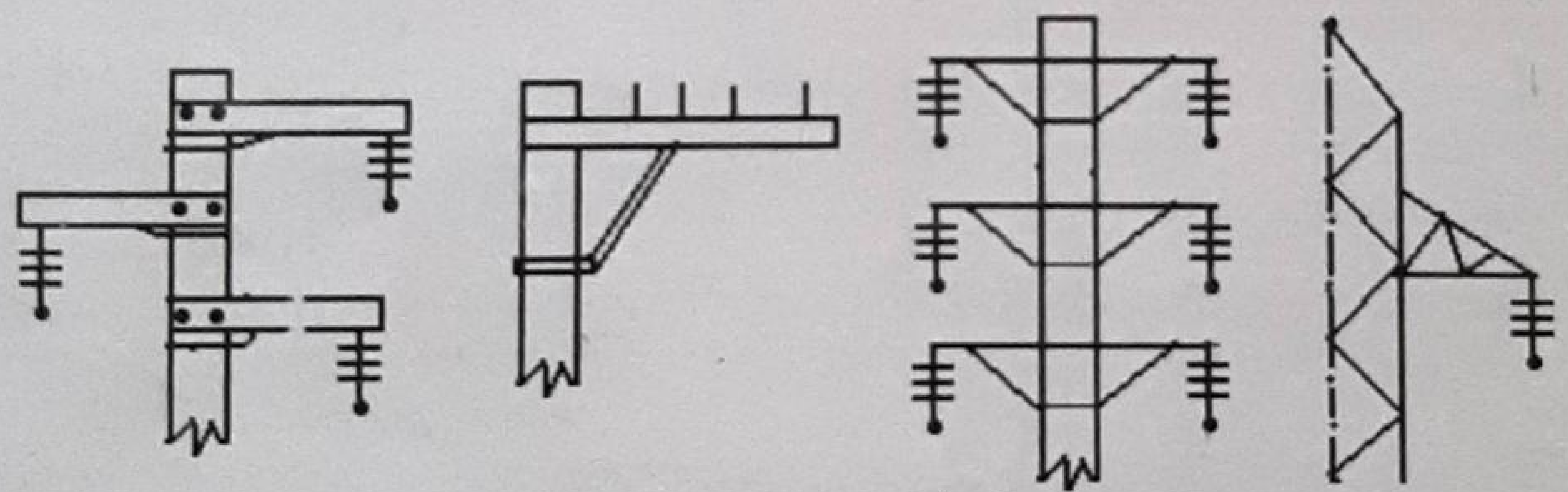
i) Straight cross arms: For LT line (440V) straight cross arms or Propped cross arms are used for both horizontal or vertical configuration of conductors.

ii.) V, U or zigzag cross arms : These are used for 11 kV and 33 kV lines

iii) Lattice cross arms: They are integral components of EHT towers.

Straight and zigzag cross arms are made of MS channels or angles but V and U cross arms are made of M.S channel. Some cross arm arrangements are shown.





3.4 Sag and Tension: (Approximate formula): *Some important terms:*

Sag: The difference in level between the points of support and the lowest point of the conductor is called sag. S is the sag as indicated in the given figure.

Conductor shape: When the conductor is suspended between two supports at the same level, the conductor takes the shape of a catenary. Usually the sag is small compared to the span. In that case the shape is like a parabola.

Tension: The tension at any point on the conductor acts tangentially. Thus the tension at the lowest point O in the given figure acts horizontally. The horizontal component of tension at every point is constant.

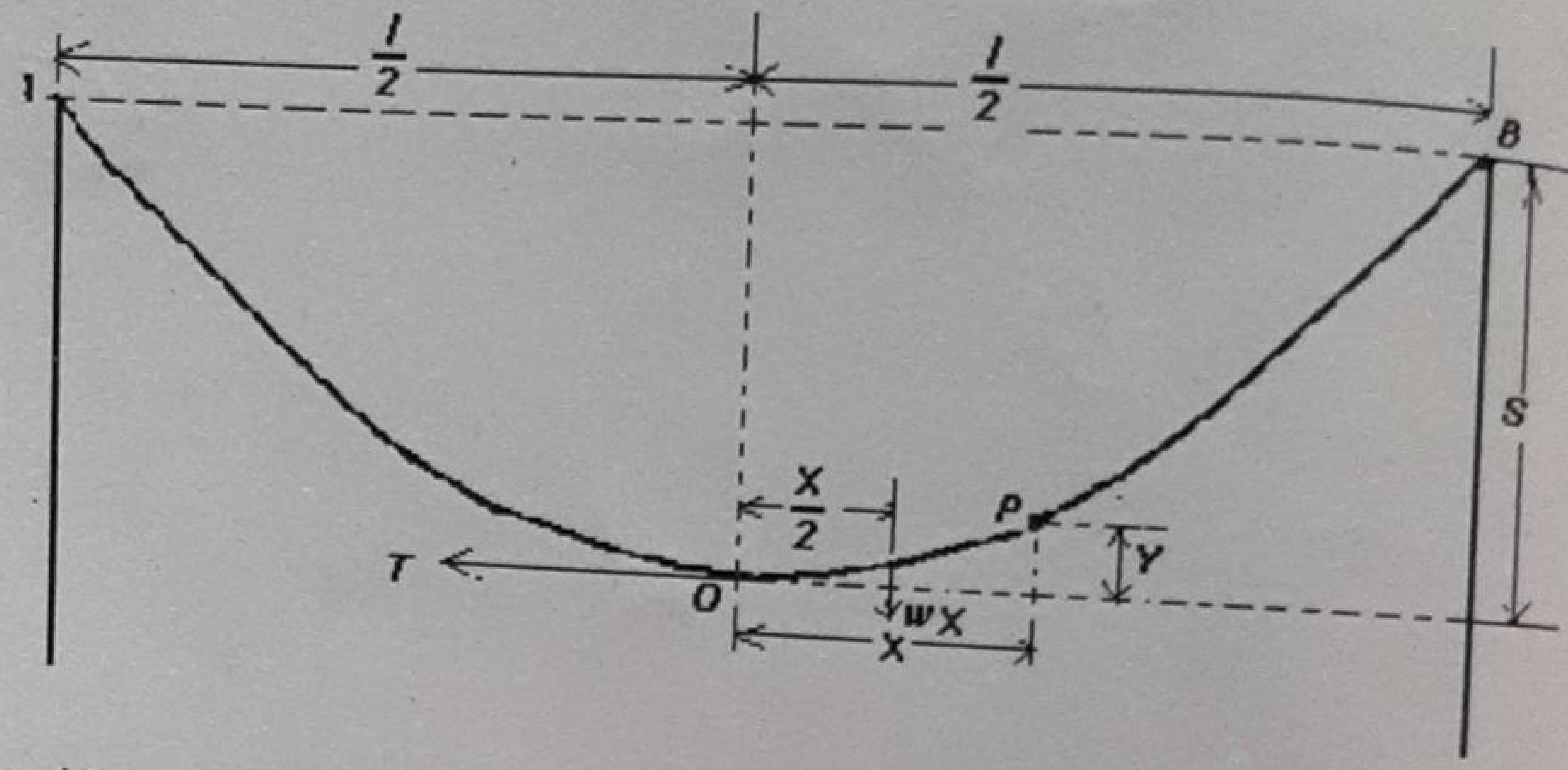
Tension at the support: Tension at the support is approximately equal to the horizontal tension acting at any point on the conductor. Thus tension at the support is equal to the tension at the lowest point of the conductor.

Ultimate strength: It is the force that develops the maximum stress in the material while being pulled before failing or breaking.
Break down stress: It is the maximum stress that the material can withstand without risk of permanent damage.
Factor of safety: It describes the degree of safety limit beyond risk of failure of the material.

3.4.1 Calculation of sag:

i) Support at same level:

In the given figure a conductor with lowest point at O, the mid way between AB is shown between two equal level supports. The span AB = l m. w = resultant weight per meter of conductor in kg/m.
T = Working Tension in the conductor in kg.



Taking O as the origin consider a point P on the conductor whose coordinates are x and y. The curvature of OP being very small we can take OP ≅ x. The forces acting on OP are i) T at O and ii) wx at $\frac{x}{2}$ from O. In order that P is is equilibrium the moments of these two forces about P must be equal. So $Ty = wx \cdot \frac{x}{2} = \frac{wx^2}{2}$ or $y = \frac{wx^2}{2T}$ When $x = \frac{l}{2}$, sag is maximum (S). So maximum sag $S = \frac{wl^2}{8T}$.

ii) Supports are at unequal level: See the figure given bellow: In figure-I, the supports are at such levels that the lowest point O is in between the support points, where as in fig-II the lowest point is outside the support points. In fig-I span $l = x_1 + x_2$, where as in fig-II $l = x_1 - x_2$.

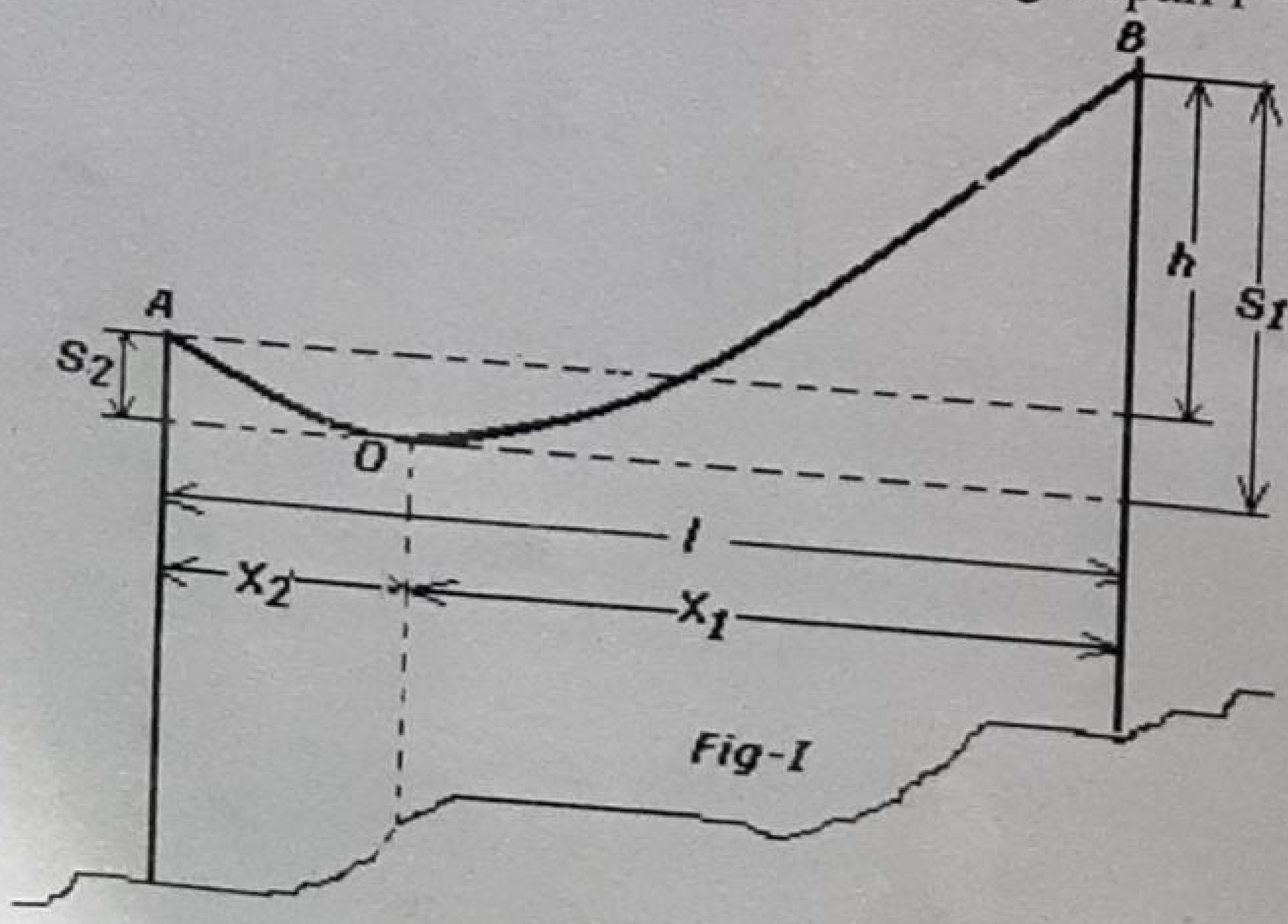


Fig-I

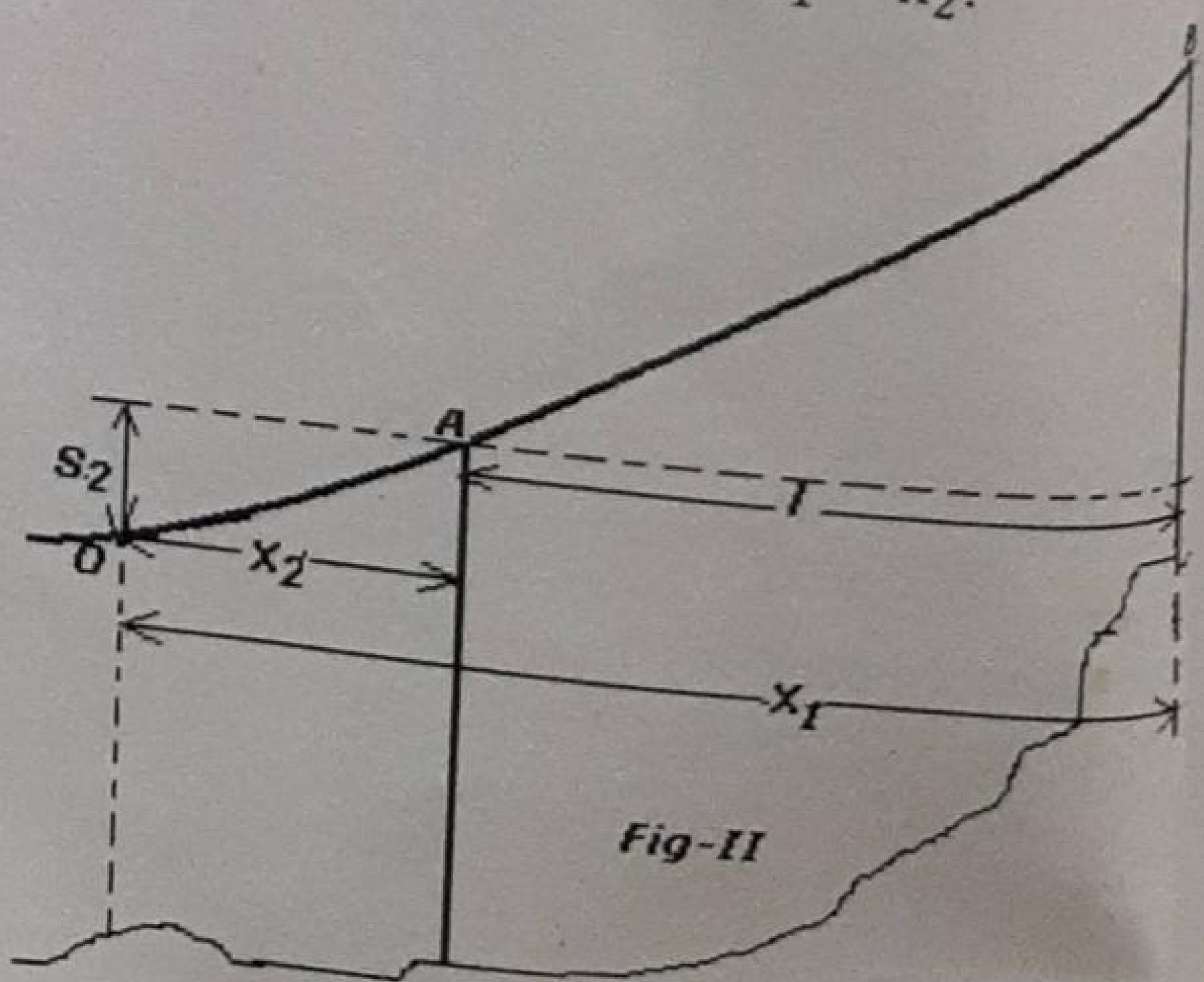
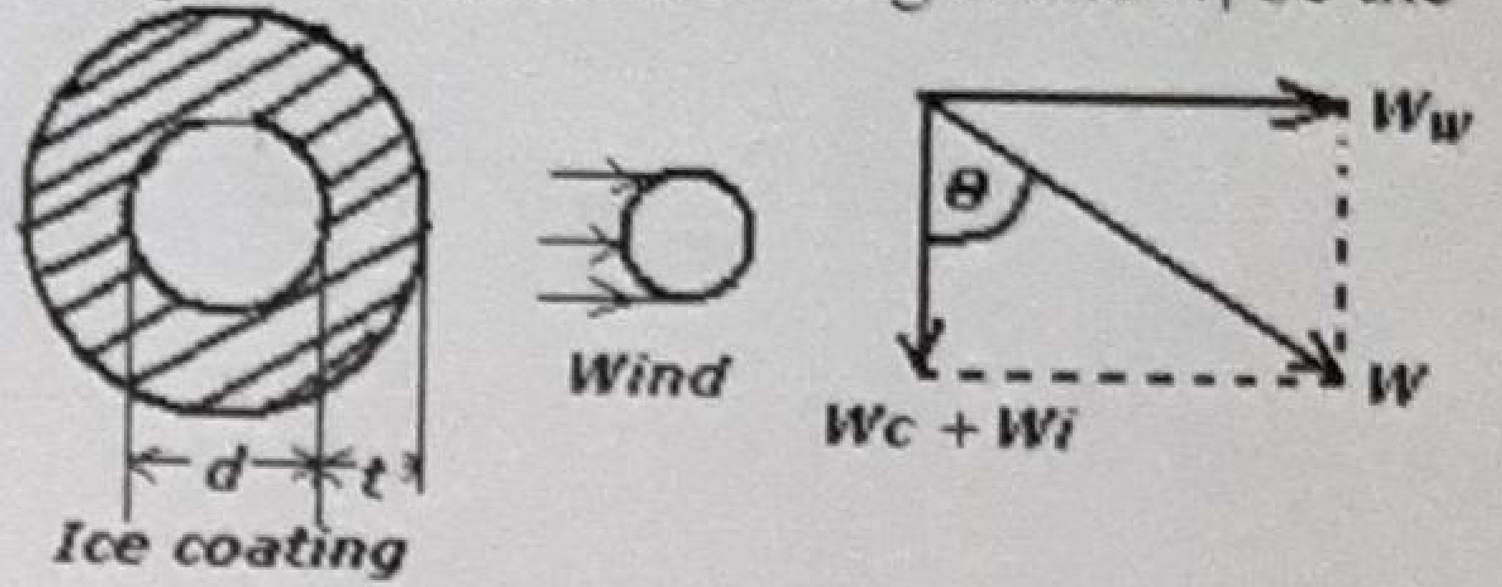


