LECTURE NOTES

ON

GENERATION, TRANSMISSION AND DISTRIBUTION (TH-4)

DIPLOMA COURSES

4TH SEMESTER

ELECTRICAL ENGINNERING

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SYLLABUS

Th4. GENERATION TRANSMISSION & DISTRIBUTION

Name of the Course: Diploma in Electrical Engineering			
Course code:	Semester		4th
Total Period:	60	Examination	3 hrs
Theory periods:	4P / week	Internal Assessment :	20
Maximum marks:	100	End Semester Examination:	80

A. RATIONALE :

Power system comprises generation, transmission and distribution. In this subject generation, transmission and distribution, types of generation schemes, transmission with transmission loss and efficiencies, different type of sub-stations, different type of distribution schemes, EHV AC and HV DC overhead transmission, underground cable transmission and economic aspects involved are dealt with. Further, types of tariff are briefly included to give brief and overall idea to the students.

B. OBJECTIVES :

After completion of this subject the student will be able to:
1. Different schemes of power generation with their block diagram.
2. Mechanical and electrical design of transmission lines and numerical problems.
3. Types of cables and their methods of laying and testing.
4. Different schemes of distribution with problem solving
5. Different types of sub-stations.
6. Economic aspects of power supply system with problem and type of tariff of electricity.

C. TOPIC WISE DISTRIBUTION OF PERIODS

Sl. No.	**Topics**	Periods
1.	Generation of electricity	07
2.	Transmission of electric	05
3.	power 05	07
4.	Over head line	07
5.	Performance of short &	07
6.	medium lines 07	07
7.	EHV transmission	06
8.	Distribution System 07	06
9.	Underground cable 06	03
10.	Economic Aspects	05
	Types of tariff	
	Substation	
TOTAL		**60**

D. COURSE CONTENTS IN TERMS OF SPECIFIC OBJECTIVES.

1. GENERATION OF ELECTRICITY

1.1 Elementary idea on generation of electricity from Thermal, Hydel, Nuclear, Power station.
1.2 Introduction to Solar Power Plant (Photovoltaic cells).
1.3 Layout diagram of generating stations.

2. TRANSMISSION OF ELECTRIC POWER

2.1 Layout of transmission and distribution scheme.
2.2 Voltage Regulation & efficiency of transmission.
2.3 State and explain Kelvin's law for economical size of conductor.
2.4 Corona and corona loss on transmission lines.

3. OVER HEAD LINES
3.1 Types of supports, size and spacing of conductor.
3.2 Types of conductor materials.
3.3 State types of insulator and cross arms.
3.4 Sag in overhead line with support at same level and different level. (approximate formula effect of wind, ice and temperature on sag)
3.5 Simple problem on sag.

4. PERFORMANCE OF SHORT & MEDIUM LINES
4.1. Calculation of regulation and efficiency.

5. EHV TRANSMISSION
5.1 EHV AC transmission.
5.1..1. Reasons for adoption of EHV AC transmission.
5.1..2. Problems involved in EHV transmission.
5.2 HV DC transmission.
5.2..1. Advantages and Limitations of HVDC transmission system.

6. DISTRIBUTION SYSTEMS
6.1 Introduction to Distribution System.
6.2 Connection Schemes of Distribution System: (Radial, Ring Main and Inter connected system)
6.3 DC distributions.
6.3.1 Distributor fed at one End.
6.3.2 Distributor fed at both the ends.
6.3.3 Ring distributors.
6.4 AC distribution system.
6.4.1. Method of solving AC distribution problem.
6.4.2. Three phase four wire star connected system arrangement.

7. UNDERGROUND CABLES
7.1 Cable insulation and classification of cables.
7.2 Types of L. T. & H.T. cables with constructional features.
7.3 Methods of cable lying.
7.4 Localization of cable faults: Murray and Varley loop test for short circuit fault / Earth fault.

8. ECONOMIC ASPECTS
8.1 Causes of low power factor and methods of improvement of power factor in power system.

8.2 Factors affecting the economics of generation: (Define and explain)
8.2.1 Load curves.
8.2.2 Demand factor.
8.2.3 Maximum demand.