Fig-II

Referring to Fig-I, $S_1 = \frac{wx_1^2}{2T}$ and $S_2 = \frac{wx_2^2}{2T}$. $x_1 + x_2 = l$...(i) Now $S_1 - S_2 = h = \frac{w}{2T}(x_1^2 - x_2^2) = \frac{w}{2Y}(x_1 + x_2)(x_1 - x_2) = \frac{wl}{2T}(x_1 - x_2)$ or $(x_1 - x_2) = \frac{2T(S_1 - S_2)}{wl} = \frac{2Th}{wl}$ ...(ii) Solving eq. (i) and (ii) $x_1 = \frac{l}{2} + \frac{Th}{wl}$ and $x_2 = \frac{l}{2} - \frac{Th}{wl}$. Note that if value of x_2 comes –ve then point O is outside as in fig-II.

iii) Effect of wind and ice: In the above formula for calculation of sag w is the resultant weight acting per meter length of conductor. In still weather without any ice coating over conductors w = Conductor weight/m vertically down ward . Now we shall consider the effect of ice coating and wind pressure on the conductor. Let w_c be the weight of conductor/m length and w_i be the weight of ice coating over meter length of conductor. So total down ward force acting per meter of conductor = $(w_c + w_i)$ kg. Similarly the wind load acting horizontally over a meter length of conductor is = w_w kg. Then the resultant weight $w = \sqrt{(w_c + w_i)^2 + w_w^2}$



Is acting at an angle $\theta = \cos^{-1}\frac{w_c + w_i}{w}$. For ice coating and wind load the sag calculated is slant at an angle θ to the vertical. Vertical sag = slant slag x cos θ.

$w_i = \frac{\pi}{4}\rho\,[(d + 2t)^2 - d^2]x\,1$, where ρ is density of ice and $w_w = p_w x\,(d + 2t)x1$, where p_w is wind pressure per unit area. In absence of ice t=0.

4.0 Performance of short and medium lines:

i) Short transmission line: When the length of an overhead line is up to 50 km and the line voltage is less than 20 kV, it is considered as 'Short transmission line. In this case due to short length and smaller voltage the shunt capacitance effect is neglected and only resistance and inductive reactance of the line are considered for study of its performance.

ii) Medium transmission line: When the length of an overhead line is more than 50 km but less than 150 km and the line voltage is more than 20 kV but less than 100 kV, it is considered as 'Medium transmission line. In this case the distributed shunt capacitance is lumped at one or more points along with series lumped resistance and inductive reactance (L, π or T) for study of performance.

iii) Long transmission line: When the length and voltage exceeds 150 km and 100 kV respectively the line is classified as long transmission line and its analysis is complicated.

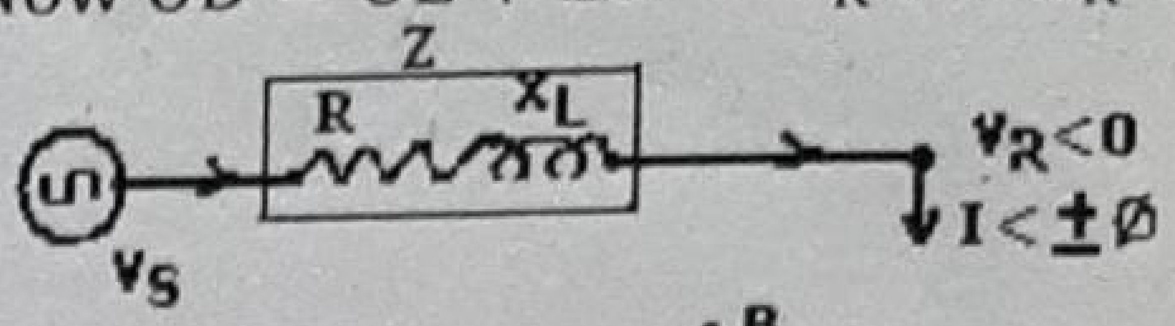
4.1. Performance parameters:

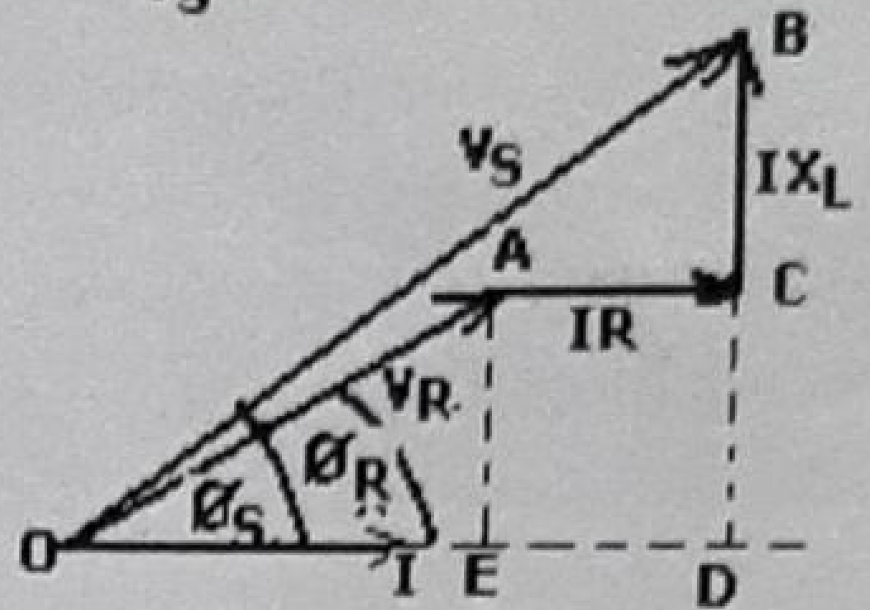
i) Voltage Regulation: The voltage drop between sending end and the receiving end expressed as a percentage of receiving end voltage is called Voltage regulation. % voltage regulation = $\frac{V_S - V_R}{V_R}$ x 100, where V_S is the sending end voltage and V_R is receiving end voltage.

ii) Transmission efficiency: It is the ratio of receiving end power to the sending end power. % Transmission efficiency = $\frac{V_R I_R \cos\emptyset_R}{V_S I_S \cos\emptyset_S} x100$, where I_R, $\cos\emptyset_R$ are receiving end current and power factor respectively and I_S, $\cos\emptyset_S$ are sending end current and power factor respectively

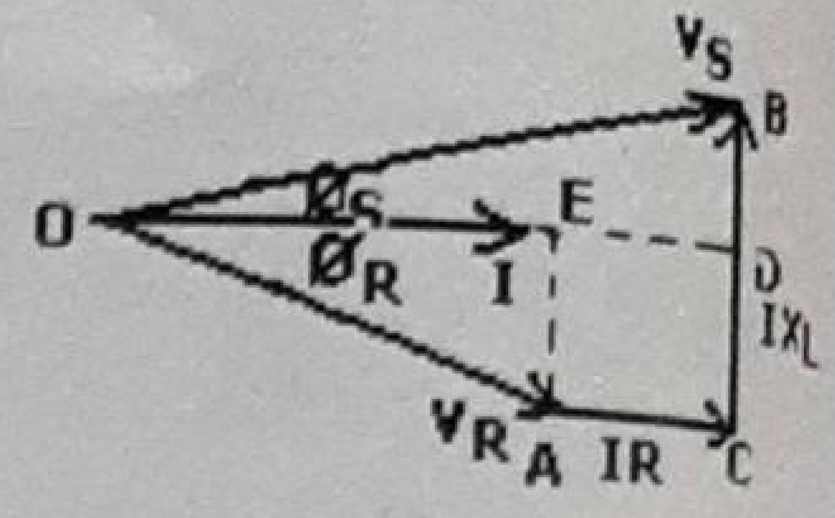
4.2 Performance calculation:

4.2.1 Short transmission line: In case of 3-∅ line; phase values are considered. Let P_R, V_R, I and $\cos\emptyset_R$ are the phase values of receiving end power, voltage, current and power factor respectively. The power factor may be leading or lagging. Similarly P_S, V_S, I and $\cos\emptyset_S$ are the phase values of sending end power, voltage, current and power factor respectively. The single line diagram of the one phase and the phasor diagram taking I as reference vector for both lagging and leading pf is shown bellow. From the phasor diagram $OE = V_R \cos \emptyset_R$, $AE = CD = V_R \sin \emptyset_R$, $AC = ED = IR$ and $BC = I X_L$. Now $OD = OE + ED = V_R \cos \emptyset_R + IR$, $BD = BC \pm CD = I X_L \pm V_R \sin \emptyset_R$. (+ is for lagging pf and – is for leading pf). In the OBD right angled triangle, $OB^2 = OD^2 + BD^2$ or $V_S{}^2 = (V_R \cos \emptyset_R + IR)^2 + (I X_L \pm V_R \sin \emptyset_R)^2 = V_R{}^2 \cos^2 \emptyset_R + V_R{}^2 \sin^2 \emptyset_R + I^2R^2 + I^2 X_L{}^2 + 2IRV_R \cos \emptyset_R \pm 2 I X_L V_R \sin \emptyset_R = V_R{}^2 + I^2(R^2 + X_L{}^2) + 2V_R(IR \cos \emptyset_R \pm I X_L \sin \emptyset_R)$. So





Lagging pf



Leading pf

$V_S = \sqrt{[V_R{}^2 + I^2(R^2 + X_L{}^2) + 2V_R(IR \cos \emptyset_R \pm I X_L \sin \emptyset_R)]} = V_R[1 + \frac{I^2(R^2+X_L{}^2)}{V_R{}^2} + \frac{2}{V_R}(IR \cos \emptyset_R \pm I X_L \sin \emptyset_R)]^{\frac{1}{2}}$ This is the exact equation to find V_S. To find out the approximate value of V_S, we can neglect the term $\frac{I^2(R^2+X_L{}^2)}{V_R{}^2}$ as it is very small.

So $V_S = V_R[1 + \frac{2}{V_R}(IR \cos \emptyset_R \pm I X_L \sin \emptyset_R)]^{\frac{1}{2}} \cong V_R[1 + \frac{2}{2V_R}(IR \cos \emptyset_R \pm I X_L \sin \emptyset_R)]$; (by taking first two terms of binomial expansion). Or $V_S \cong V_R + (IR \cos \emptyset_R \pm I X_L \sin \emptyset_R)$. It may be noted that i) the approximate formula is fairly correct for lagging pf but erroneous for leading pf ii) The solution in complex notation is advisable. For this when receiving end current is taken as reference vector the receiving end voltage $\vec{V_R} = V_R(\cos \emptyset_R + j \sin \emptyset_R)$ for lagging pf and $\vec{V_R} = V_R(\cos \emptyset_R - j \sin \emptyset_R)$ for leading pf and $\vec{V_S} = \vec{V_R} + I\vec{Z} = V_R(\cos \emptyset_R \mp j \sin \emptyset_R) + I (R + jX_L) = (IR + V_R \cos \emptyset_R) + j(IX_L \mp V_R \sin \emptyset_R)]$.

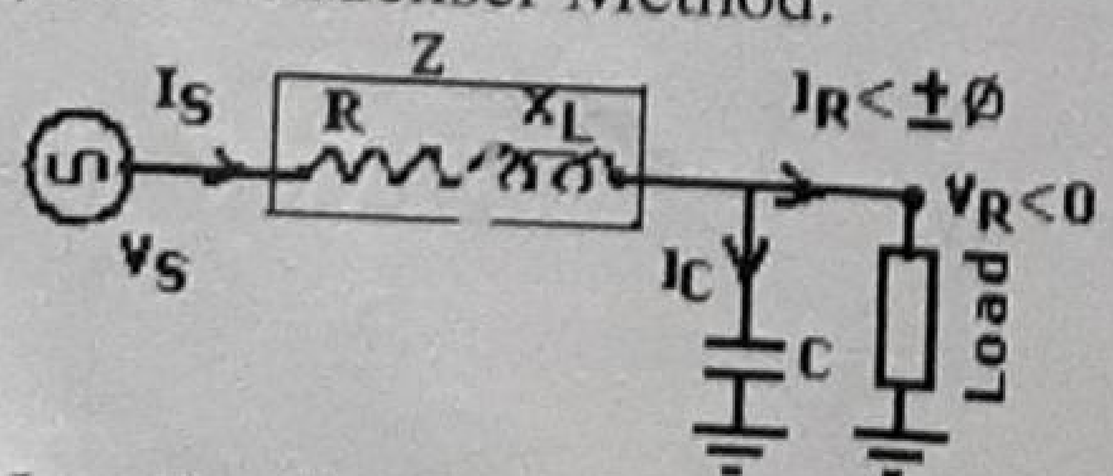
% Voltage regulation $= \frac{|V_S| - |V_R|}{|V_R|} x100 = \frac{1}{|V_R|}(IR \cos \emptyset_R \pm I X_L \sin \emptyset_R)$ x 100

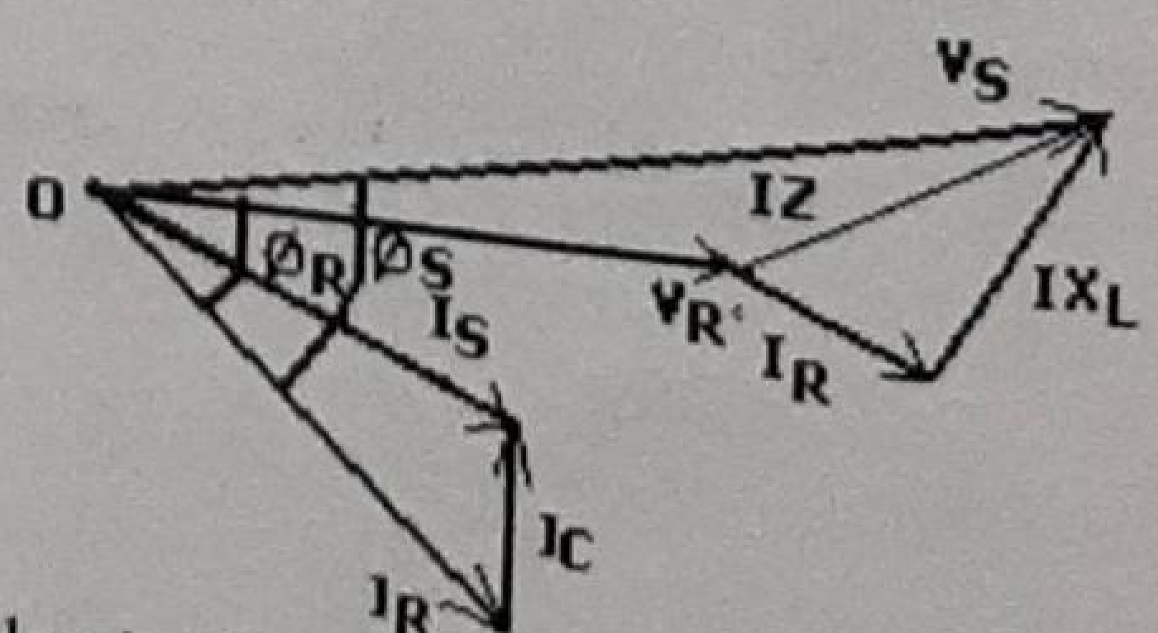
Sending end pf $\cos \emptyset_S = \frac{OD}{OB} = \frac{V_R \cos \emptyset_R + IR}{V_S}$, Power delivered = $V_R I \cos \emptyset_R$, Power sent out = Power delivered + losses = $V_R I \cos \emptyset_R + I^2R$. % Transmission efficiency = $\frac{\text{Power delivered}}{\text{Power sent out}}$x100 = $\frac{V_R I \cos \emptyset_R}{V_R I \cos \emptyset_R + I^2R}$x100.

4.2.2. Single phase Short transmission line: The solution procedure and the formulae are the same but the resistance and the reactance are to be considered for the loop i.e for both wires.

4.2.3 Medium transmission line:

i) End condenser Method.



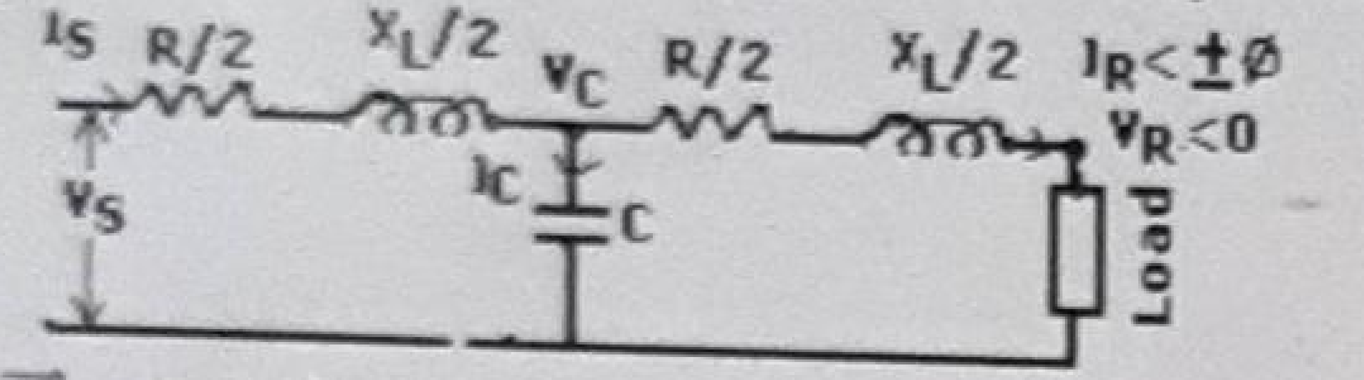


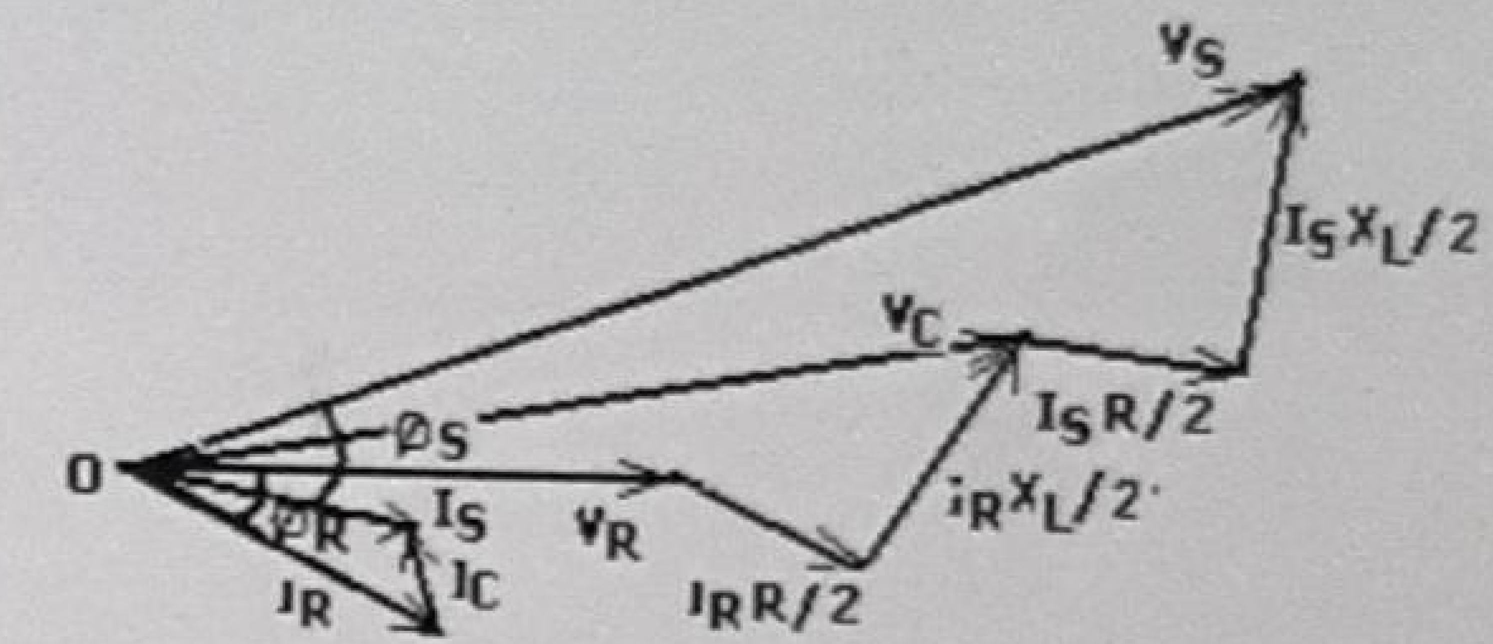
Here the distributed line capacitance is lumped at the load end as shown. We consider one phase of the three phase line. The vector diagram also is shown. I_R is the load current per phase and receiving end lagging pf = $\cos \emptyset_R$. R and X_L are the resistance and inductive reactance per phase and C is the capacitance per phase. V_S

Is the sending end voltage. From the circuit diagram $\vec{I_S} = \vec{I_R} + \vec{I_C} = I_R(\cos \emptyset_R - j\sin \emptyset_R). + j\omega C \times V_R$
$= I_R(\cos \emptyset_R - j\sin \emptyset_R). + j2\pi fC \times V_R =$
$I_R \cos \emptyset_R - j\,(I_R \sin \emptyset_R - 2\pi fC \times V_R)$
$\vec{V_S} = V_R + \vec{I_S}(R + jX_L) = V_R + \vec{I_S}\,Z$. % Regulation $\frac{|V_S| - |V_R|}{|V_R|} \times 100$. % Transmission efficiency $= \frac{\text{Power delivered per phase} \times 100}{\text{Powerdelivered per phase} + \text{Losses}} = \frac{V_R I_R \cos \emptyset_R \times 100}{V_R I_R \cos \emptyset_R + I_S^2 R}$.

Limitations: Although this method of solution is simple yet it has some draw backs. i) Due to lumping the distributed capacitance an error about 10% is introduced in the calculation ii) This method over estimates the capacitance.

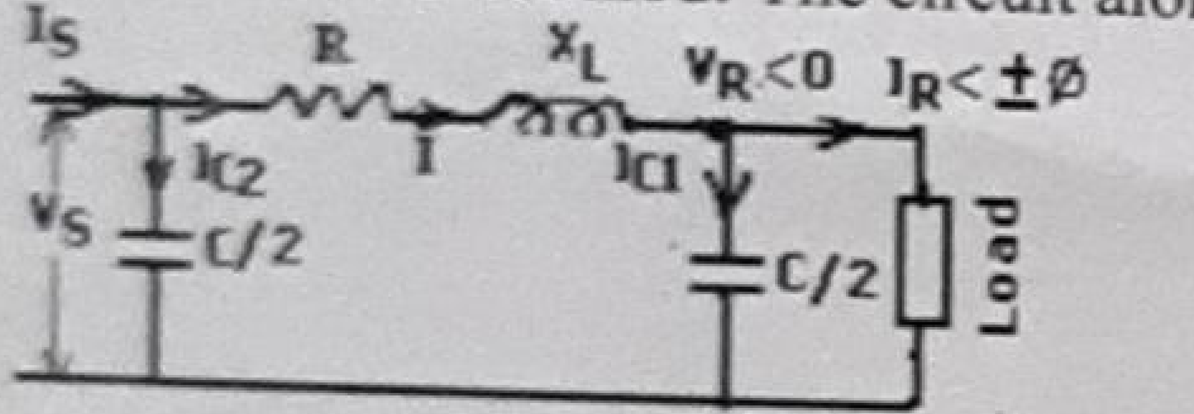
ii) Nominal T method: The circuit along with the vector diagram is shown bellow:

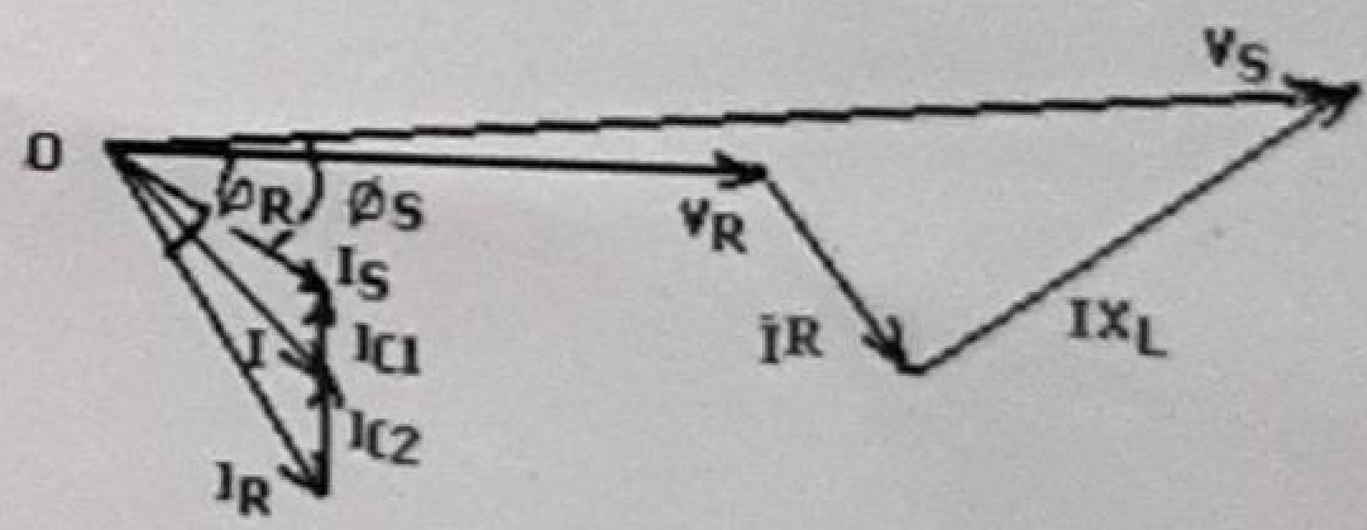




$\vec{I_R} = I_R(\cos \emptyset_P - j\sin \emptyset_R)$.
$\vec{V_C} = V_R + \vec{I_R}(\frac{R + jX_L}{2})$; $\vec{I_C} = 2\,j2\pi fC \times \vec{V_C}$
$\vec{V_S} = V_C + \vec{I_S} \times \frac{R + jX_L}{2}$.

iii) Nominal π- method: The circuit along with the vector diagram is shown bellow:





$\vec{I_R} = I_R(\cos \emptyset_R - j\sin \emptyset_R)$. $\vec{I_{C1}} = j\frac{2\pi fCV_R}{2} = j\pi fCV_R$; $\vec{I} = \vec{I_R} + \vec{I_{C1}}$; $\vec{V_S} = V_R + \vec{I}(R + jX_L)$. .

$\vec{I_S} = \vec{I} + \vec{I_{C2}}$; $\vec{I_{C2}} = j\frac{2\pi fCV_S}{2} = j\pi fCV_S$.

5.0 EHV Transmission:

5.1 EHV A.C transmission. It is required to transmit bulk power from the generating stations to load centers situated at long distance away from the generating stations. The generating voltage is mostly at 11 kV. In order to economically transmit bulk power over long distance the voltage of transmission should be high. In this regard the American practice is $V = 5.5\sqrt{0.62l + \frac{3P}{150}}$ kV., where V is the transmission voltage in kV, l is the length of transmission line in km and P is the kW per phase to be transmitted. Further in case of A.C the voltage can easily be stepped up and stepped down as per requirement by use of transformers. The standard EHV A.C transmission voltages in India is 132kV, 220 kV, 400 kV, 765 kV etc.

i) Advantages:

a) Bulk power can economically transmitted over long distances.
b) Maintenance of a.c substations is easy and cheap.
c) Transformers are very convenient and cheap for stepping up or stepping down the a.c voltage as per requirement.
d) The termina equipments for step up and step down are simple and cheap.

e) High expertise is not necessary for operation and maintenance of switch yards. Only trained personnel can handle the job.

ii) Disadvantages::

a) Construction of A.C EHV transmission line is more complicated.
b) Due to skin effect in a.c the conductor outer area is utilized only increasing resistance hence more power loss.
c) In a.c due to skin effect inner conductor area is unutilized involving unnecessary cost on conductor account.
d) The distributed shunt capacitance requires charging VAR which is provided by the alternators. So alternator becomes bulky and costly.
e) The charging current also causes additional $I^2 r$ loss in the line.
f) Due to distributed capacitance the long transmission line dangerously raises receiving end voltage due to Ferranti effect under light load conditions.

iii) Reasons for adoption of EHV transmission:

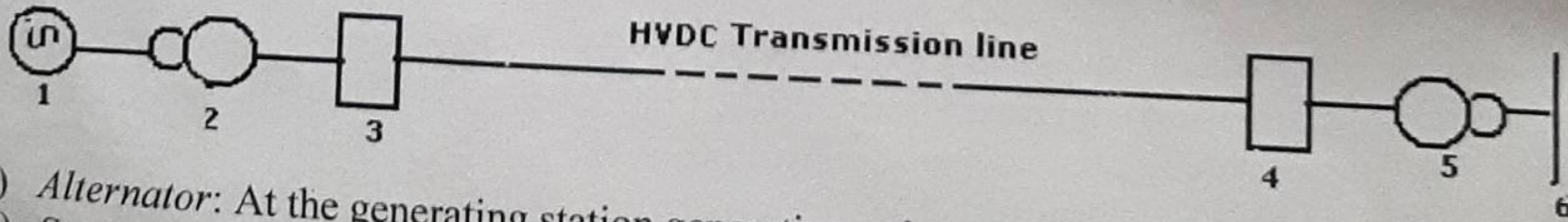
a) *Reduces volume of conductor material*: line current $I = \frac{P}{\sqrt{3}V\cos\phi}$ and resistance per conductor $R = \frac{\rho l}{a}$, power loss $W = 3I^2R = \frac{P^2\rho l}{aV^2\cos^2\phi}$ or volume of conductor material $3al = \frac{3P^2\rho l^2}{WV^2\cos^2\phi}$. This shows the volume of conductor material is inversely proportional to the voltage of transmission

b) Increases transmission efficiency: EHV reduces the line current for same power transmission. Reduced current means reduced line losses hence better efficiency.
c) Decreases percentage line drop. Line drop = Ix Z. since I is small the line drop is also dmall.

iv) Problems or limitations involved in EHV transmission:

a) High voltage transmission requires elaborate insulation coordination. Higher is the voltage higher is the Basic Insulation Level. Hence higher is the cost.
b) In case of EHV the terminal equipments at substations are costly. They are to be designed to withstand all eventualitics.
c) The structure height increases for proving required ground clearance. Further the spacing of conductor increases which call for special design of cross arms and wider right of the way. These involve more cost. Besides the cost of other line components like insulator string etc are costly.