8.2.4 Load factor.
8.2.5 Diversity factor.
8.2.6 Plant capacity factor.
8.3 Peak load and Base load on power station.

9. TYPES OF TARIFF
9.1. Desirable characteristic of a tariff.
9.2. Explain flat rate, block rate, two part and maximum demand tariff. (Solve Problems)

10. SUBSTATION
10.1 Layout of LT, HT and EHT substation.
10.2 Earthing of Substation, transmission and distribution lines.

GENERATION OF ELECTRICAL POWER

Hydro-electric Power Station

A power generation station which uses the potential or kinetic energy of water for the generation of an electrical energy is called hydro-electric power station.

Water has a kinetic energy when it is in motion. While the water stored at high level has a potential energy. The difference in level of water between the two points is called head. Such a water head is practically created by constructing reservoirs across river or lake. Generally a dam is constructed at high altitudes, which can be used as a continuous source of the water for the hydro-electric power stations. The water from the dam is taken through pipes and canals to the water turbine, which is at lower level. The turbine obtains the energy from the falling water and changes it into a mechanical energy. This mechanical energy of the turbine is then used to drive the alternator, which converts the mechanical energy into an electrical energy. The energy conversion involved in hydro-electric power generation is shown in the Fig. 1.

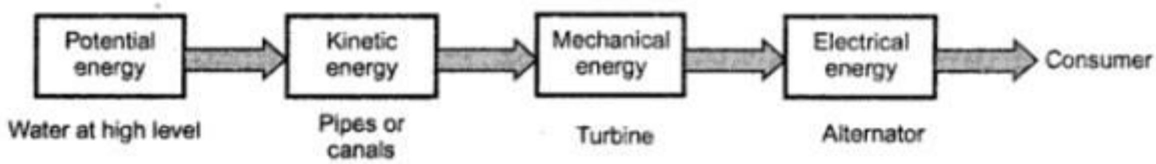


Fig. 1 Energy conversion

1.*Factors for Selection of Site*

The water reservoir like dam can not be constructed anywhere. There are number of factors of affecting the choice of site for the hydroelectric power station.

1. **Availability of water** : As the basic requirement of hydro-electric plant is the water, the availability of huge quantity of water is the main consideration. The plant must be constructed where sufficient quantity of water is available at a good head. The previous rainfall records are studied and the maximum and minimum quantity of water available during the year estimated. Considering the losses such as evaporation, the water necessary for the plant is calculated. Then by comparing both the estimations, the choice of the site is done.
2. **Storage of water** : The rainfall is not consistent every year. Hence the available water should be stored. This makes necessary to construct dams. The storage helps in equalizing the flow of water throughout the year. So site should be provide sufficient facilities for erecting dam and the storage of water.
3. **Head of water** : For getting sufficient head, the dam or reservoir should be constructed at a height in a hilly area. The availability of the head directly affects the cost and economy of the power generation. So site should be selected in proper geographical area, which can give sufficient water head.
4. **Cost and type of land** : The initial cost of the project includes the cost of the land. Hence land must be available at a reasonable price. Similarly the type of the land must be such that it should able to withstand the weight of the heavy equipments to be installed.
5. **Transportation facilities** : For transporting the equipments and the machinery, the site selected must be easily accessible by rail and road.
6. **Distance from load centers** : The load center is connected to the site by the transmission lines. Hence to keep the cost of the transmission lines minimum and the losses occurring in the line minimum, the distance of the site from the load centers must be less. Otherwise the overall cost increases considerably.

All these factors affect the selection of site for the hydro-electric power station.

General Arrangement of Hydro-electric Plant

Though hydro-electric power station simply involves the conversion of hydraulic energy to the mechanical energy, it requires many types of supporting arrangements. The Fig. 2 shows the schematic arrangement of hydro-electric power station which uses water supply from an artificially constructed dam.