5.4 HVDC Transmission: HV DC transmission in many ways is superior to EHV A.C transmission: The basic principle is shown in the block diagram given bellow.



a) *Alternator*: At the generating station generating voltage of alternators is at 11kV.
b) *Step up transformer*: In the switch yard of the power station the generating voltage is stepped-up by step-up transformers and are connected to high voltage bus-bar through isolator, circuit breaker and other protective devices.

c) *Mercury arc rectifiers*: The mercury arc rectifiers are used to covert HV AC to HVDC. The rectifier system may be for mono polar, bi-polar or homo-polar HVDC transmission system. The HVDC transmission lines are very long otherwise they will not be economical.

d) *Thyratron Inverter*: At the receiving station the HVDC is inverted to HVAC by Thyratron inverters. The step down transformer steps down to suitable voltage. transmission.

e) *Step-down transformer*,

f) 3-phase a.c bus-bar. The step down transformers are connected to the 3-phase a.c bus-bar system from where for local transmission lines are taken.

Advantages: i) It requires only two conductors unlike three in AC transmission.

ii) There is no inductance, capacitance, phase shift and surge problems in D.C system

iii) For same load and sending end voltage, voltage drop in D.C transmission is less compared to A.C transmission due to absence of inductance and capacitance. Hence voltage regulation is better.

iv) There is no skin effect in D.C system. So, entire cross section of the conductor is utilized.

v.) For same working voltage the potential stress is less compared to a.c system. So insulation co-ordination problem is less in D.C system.

vi) A D.C line has less corona loss and interference in communication line compared to a.c line

vii) The high voltage d.c trans mission is free from dielectric losses particularly in case of cables.

viii) D.C transmission does not have stability problem and does not require any synchronization arrangement.

Disadvantages: i) High voltage d.c generation is not practicable due to commutation problem.

ii) D.C voltage can not be stepped-up or stepped-down for transmission and then distribution.

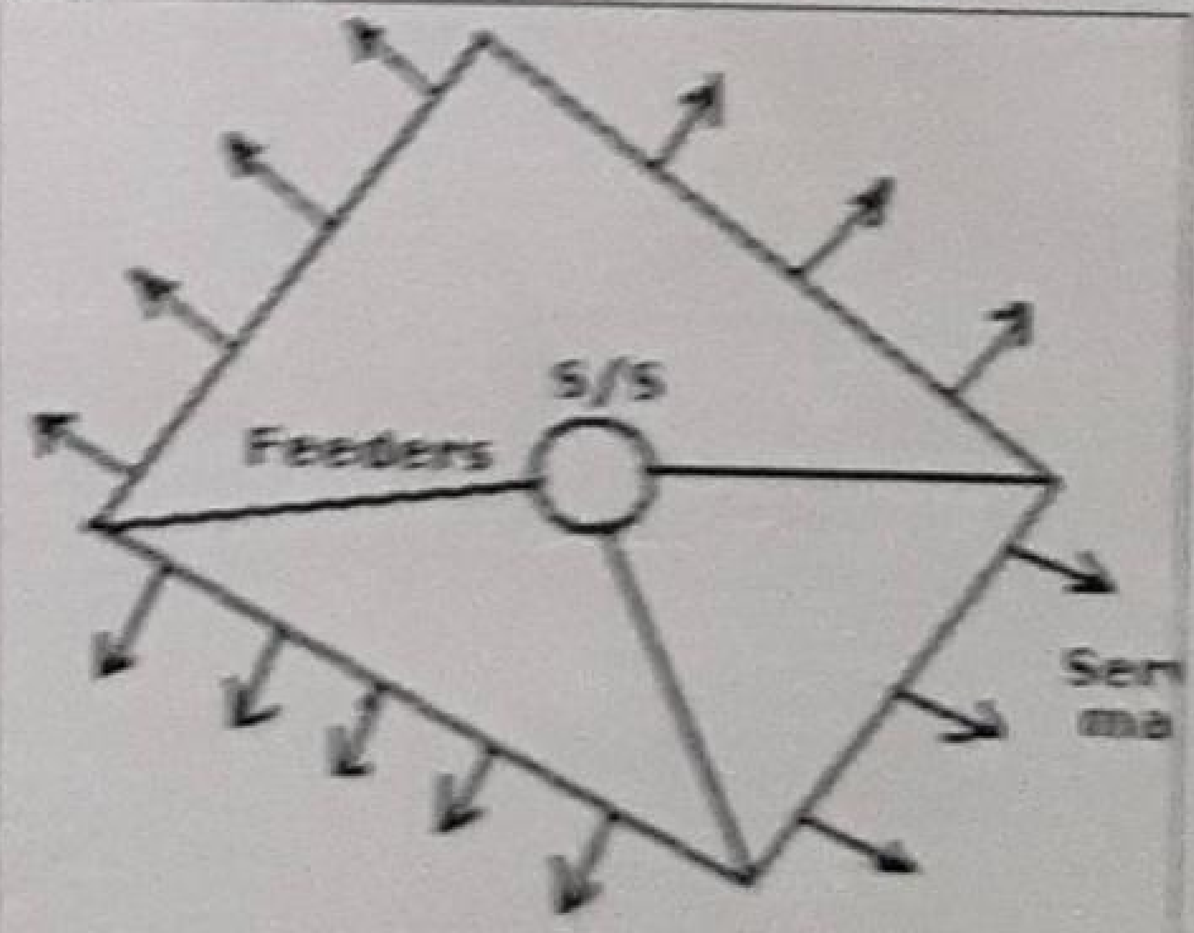
iii) D.C switch gears have their limitations.

iv) The conversion and inversion terminal equipments are very costly and requires expert man power for handling, operation and maintenance.

6. Distribution system:

Introduction: Distribution system is that part of electrical network which distribute electrical power for local use. It has three parts: *i) Feeders* – They connect the area to the step-down substation or the local generating station. Normally no tapping are taken from the feeders *ii) Distributors*: These are the conductors which are tapped at various points to provide electric supply to the consumers *iii) Service mains*: It may be a underground cable or over head service connection wire supported by GI wire which connects consumers terminal to the distributor.

The electric power distribution may either be a.c or d.c. The network may be in underground cable or overhead.

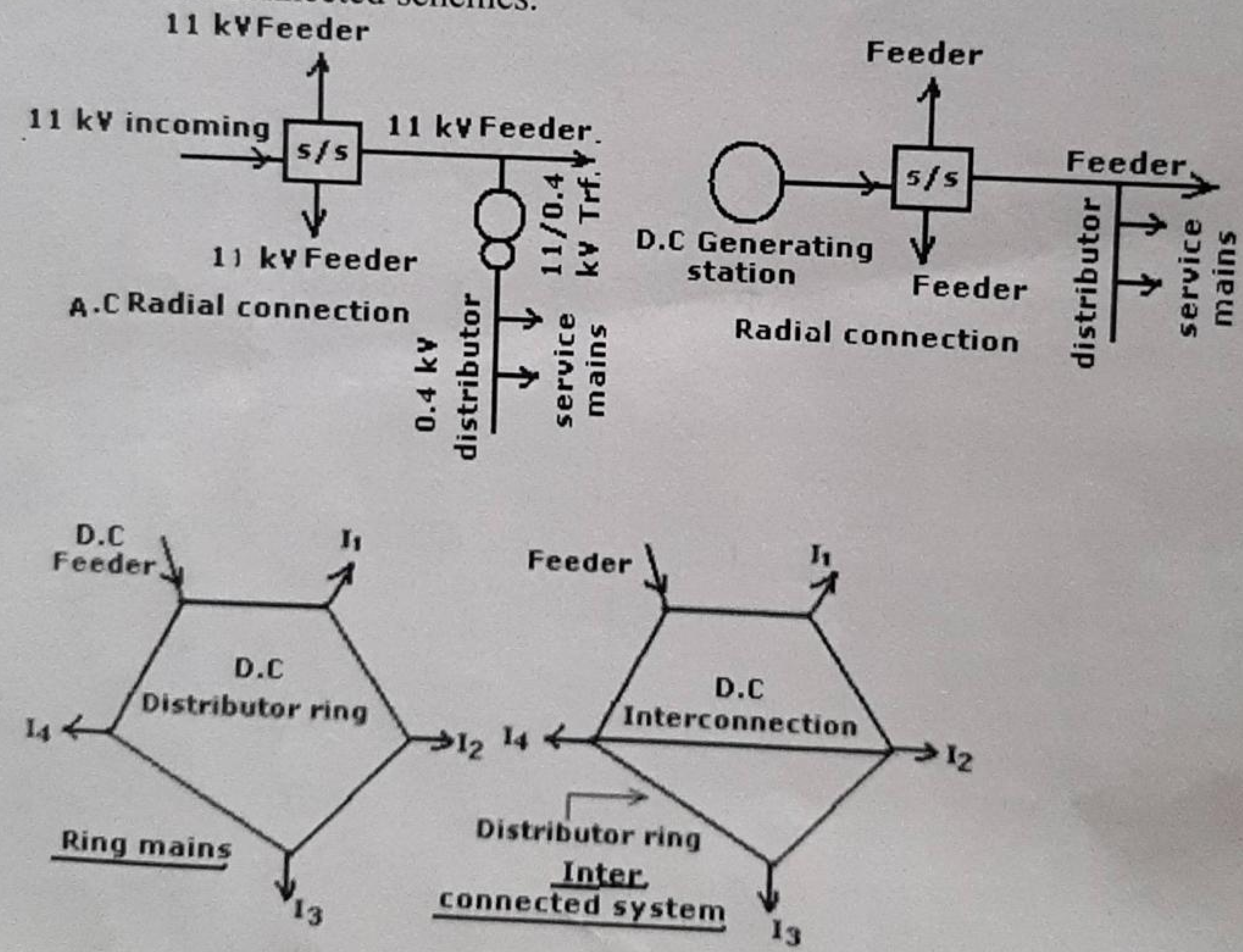


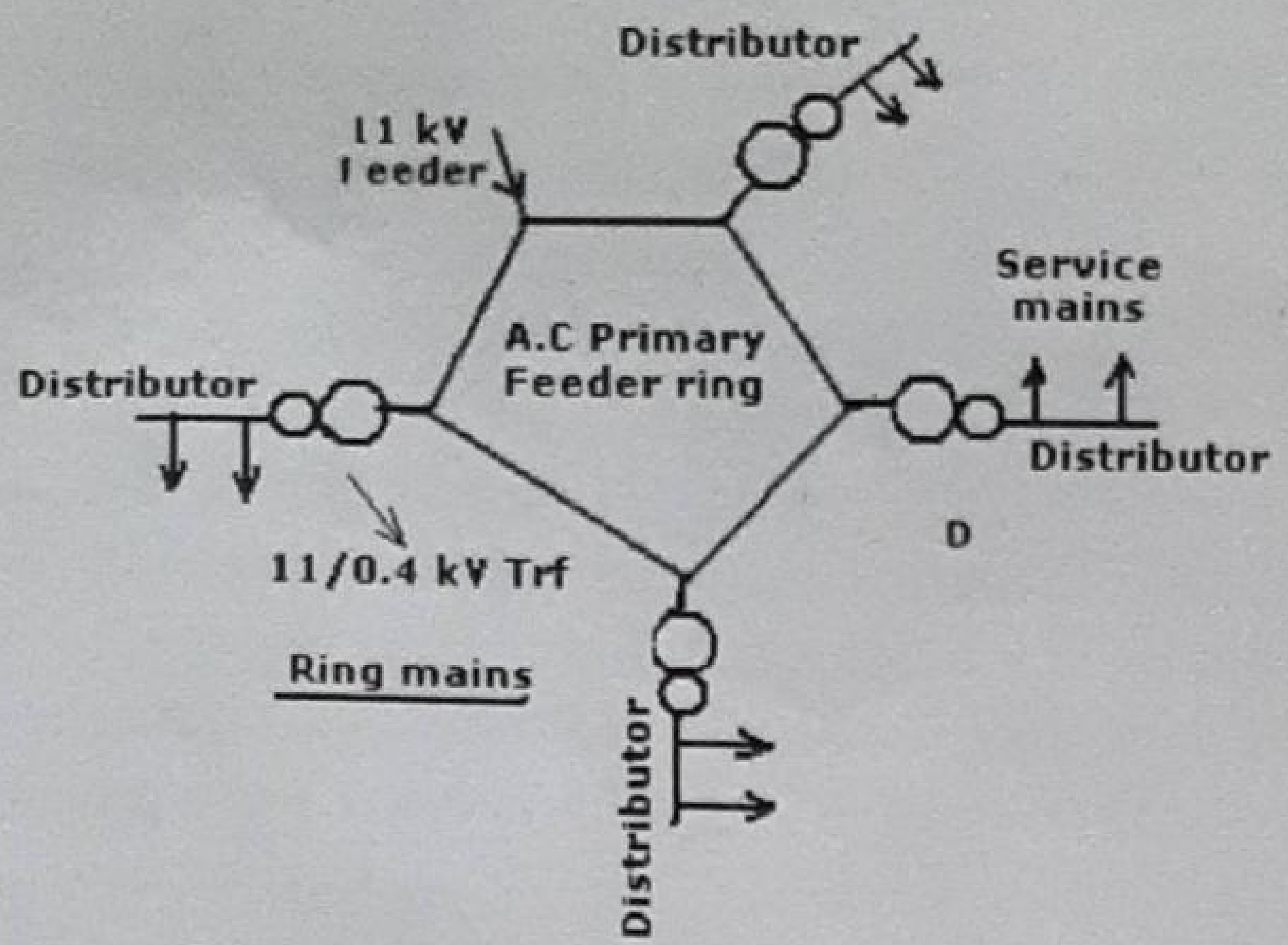
Comparison of overhead distribution with underground distribution:

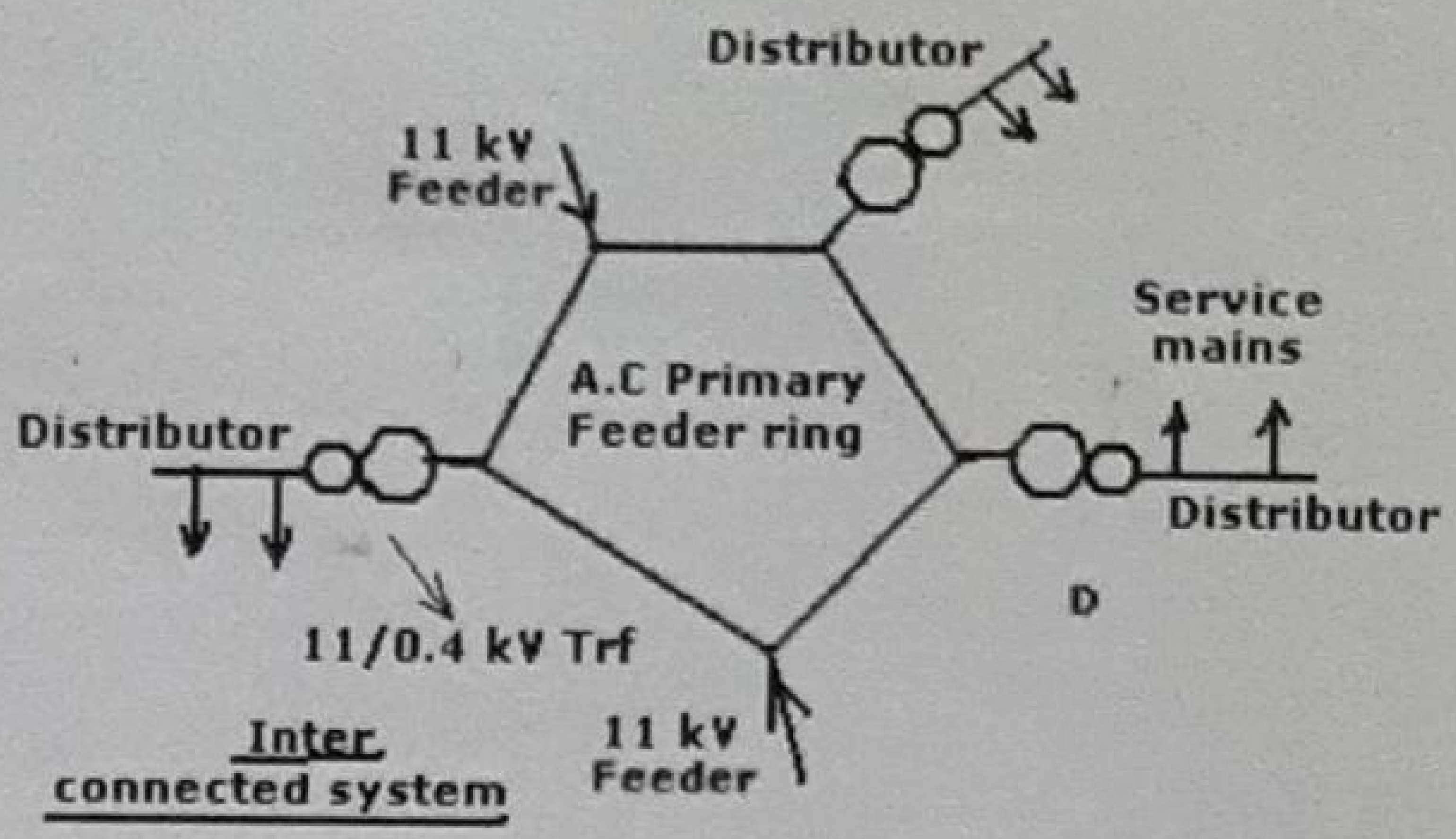
Sl.	Item	Overhead	Underground
1	Public safety	Less safe	More safe
2.	Initial cost	Cheap	Costly (5 to 10 times)
3.	Flexibility	Flexible for modification to accommodate load growth.	Less flexible. Separate cable to be laid for additional load
4	Fault	Prone to fault as conductors	Less chance of fault as conductors

		are bare and in the open.	are adequately insulated
5	Repair and maintenance	Easy	Difficault
6	Cross section area	Conductor c/s area required is more as current density considered in bare conductors is less	Current density adopted is more. Hence, c/s is less.
7	Voltage drop	More due to increase in resistance by heating in the sun	Less
8	Useful life	Less (25 to 30 years)	More (>50 years
9	Maintenance cost	High	Low
10	Interference with communication signal	Causes interference	No interference.

6.1 Connection schemes: Connection schemes for distribution may be classified as radial, ring mains or interconnected schemes.







Both A.C and D.C connection schemes for distribution are shown above: Now a days D.C distribution has become obsolete and no more in existence.

Radial Distribution: This system is fed at one end only In case of D.C the generation is at low voltage and the generating station is in the load centre. In case of A.C 11 kV line is stepped down to 400 V for providing service mains.

Advantages: It is simple and of low cost.

Drawbacks: a) Section nearest to the feeding point is heavily loaded b) It is not reliable. Power is cut-off to the consumers who are on the side of the fault away form the substation due to any fault in the distributor or feeder , c) Consumers at the far end suffer from sever voltage fluctuations when load on the distributor changes.

Ring mains system: In case of DC the LT feeder starts from the bus bar of the substation, runs through the area and returns to the substation bus bar forming a loop. The consumers are given connection from this loop. In case of A.C, the 11 kV feeder from the feeder substation bus bar forms a loop in the area. At different points on this loop radial distributors are tapped through distribution transformers for providing service mains to the consumers.

Advantages: a) Voltage fluctuation is minimized at consumer end b) In case of fault alternate route is available for supply after isolating the faulty section.

Interconnected system: When the ring mains system is fed by more than one source it is called interconnected system

Advantages: a) Increases supply reliability. This means continuity of supply is ensured b) Both sources combines can meet the peak load demand of the area c) Reserve capacity each station can be reduced d) The efficiency of the system increases e) The voltage fluctuation is minimized.

Requirement of Distribution system:

i) Proper voltage: The voltage variation at the consumer end should be within permissible limit ($\pm$ 6%).

ii) Availability of power on demand: The system should be such that the power demand at different hours of the day is smoothly met

iii) Continuity of service: Services of operating staff must be ensured round the clock to attend to the fault

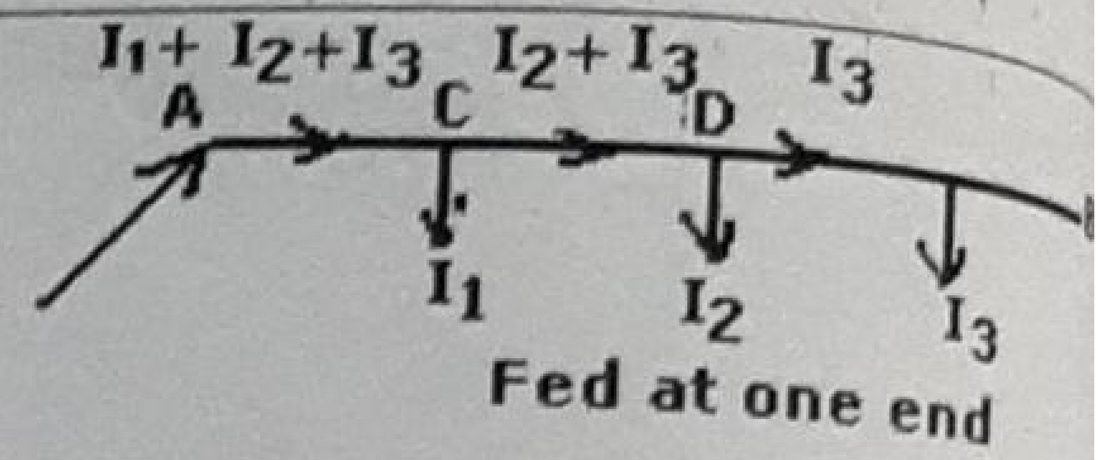
iv) Load scheduling and load dispatch: Efficient load scheduling for different time of the day for different seasons be made and accordingly load dispatch should be done by operating staff.

v) Future load expansion: The distribution system should be capable of taking care of future load growth.

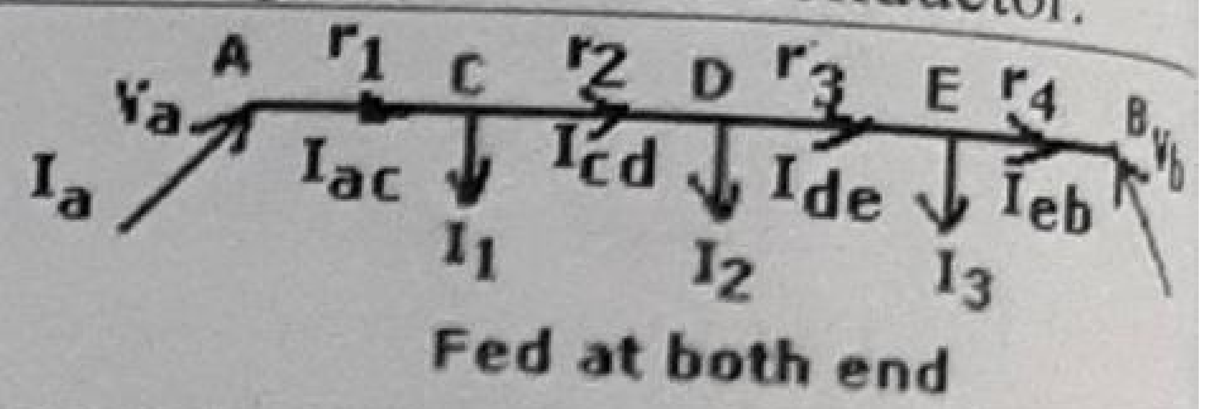
vi)Reliability: Adoption of interconnected system, automation, adequate reserve capacity, regular maintenance ensures reliability of supply.

6.2 D.C Distributors:

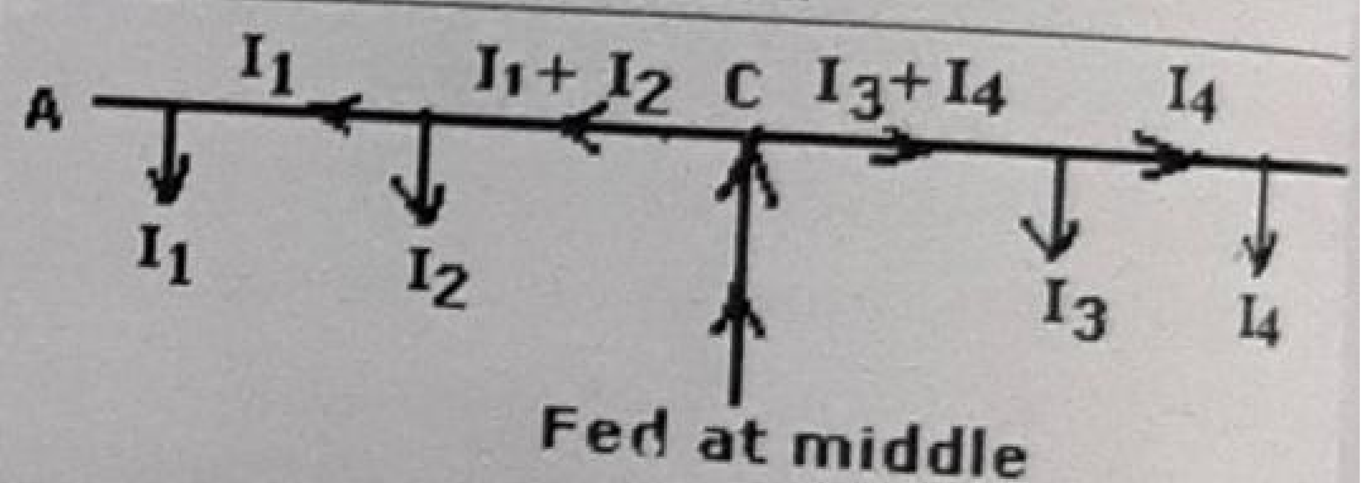
i) Fed at one end (Concentrated load) : a) The voltage across load away from feeding point goes on decreasing b) Voltage is the least across the load at none-feeding end, c) the Current in various sections of the distributor goes on decreasing d) Current at feeding point A = $\sum_1^n I_n$, where n is the number of load points e) Current in any section is equal to the sum of all load currents less sum of the load currents previous to the section, f) The voltage drop in any section is the product of current in that section and the resistance of that section for both go and return conductor.



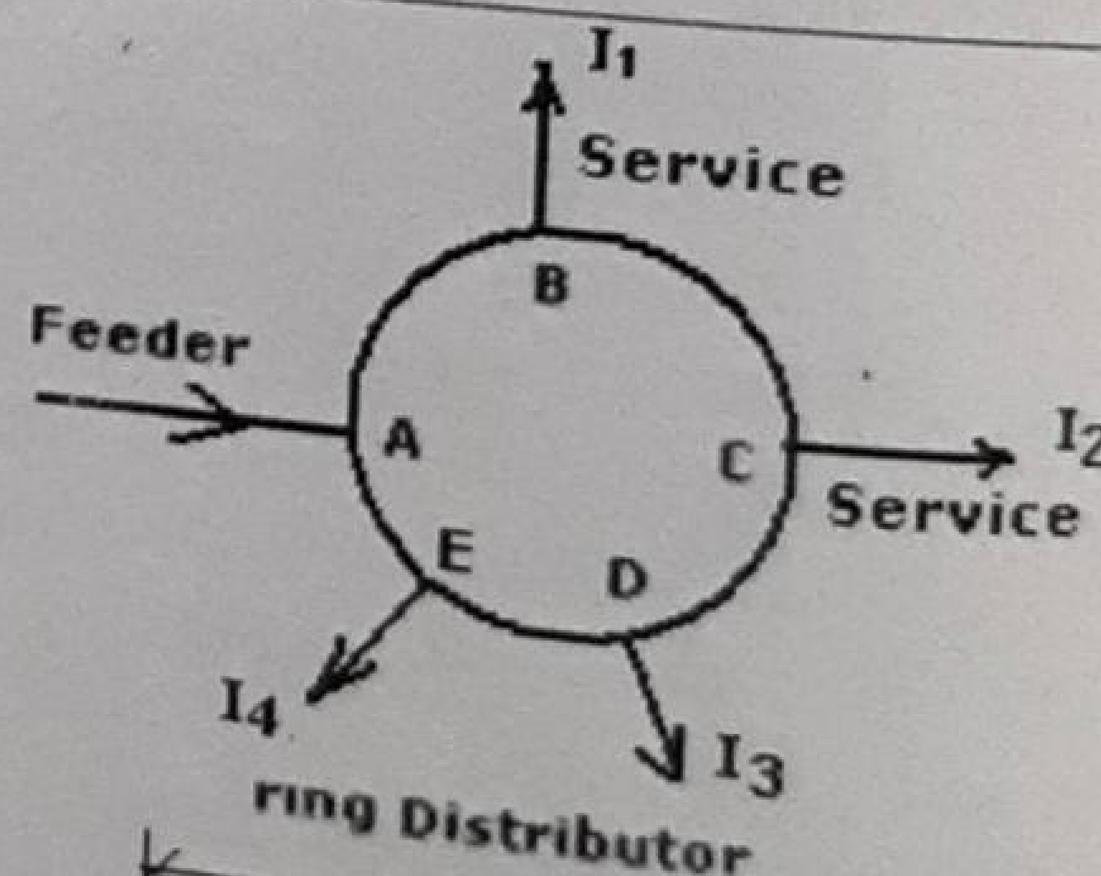
ii) Fed at both ends (concentrated load) : $I_{ac} = I_a$, $I_{cd} = I_a - I_1$, $I_{de} = I_a - I_1 - I_2$, $I_{eb} = I_a - I_1 - I_2 - I_3$. $V_a - V_b = I_{ac}r_1 + I_{cd}r_2 + I_{de}r_3 + I_{eb}r_4$ From these equations Ia as well as section currents can be found out. The point of minimum voltage is the point where current from both sides meet.