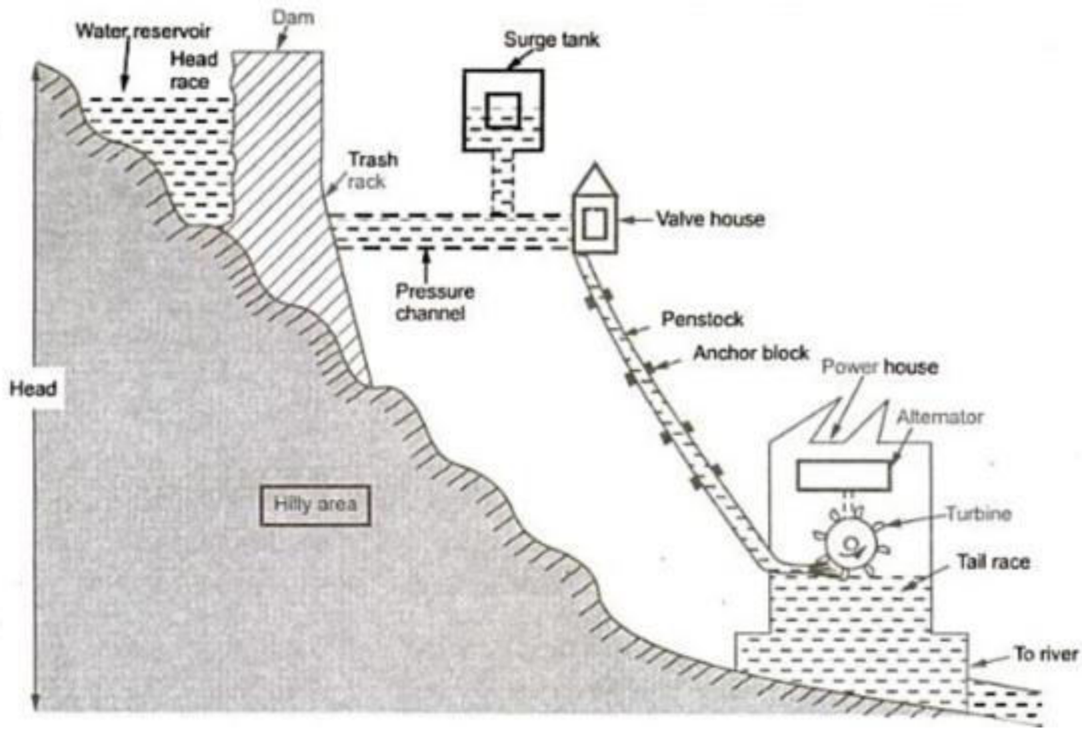


Fig.2 Schematic arrangement of hydro-electric power plant

The dam is constructed across the river and water from catchment area is collected behind the wall of the dam, in high mountains. A pressure channel is taken from such a water reservoir which takes water to a surge tank. The surge tank is a controlling room which controls the flow of water i.e. adjusts the discharge of water according to the need of the turbine and load on it. Trash rack does not allow floating and other impurities to pass to the turbine. The pressure channels plays a very important role. It relieves the pressure on the penstocks when the turbine valves are open or closed suddenly. The water is then taken to a valve house from where the penstocks start. The valve house contains main sluice valve and the automatic isolating valves. These valves also regulate the flow of water to the power house and isolates the supply of water if there is any emergency such as bursting of a penstock. Through the penstocks, the water is taken to the power house which consists of turbine and the alternator. The penstock are nothing but the steel pipes which are arranged in the form of open or closed conduits, supported by the anchor blocks.

When the water from the penstock is hammered through a nozzle, on the turbine blades, the turbine starts rotating. At this stage the hydraulic energy is converted to a mechanical energy. The turbine drives the alternator which is coupled to the shaft of the turbine. The alternator converts the mechanical energy into an electrical energy. This electrical energy is then transmitted to the load centers. The water collected from the turbine is called tail race. This tail race is then taken off to the river.

Constituents of Hydro-electric Power Station

Let us discuss the constituent and their functions in the operation of the hydroelectric power station.

Dam

The water reservoir in the form of a dam is the main part of the power station. It stores the water, provides the continuous supply of water and maintains the necessary water head. The dams are built up of stones and concrete. The design and type of the dam us selected according to the topography of the site and economical aspects.

Spillways

There are certain times when the river flow exceeds the storage capacity of the dam, due to the heavy rainfall. The spillways are provided to discharge this surplus water and maintain safe water level in the dam.

Surge Tank

This is an important projecting device in a hydro-electric power plant. It is built just before the valve house. It protects the penstocks from bursting due to sudden pressure changes.

If the load on the turbine is thrown off suddenly then by the governing action, the turbine input gates get suddenly closed. Thus there is sudden stopping of water at the lower end of the penstock. This time the excess water at the lower end of the penstock, rushes back to the surge tank. The surge tank water level increases. Thus the penstock is protected from bursting due to high pressure. The surge tank absorbs this high pressure swing by increasing its water level.

On the other hand, when the load on the turbine suddenly increases, the additional water required is drawn from the surge tank. This satisfies the increased water demand instantly.

Thus the surge tank controls the pressure changes created due to rapid changes in the water flow in penstock and hence protects the penstock from water hammer effects which might burst the penstock.

Penstocks

The penstocks are made up of steel or concrete and arranged in the form of conduits, supported by the anchor blocks. The penstocks are used to carry water to the turbine. For the low head (less than 30 m) power stations, the concrete penstocks are used. The steel penstocks are suitable for any head.

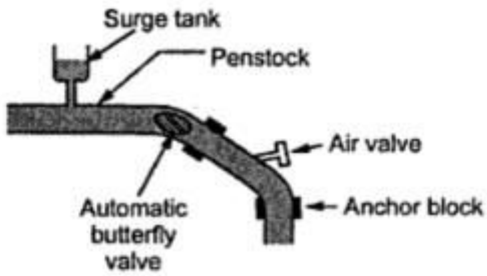


Fig. 3 Protecting devices of penstock

There are certain protective devices attached to the penstocks. These devices are shown in the Fig.3.3.

The automatic butterfly valve completely shuts off the water flow if the penstock bursts.

The air valve maintains the air pressure inside the penstock equal to the outside atmospheric pressure.

The anchor block supports the penstock and holds it in the proper position.

The surge tank also protects the penstock from sudden pressure changes.

<u>.5 Water Turbines</u>

The main two types of water turbines are,

i) Impulse and ii) Reaction

In an impulse turbine, the entire pressure of water is converted into a kinetic energy in a nozzle. Then the water jet is forced on the turbine which a large velocity which drives the wheel. The pelton wheel is an example of impulse turbine which is shown in the Fig. 3.4.

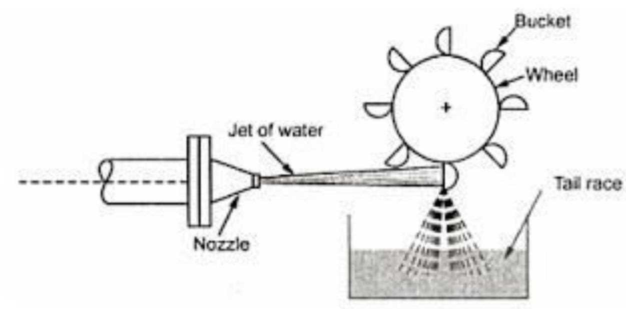


Fig.4 Impulse turbine

It contains elliptical buckets mounted on the periphery of a wheel. The force of water jet on the buckets, drives the wheel and the turbine. There is a needle or spare at the tip of the nozzle. The governor controls the needle which controls the force of the jet, according to the load demand. The impulse turbines are used for the high head power stations.

In the reaction turbines, the water enters the runner, partly with pressure and partly with velocity head. There are two type of reaction turbines.
i) Francis and ii) Kalpan

The Fig.3. 5 shows the basic principle of reaction turbine. The reaction turbine consists of an outer ring of stationary guided blades and an inner ring of rotating blades. The guided blades control the flow of water to the turbine. Water flows radially inwards and changes to a downward direction when it passes through the rotating blades. While passing over the rotating blades, the pressure and velocity of water are decreased. This causes reaction force to exist which drives the turbine. For large variation of head, Kalpan is used as its efficiency does not vary with change in load. For fairly constant head, a Francis or propeller turbine is used.