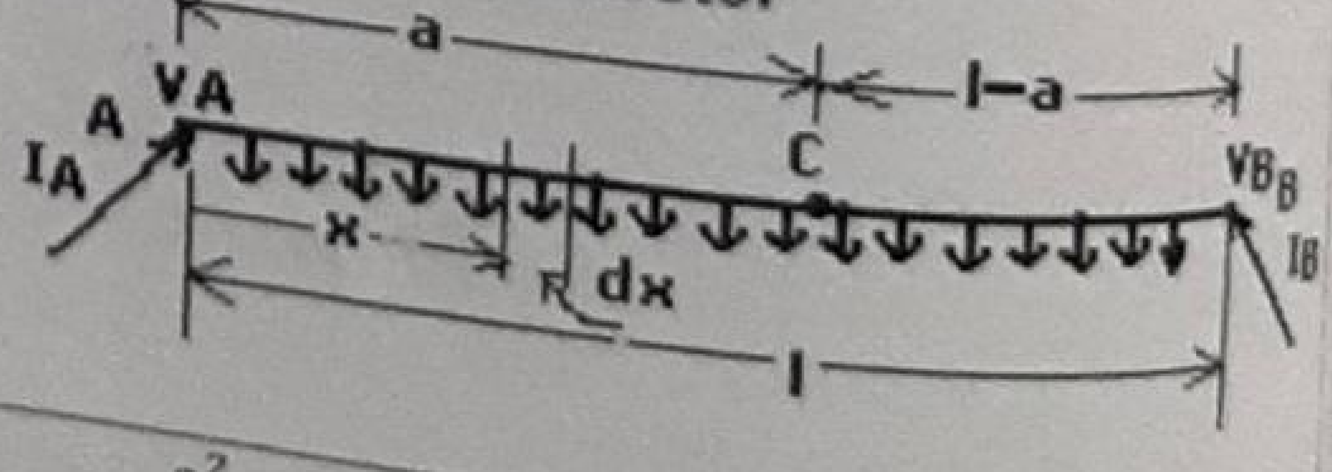
iii) Fed at the middle(concentrated load): The current distribution is shown. For each section voltage drops can be calculated and the voltages at each load point can be calculated.



iv) Ring distributor(concentrated load): Kirchhoff's voltage law can be applied to the ring to solve the problem. The analysis is similar to the case of fed at both ends with equal voltages.



vi)*Uniformly distributed load fed at both ends $V_A \neq V_B$*
Let i be the current drawn per unit length of the feeder, V_A and V_B be the voltages and I_A and I_B be the currents at feeding points A and B respectively. Total current supplied from both feeding points is = $I_A + I_B = il$. Let C be the point of minimum voltage. As such C is fed by the current from both ends. We consider voltage drop for a small length dx at a distance x form end A, dv = i(a−x) r dx. So the voltage drop between AC =



$\int_0^a dv = \int_0^a ir\,(a-x)\,dx = ir\,[ax-\frac{x^2}{2}]_0^a = ir\,\frac{a^2}{2}$. $V_C = V_A - ir\,\frac{a^2}{2}$ .... (i), where V_C is the potential of point C. Similarly voltage drop in the stretch BC = $ir\,\frac{(l-a)^2}{2}$. $V_C = V_B - ir\,\frac{(l-a)^2}{2}$ .... (ii).
Equating (i) and (ii), $[V_A - ir\,\frac{a^2}{2}] - [V_B - ir\,\frac{(l-a)^2}{2}]$ or $V_A - V_B = \frac{ir}{2}[a^2 - (l-a)^2] = \frac{irl}{2}(2a - l) = irl\left(a - \frac{l}{2}\right)$ .. (iii) or $a = \frac{V_A - V_B}{irl} + \frac{l}{2}$, $I_A = ia$ and $I_B = i(l-a)$.

vii)Uniformly distributed load fed at both ends $V_A=V_B=V$: From equation (iii) above, $irl\left(a - \frac{l}{2}\right) = 0$ or $a = \frac{l}{2}$ that is the midpoint is the point of minimum potential, and $I_A = I_B$.

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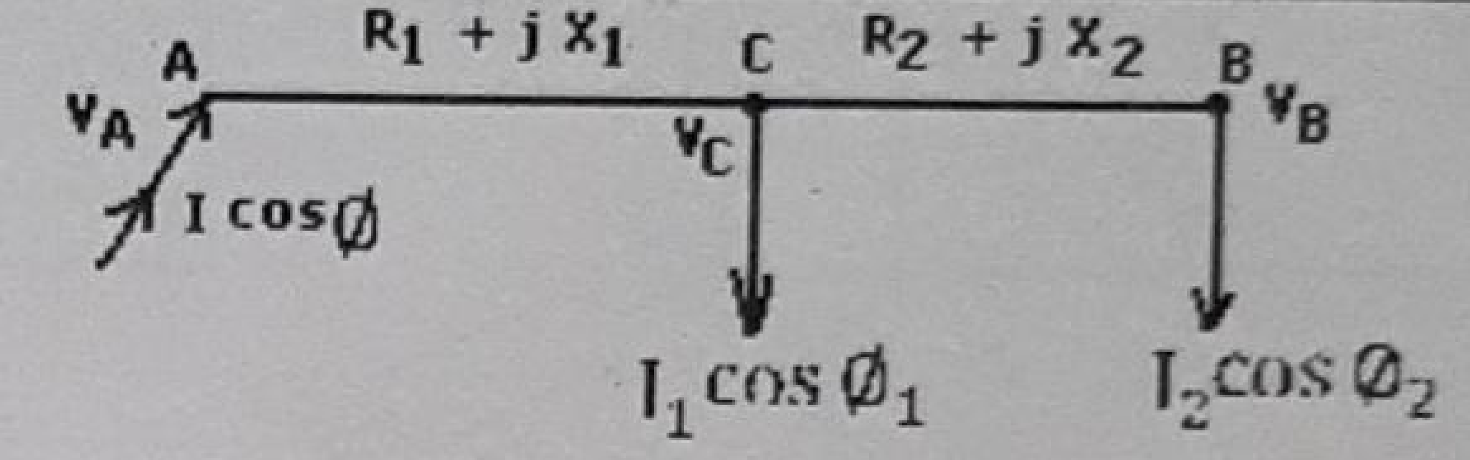
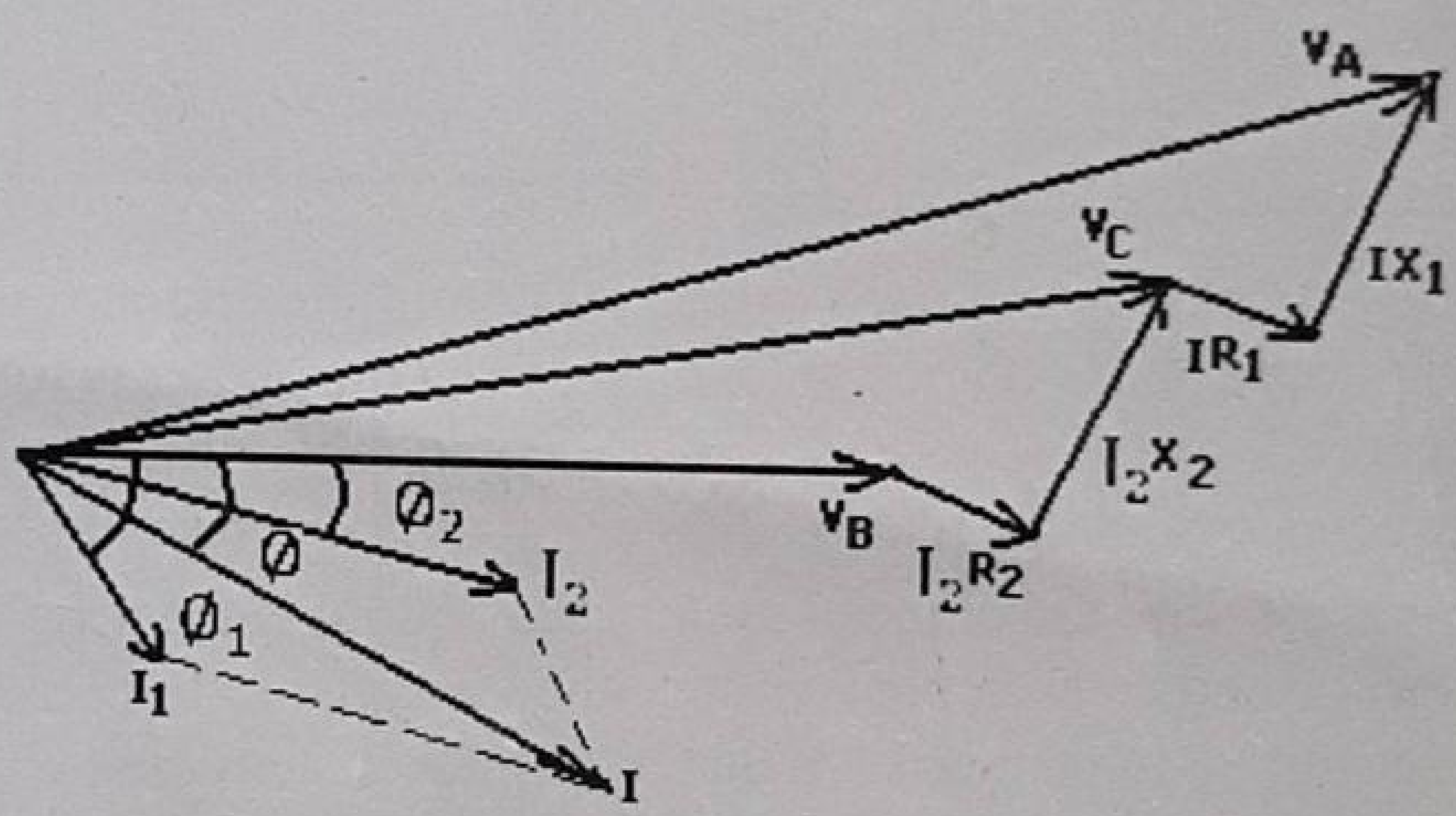
Minimum potential = $V_A - ir\frac{l^2}{8} = V - \frac{rl \times il}{8} = V - \frac{RI}{8}$, where R is the total resistance of the distributor and I is the total current fed to the distributor from both ends.

6.3 A.C distribution system: A.C distribution calculations differ from D.C distribution. i) In a.c system voltage drops are due to effect of resistance, inductance and capacitance of the conductors, ii) In case of a.c vector addition/subtraction is done instead of arithmetic addition/subtraction, iii) In case of a.c, power factor of load is to be taken into account. The load pfs may either be referred to sending end voltage or the receiving end voltage as the reference vector. It may be referred to the voltage at load point itself.

6.3.1 Methods of solving A.C. distribution problems:

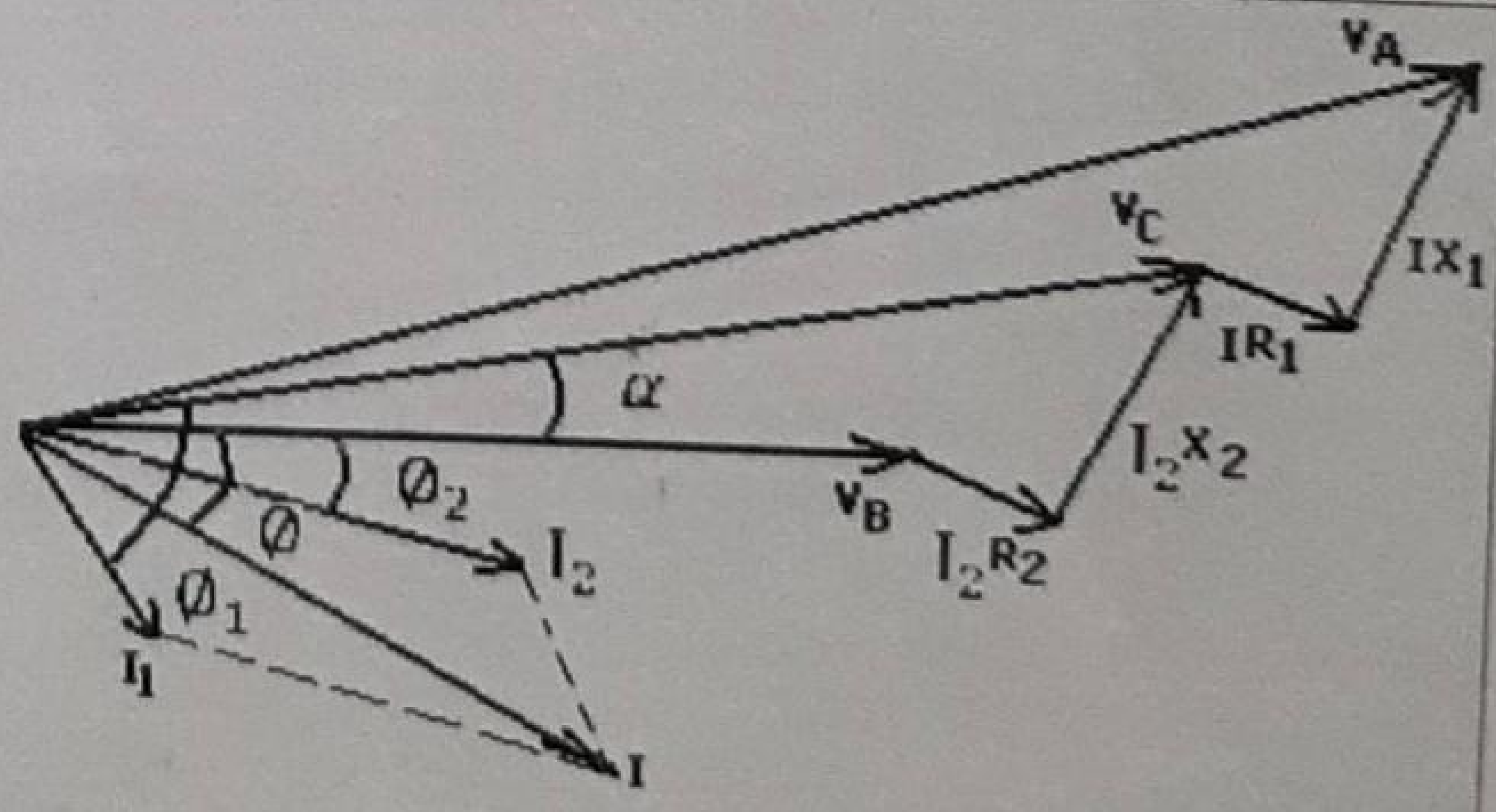
i) Power factor referred to receiving end voltage: consider an a.c distributor AB with concentrated loads of I_1 at pf $\cos \emptyset_1$ and I_2 at pf $\cos \emptyset_2$ both lagging tapped at points C and B respectively as shown in the given figure. The pfs refer to voltage at point B (receiving end). The





vector diagram is also shown. V_B is taken as reference. $\vec{V_C} = V_B + \vec{I_2}(R_2 + jX_2) = V_B + I_2(\cos \emptyset_2 - j\sin \emptyset_2)(R_2 + jX_2)$. $\vec{I} = \vec{I_2} + \vec{I_1}, \vec{I_1} = I_1(\cos \emptyset_1 - j\sin \emptyset_1)$. $\vec{V_A} = V_c + \vec{I_1}(R_1 + jX_1$