The reaction turbines are used for the low head power stations.

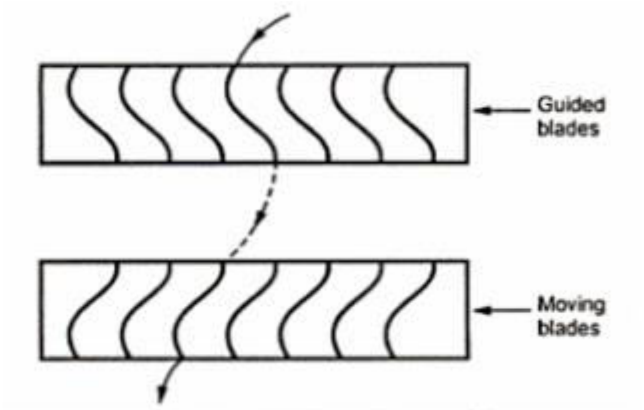


Fig. 5 Reaction turbine

Advantages

1. If the proper site is selected, the continuous water supply is available.
2. Requires no fuel as water is used.
3. No burning of fuel hence neat and clean site as no smoke or ash is produced.
4. It does not pollute the atmosphere.
5. The operating cost is very low as free water supply is available.

6. The turbines in this plants can be switched on and off in a very short period of time.
7. It is relatively simple in construction, self contained in operation and requires less maintenance.
8. It is robust and has very long life.
9. It gives high efficiency over a considerable range of load. This improves the overall system efficiency.
10. It provides the additional benefits like irrigation, food control, afforestation etc.
11. Being simple in design and operation, highly skilled workers are not necessary for the daily operation. Thus man power requirements is low.

5 *Disadvantaes*

1. Due to the construction of dam, very high capital cost.
2. The low rate of return.
3. Uncertainity of availability of water due to unpredictable rainfall.
4. As its location is in hilly areas and mountains, the long transmission lines are necessary for the transmission of generated electrical energy. This requires high cost.
5. The large power stations disturb the ecology of the area by the way of disforestation, destroying vegetation and uprooting people.
6. Highly skilled and experienced persons are necessary at the time of construction.

Steam Power Station

A generating station which converts the heat energy of local combustion into an electrical energy is called steam or thermal power station.

In this power station, the steam is produced in the boiler by using the heat of the cool combustion. The steam is then expanded in steam turbine which drives the alternator which converts the mechanical energy of the turbine into an electrical energy. The exhaust steam gets condensed in the condenser and fed back into the boiler again, completing the cycle of the power station. This principle is called Rankine cycle.

The energy conversion involved in steam power station is shown in the Fig. 1.

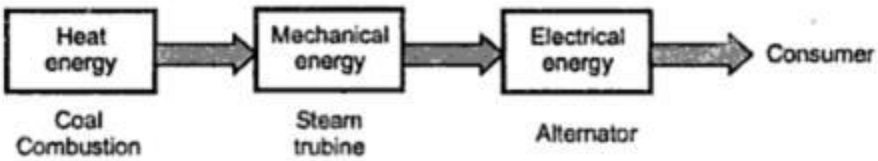


Fig. 1 Energy conversion

Factors of Selection of Site

The following factors are to be considered for the selection of site for the steam power station, in order to achieve the economical and successful operation of the plant.
1. **Supply of fuel** : The main fuel for the steam power plant is coal. Thus the power station should be located near the coal mine so that the fuel supply is continuous and adequate. If the plant is located away from the coal mine then sufficient transportation facility must be available.
2. **Availability of Water** : For the condenser, huge amount of water is required. Hence site must near be the river so that abundant quantity of cooling water is available.
3. **Transportation facilities** : For transporting the equipments and the machinery required by a modern steam power plant, he site selected must be easily accessible by rail and road.