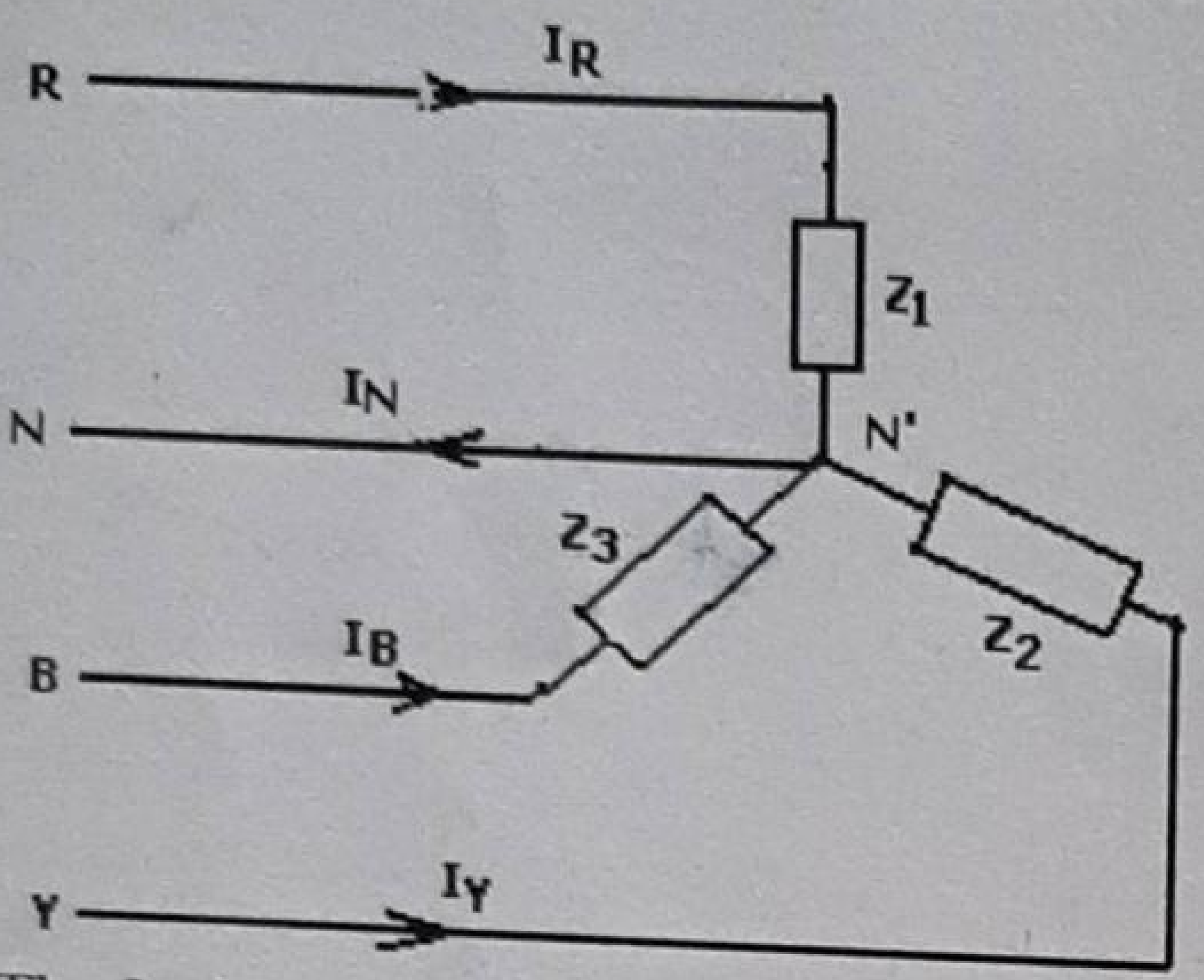
ii) Power factor referred to respective load voltages: Consider load I_2 at lagging pf $\cos \emptyset_2$ referred to load voltage at B and I_1 at lagging pf $\cos \emptyset_1$ referred to load voltage at C. Let α be the phase difference between V_B and V_C. The phasor diagram taking V_B as reference is shown. $\vec{V_C} = V_B + \vec{I_2}(R_2 + jX_2) = V_B + I_2(\cos \emptyset_2 - j\sin \emptyset_2)(R_2 + jX_2)$. $\vec{I} = \vec{I_2} + \vec{I_1}$, When referred to V_B the pf of I_1 becomes $\cos(\emptyset_1 - \alpha)$. So

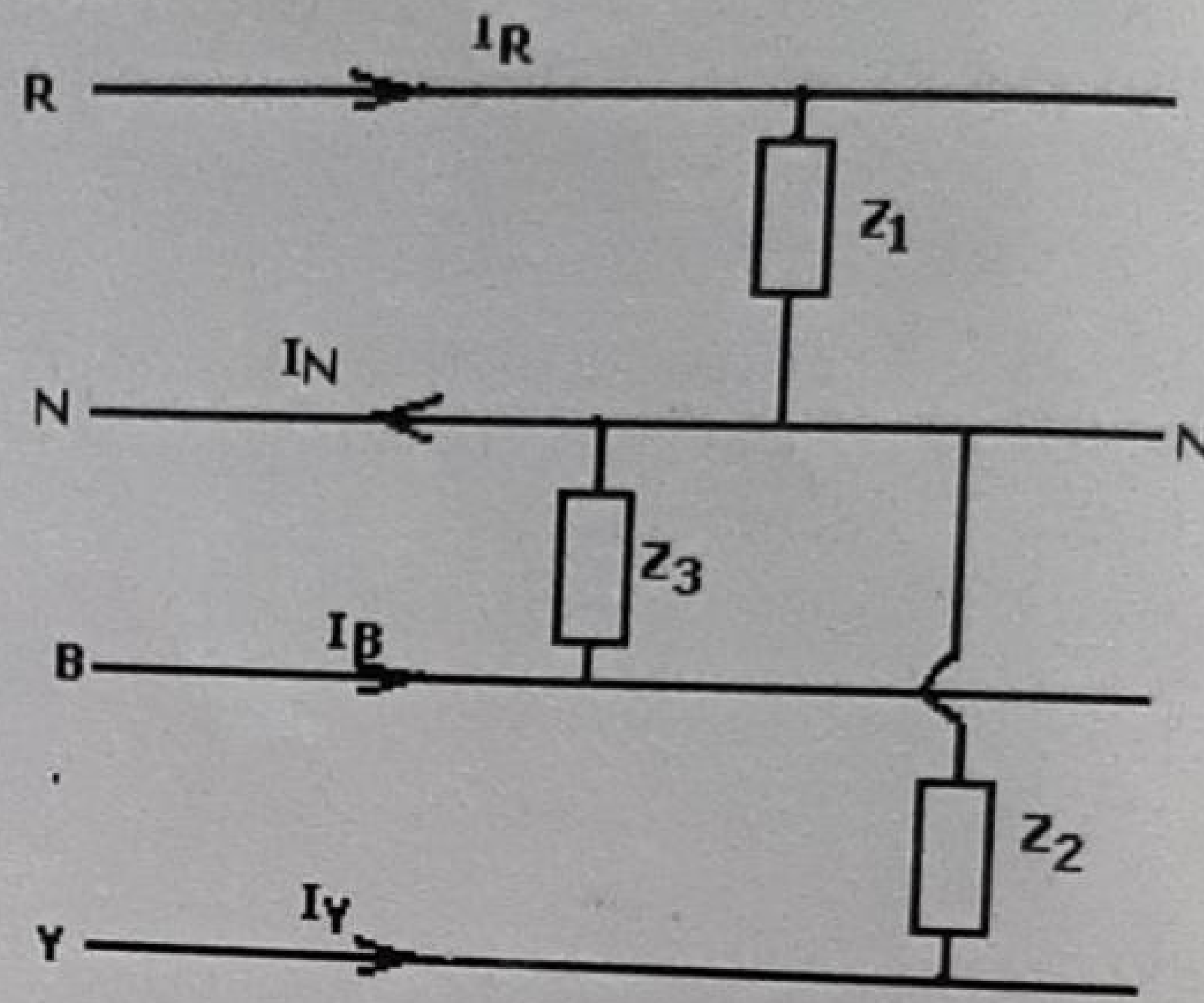


$\vec{I_1} = I_1[\cos(\emptyset_1 - \alpha) - j\sin(\emptyset_1 - \alpha)]$. $\vec{V_A} = V_c + \vec{I_1}(R_1 + jX_1)$

6.4 Explain 3-phase 4-wire star connected system: *i) Three phase balanced loads*: The three phase loads those have the same impedance and pf are called balanced loads. Here the neutral current is zero. The problems on balanced loads can be solved by considering one phase only. ii) Three phase unbalanced loads: When each phase load impedances and or pf is different, the current and power in each phase is different leading to unbalance system. Different unbalanced loads are: a) 4-wire star connected unbalanced load b) Delta connected unbalanced load c) Three wire Y-connecied unbalanced load.

iii) 3-phase 4-wire Y-connected unbalanced loads:





The 3-phase 4-wire system is widely used in distribution of electric power to commercial and small industries. For single phase domestic loads service connection is given across a phase and the neutral. The loads in 3-phase 4-wore system are invariably unbalanced. The unbalance is introduced due to presence of single phase loads along with 3- phase motor loads which are balanced. In the 3 phase 4 wire unbalanced system the neutral current $\overrightarrow{I_N} = \overrightarrow{I_R} + \overrightarrow{I_Y} + \overrightarrow{I_B}$. It may be noted that the voltage across each phase impedance is equal to the phase voltage but the phase currents are different due to unbalance impedance. Except the circuits with sever unbalance, the neutral current is equal to or less than one of the line currents.

7. Under ground cables:

8. Economic Aspects:

8.1 State and explain causes of low power factor: *i). Power factor* : Power factor is the cosine of angle between the voltage and current in an a.c circuit. Where the current lags the voltage the pf is lagging and where it leads the voltage the pf is leading. If Ø is the angle of lead or lag of the current then pf = cos Ø. The power factor also is given by $pf = \frac{R}{Z} = \frac{\text{Resistance}}{\text{Impedance}}$ or $\frac{VI \cos Ø}{VI} = \frac{\text{Active powe}}{\text{Apparent power}}$

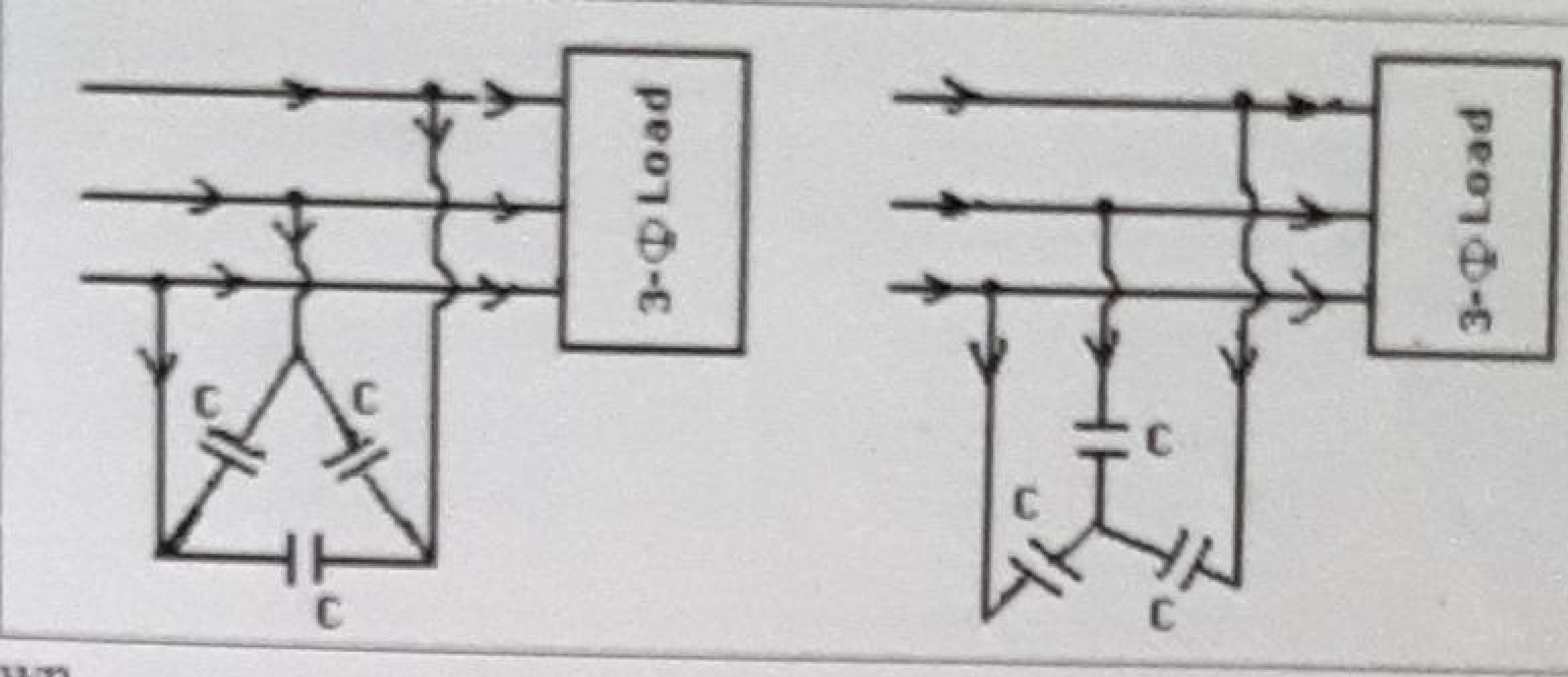
ii) Disadvantages of low power factor: a) Large kVA rating of equipments: The electrical equipments are mostly rated in kVA. kVA = (kW/ cos Ø). Therefore at low pf the KVA rating will be large for which the equipment will be bulky and costly b) Greater conductor size: For carrying same power the current will be more for low pf. So large size conductor is required c) Losses increase due to more current d) Poor voltage regulation: As the current is more the voltage drop is more. So poor voltage is available at far end e) Under utilization of system capacity: If the system has low power factor the machineries are run at under capacity due to current limitations.

iii) Causes of low power factor: a) Most industrial drives use 3-Φ or 1-Φ induction motors whose pf at light loads is as low as 0.2 to 0.3 lagging. This contributes to the cause of low pf.

b) Arc lamps, discharge lamps, Thermionic valves like mercury arc rectifiers and industrial heating furnaces specifically induction furnaces operate at low lagging pf.
c) During off-peak hours the voltage rises which increases the magnetizing current in transformers. This results in reduced pf.

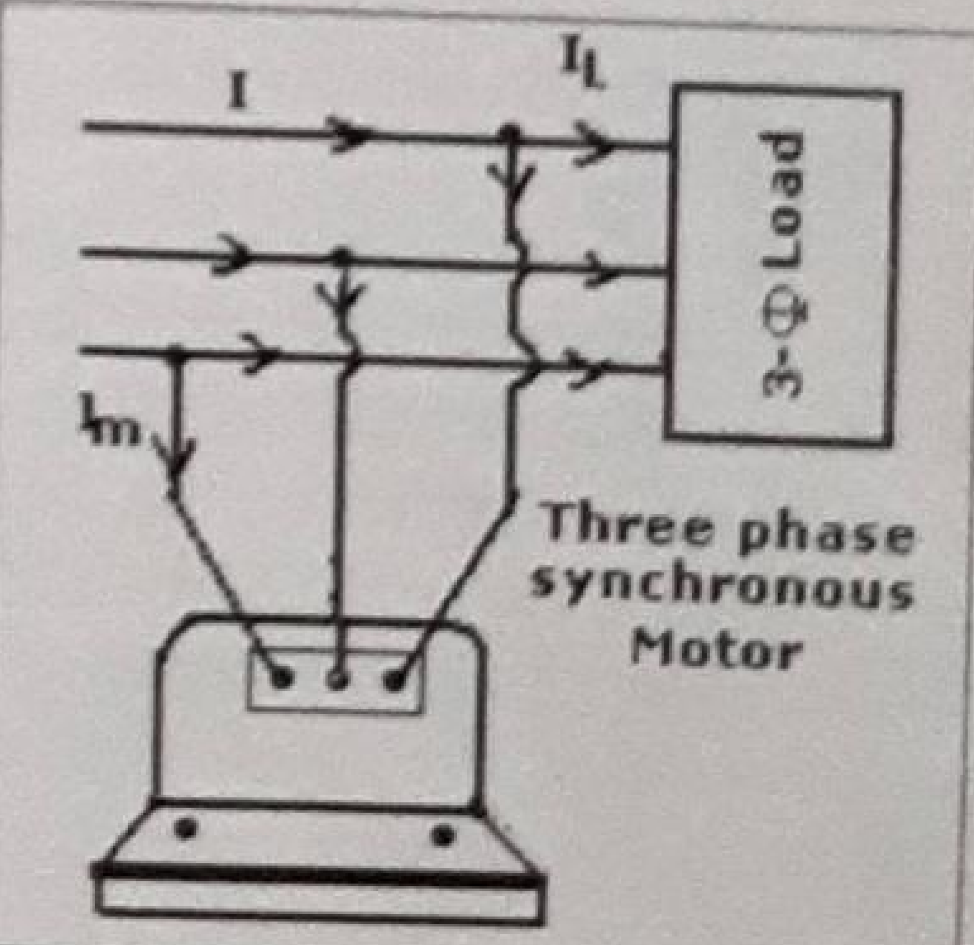
8.2 Methods of power factor improvement: Power factor can be improved by use of i) Static capacitors, ii) Synchronous condenser and iii) Phase advancer.

i) Static capacitor:
Capacitors can be connected in parallel with the equipments operating at lagging pf to improve the pf. The capacitors draws leading var to neutralize the lagging var. In case of 3-Φ loads, either delta or star connected capacitor banks are connected across the load as shown.