4. **Cost and type of land** : The land must be available at a reasonable price to keep the initial cost low. There must be provision for the extension of the plant. The type of the land must be such that it should be able to withstand the weight of the heavy equipments to be installed.
5. **Distance from load centers** : To keep the cost of the transmission and transmission losses to minimum, the site must be nearer to the load centers. For d.c. system, transmission loss plays an important role but a.c. power can be transmitted at high voltage with reduced transmission cost. Thus this factor is more important for d.c. supply system.
6. **Distance from populated area** : The continuous burning of coal at the power station produces smoke, Fumes and ash, which pollutes the surrounding area. Such a pollution due to smoke is dangerous for the people living around. Hence the site of the plant must be at a considerable distance from the populated area.

All these factories affect the selection of site for the steam power station.

General Arrangement of Steam Power Plant

Though steam power plant simply involves the conversion of heat energy to the mechanical energy, it requires many types of supporting arrangements. The Fig. 2 shows the schematic arrangement of steam power station.

The coal is burnt in a place called grate in a boiler. The flue gases are evolved which heats the water in a boiler. The water is converted to a steam by absorbing heat from the flue gases. This steam is called wet steam as it contains suspended water particles. This steam is passed to the superheater where it is converted to superheated steam from the wet steam. This superheated steam is then expanded in the turbine which rotates the turbine. Thus the heat energy is converted to a mechanical energy. The turbine shaft is coupled to an alternator which converts the mechanical energy into an electrical energy. This is then given to the busbar through a transformer and proper switchgear arrangement.

After expanding in the turbine, the exhaust steam is passed through the condenser. In the condenser, the steam is converted into liquid condensate. Using the condensate extraction pump, the condensate is taken to economizer. The economiser again transfer the heat from flue gases to the condensate and then transfer the heated water to the boiler. Thus the cycle is completed. The exhaust flue gases are released to the atmosphere through the chimney.

Constituents of Steam Power Station

The various constituents of steam power station can be divided into the following stages for the ease of understanding the working of the power plant.

1. Fuel and ash circuit 2. Steam generating circuit
3. Steam turbine 4. Alternator
5. Feed water circuit 6. Cooing water circuit