Advantages: i) Have low losses, ii) Being static they require little maintenance, iii) As they are light and need no foundation they can be easily and quickly installed at low cost, iv) They can work under ordinary atmospheric conditions.
Disadvantages: i) They have short service life span (8 to 10 years), ii) They are easily damaged if the voltage exceeds rated value, iii) Once damaged their repair is uneconomical.
Calculation of pf correction: i) consider only one phase for three phase load or the single phase load ii) Let the load voltage, current and the power factor be V, I and $\cos \emptyset_1$ lagging respectively prior to pf correction iii) Let be $\cos \emptyset_2$ the new pf (lagging) after correction. iv) Power drawn by the load $P = VI\cos \emptyset_1$, Which is the same after correction v) The lagging VAR drawn by the load prior to pf correction $= VI\sin \emptyset_1 = \frac{P}{\cos \emptyset_1} x \sin \emptyset_1 = P \tan \emptyset_1$, vi) Similarly the lagging VAR drawn by the load after pf correction $= P \tan \emptyset_2$, vii) The leading VAR drawn by the correcting device $= P(\tan \emptyset_1 - \tan \emptyset_2)$, viii) When the correcting device is a shunt capacitance, the capacitance is given by $C = \frac{P(\tan \emptyset_1 - \tan \emptyset_2)}{\omega V^2}$, where $\omega = 2\pi f$.

ii) Synchronous condenser: An over-exited synchronous motor running at no-load is called a synchronous condenser. It draws leading current from the line and improves the power factor.
Advantages: i) By varying the field excitation the current drawn by the motor can be changed by any amount. This helps in smooth control of pf ii)The motor winding have high thermal stability to short circuit currents, iii) The fault can be rectified easily.
Disadvantages: i) Losses are more in the motor, ii) Maintenance cost is high, iii) It produces noise, iv) Bellow 500 kVA, the cost is greater compared to capacitor bank of same rating, v) As the synchronous motor is not self starting an auxiliary starting device is required.



iii) Phase advancer: The low pf of induction motors is due to the fact that the stator winding draws its magnetizing current which lags almost 90^0 to the voltage. Instead of providing the a.c magnetizing ampere turns from the supply voltage it is supplied from a separate source that is phase advancer. This improves the pf. The phase advancer is mounted on the same shaft of the induction motor and provides the magnetizing AT at slip frequency to the rotor circuit. By providing more ampere turns the Induction motor can be made to operate at leading pf.

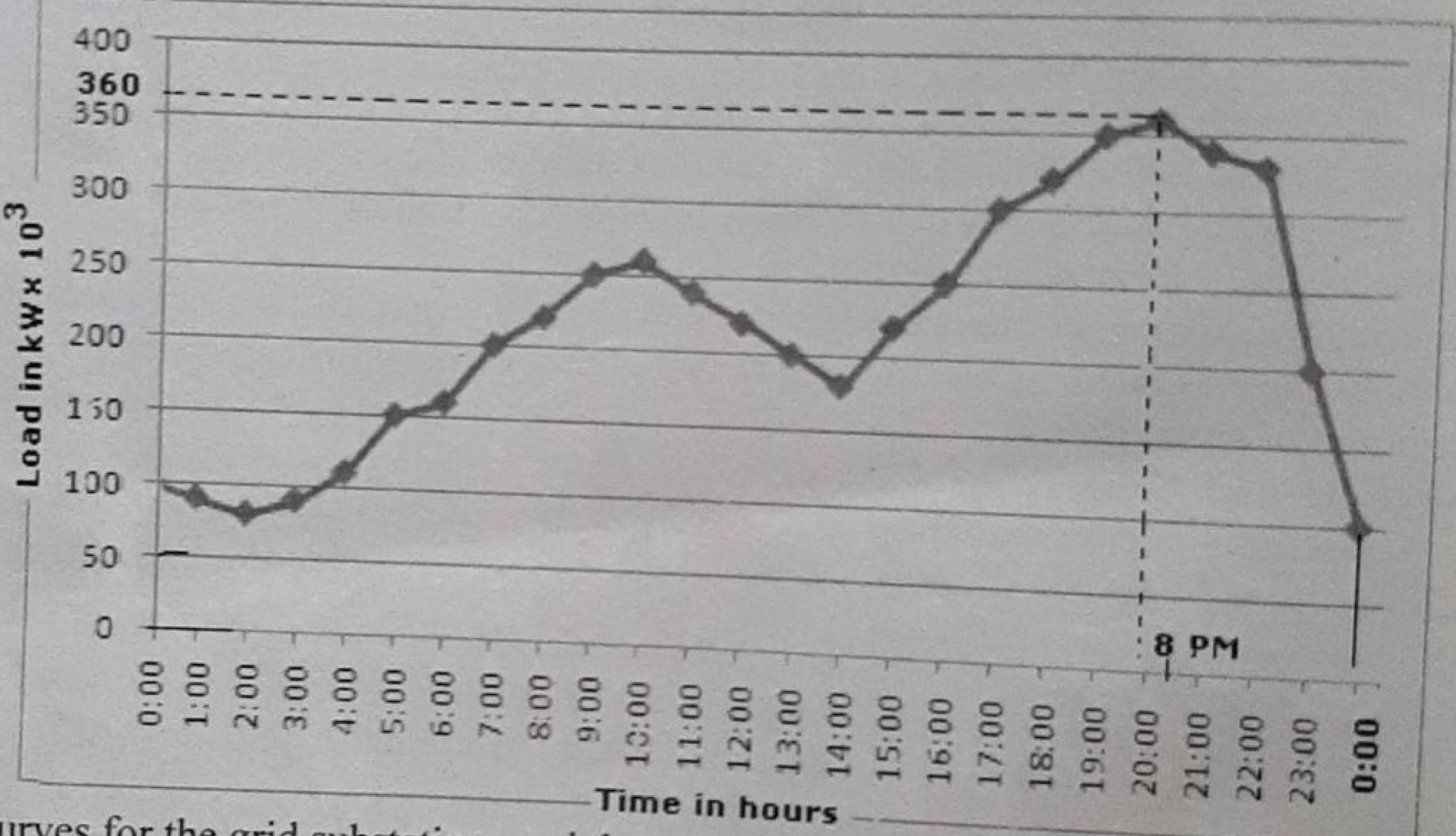
Advantages of phase advancer: i) The main advantage is that the exciting AT is supplied at slip frequency which reduces the lagging VAR drawn by the motor considerably, ii) Phase advancer can be easily used where it is not possible to install synchronous condenser.

Disadvantages: Phase advancers are not economical for motors bellow 200 H.P.

8.3 Load curves: The curve showing the variation of load on the power station with respect to time is termed as load curve. The load on a power station is never constant. It varies from time to time. If the variation is potted hourly basis from mid night to mid night for 24 hours of the day it is *daily load curve*.

Monthly load curves can be obtained from the daily load curves of the month and *Yearly load curve* can be obtained from the monthly load curves of the year.

A sample daily load curve on a power station is shown bellow:



The load curves for the grid substations and the entire interconnected electrical network are very vital documents for day today generation planning and future planning of addition of generating capacity etc.

Importance of load curve: i) Daily load curve shows the variation of load on the power station during different hours of the day.

ii) The area under the daily load curve gives the number of units generated during the day.

iii) The highest point on the daily load curve is the maximum demand on the station for that day.

iv) The area under the daily load curve divided by the number of hours (24) gives the average load on the station for that day.

v) The ratio of average load to the maximum demand is called load factor.

vi) Load curve helps in selection of the size and number of generating units.

vii) The load curve helps in scheduling the generation program of the station.

Load curve and selection of unit: The load on a power station varies from time to time. Therefore a single unit of large capacity will never be economical because its efficiency at off-peak periods will be very poor. Therefore a number of units of different capacity are chosen so that the best overall efficiency of the power station is achieved. The annual load curve helps in this regard.

Important points in selection of units:

i) The number and size of the units correctly fit to the annual load curve of the station.
ii) The capacity of units should be such that they meet the load requirement with minimum spinning reserve.
iii) The total installed capacity of the station should be 15 to 20 % more to meet the future load growth.
iv) There should be a standby unit to meet the forced break-down situations as well as to carry out maintenance and overhauling of the working units.
v) Selection of more number of units of smaller capacities to accurately fit the load curve should be avoided as it increases cost.

8.4. Maximum demand: It is the highest demand of load on a power station during a given period. The maximum ordinate on the load curve gives the maximum demand. It may be for a particular day, month or year. In the daily load curve shown above, the maximum demand is 360 MW at 8.00 PM.

8.5. Demand factor: Demand factor is the ratio of maximum demand to the connected load. Connected load is the sum of the continuous ratings of all equipments and devices connected to the supply system. The value of demand factor is less than 1

Average load or average demand: $\frac{\text{The total number of units generated in a given period}}{\text{number of hours of that period.}}$

Daily average load $= \frac{\text{The total number of units generated in a given day}}{24.}$

Monthly average load $= \frac{\text{The total number of units generated in a given month}}{\text{number of hours in that month.}}$

Yearly average load $= \frac{\text{The total number of units generated in a given year}}{\text{number of hours in that year .(8760 except leap year)}}$

8.6 Load factor: The ratio of average load to the maximum demand during a given period is called load factor.

Load factor for T hours $= \frac{\text{Average load x T (hours)}}{\text{MAximum demand x T (hours)}}$. Load factor is always less than 1. Higher is the load factor lesser is the cost of generation because Installed capacity is reduced hence capital investment cost is less.

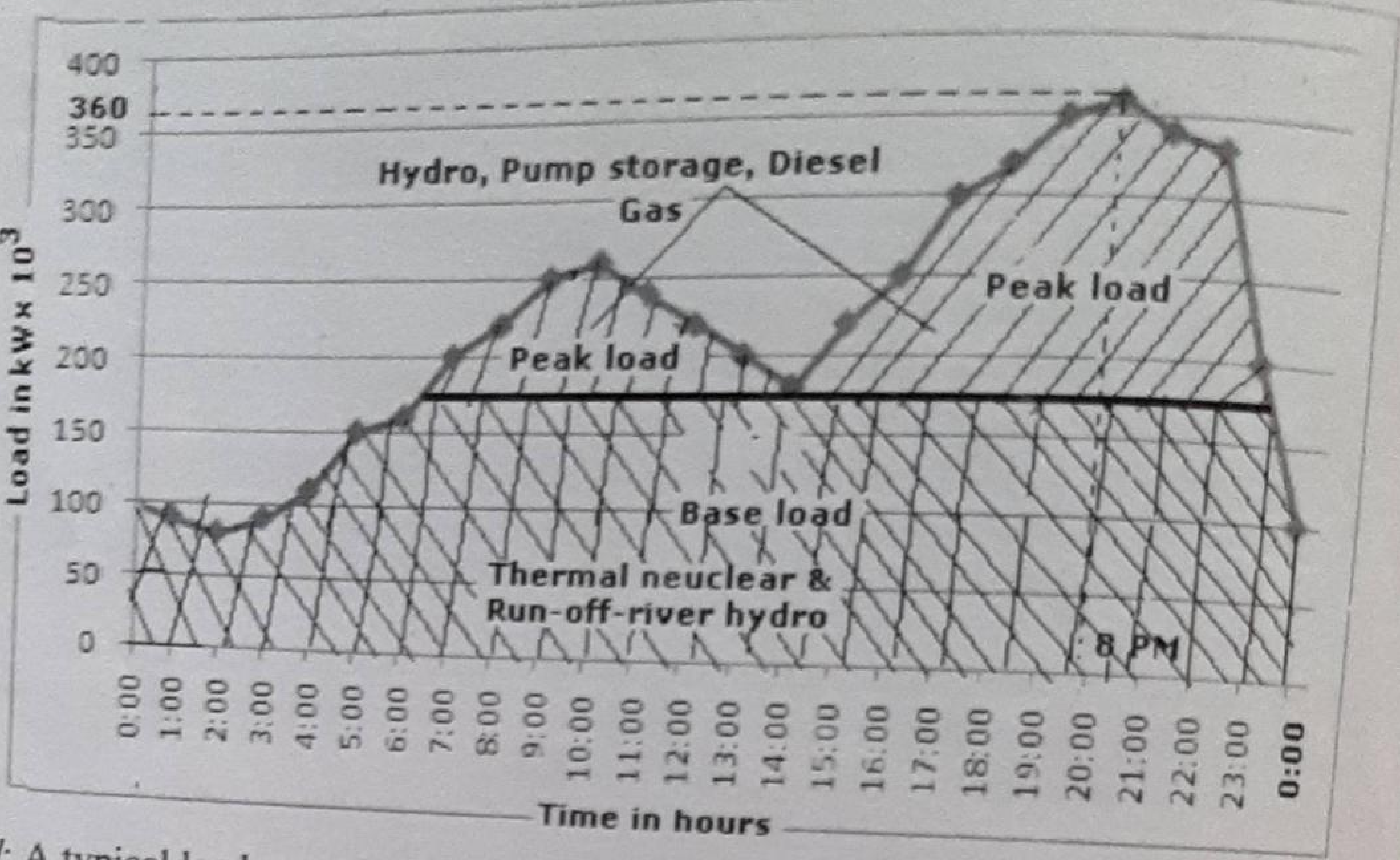
8.7 Diversity factor: It is the ratio of the sum of maximum demands of all the individual consumers connected to the power station to the simultaneous maximum demand on the power station that is $\frac{\text{Sum of individual max.demands}}{\text{Max. demand on the power station}}$. The maximum demands of all the individual consumers connected to the power station do not occur at the same time. Therefore the maximum demand don the power station is always less than the sum of individual maximum demand. So, diversity factor is always more than 1. The greater is the diversity factor lesser is the cost of generation.

8.8 Plant capacity factor: Plant capacity factor $= \frac{\text{Actual energy produced}}{\text{MAx.energy that could have been produced}} = \frac{\text{Average deddmand x T}}{\text{Plant capacity x T}} = \frac{\text{Average deddmand}}{\text{Plant capacity}}$. Annual plant capacity factor $= \frac{\text{Annual kWh output}}{\text{Plant capacity x 8760}}$

Plant capacity factor is an indication of reserve capacity of the station. Reserve capacity = Plant capacity – max. demand. Difference between load factor and plant capacity factor is an indication of reserve capacity. When the max. demand is equal to plant capacity there would be no reserve capacity.

8.9: Plant use factor: $= \frac{\text{Station output in kWh}}{\text{Plant capacity x Hours of use}}$

8.10 Peak load and base load on the power station:



Base load: A typical load curve is shown. The load on a electrical network changes at every instant. But there is a unvarying portion of the load which occurs for the most part of the time during the day which is called base load. This portion of the load demand is shared by thermal, nuclear, run-off-river hydro and hydro electric power stations. There is some flexibility in operation of hydro power plants while in case of thermal and nuclear there is no flexibility. Frequent ramp-up or ramp-down of load in case of thermal and nuclear stations is not possible. This is the reason they constitute the base load stations.

Peak load: Various load demands over and above the base load are known as peak loads. They are met by Pump storage, hydro, diesel and gas operated power stations.

9. Tariff: The rate at which electricity is supplied to the consumers is known as tariff.

Objective: i) Recovery of pooled cost of generation, ii) recovery of cost on capital investment (depreciation and interest) on transmission and distribution network, iii) recovery of cost of operation and maintenance (spares, consumables, metering, salary and allowances of operating staff etc), iv) A reasonable profit on capital investment.

Desirable characteristics: i) *Proper return*: Total annual cost including profit need to be recovered from the consumers, ii) *Fairness*: The tariff should be fair to all categories of consumers (Domestic, agricultural, industrial, commercial etc) so that they are satisfied. After reform of electric sector, the fixation of tariff is regulated by the State Electric Regulating Commission through public hearing, iii) *Simplicity*: The tariff should be simple so that an ordinary consumer can understand it, iv) *Reasonable profit*: Since electricity is an essential commodity and the general public is involved the supply company must charge a minimum profit. Since the tariff is being regulated by SERC there is little scope to pass on unreasonable profit component in the tariff, v) *Attractive*: The tariff should be such that large number of consumers are encouraged to use electricity. Further in the present scenario of regulatory regime a consumer is free to buy electricity from any electric supply company operating in the state whose tariff is cheap.