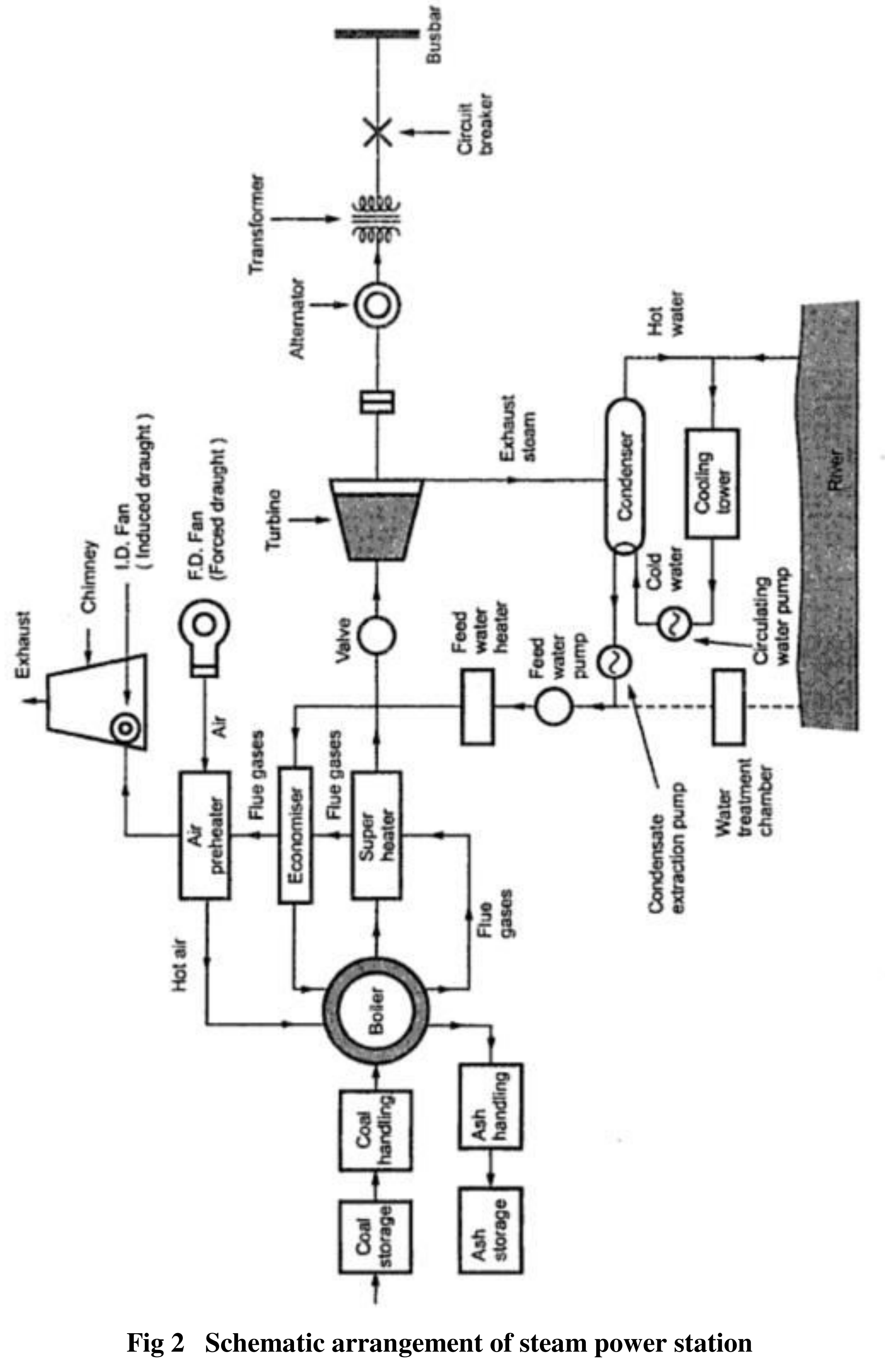


Fig 2 Schematic arrangement of steam power station

1.3.1 Fuel and Ash Circuit

In steam power plant, the coal is used as a fuel. The coal is stored in a coal storage plant where coal is transferred from all the parts of the country by the rail or the road. The storage helps to supply the coal continuously, in case of situations like strikes, failure of transportation system etc. Then the coal is transferred to the coal handling plant where the coal is pulverized i.e. crushed into small pieces. The pulverization increases the surface exposure of the coal and this helps for rapid combustion of coal without using large quantity of air. Such a crushed coal is transferred to the boiler from the local handling plant.

As a result of combustion of the coal. large quantity of ash is produced in the boiler. For the proper combustion of the coal, ash is removed to the ash handling plant. Then it is delivered to the ash storage plant, from where it is disposed off.

1.3.2 Steam Generating Circuit

The main component of steam generating circuit is the boiler. But many other auxiliary equipments are used so as to completely utilize the heat of flue gases.

1. **Boiler** : The boiler is a closed vessel where water is converted to the steam using the heat of the local combustion. Hence the boiler is called steam generator. In the boilers, the grate is provided for the combustion of coal. The steam produced in the boiler contains suspended water particles and hence called wet steam.
2. **Superheater** : It is an accessory attached to the boiler and located in the path of flue gases leaving the boiler and flowing towards chimney. By using the heat of the flue gases, the superheater converts the wet steam into superheated dry steam. There are two advantages of superheating that it increases the overall efficiency and it avoids the corrosion of the turbine blades due to wet steam. The superheated steam is then passed to the turbine through a main valve between the two. The two types of superheaters used are radiant type and convection type.
3. **Economizer** : It is another accessory attached to the boiler and located in the path of flue gases. Thus it utilizes the heat of flue gases which would otherwise wasted to the atmosphere. The water from the feed pump is passed through the economizer to the boiler drum so that before entering the boiler, it is heated and hence less efforts are required to convert it into steam. This increases the overall boiler efficiency, saves the fuel and reduces the stress on the boiler.
4. **Air preheater** : This is also an accessory attached to the boiler and located in the path of flue gases. The air is required for the local combustion. Air is drawn from the atmosphere by a forced draught fan and is supplied to the air preheater. The air preheater extracts the heat from the flue gases and makes the air hot before supplying to the boiler. This increases the temperature of the furnace and helps in the production of the steam. This increases the thermal efficiency and the steam capacity per square meter of the boiler surface.

The two types of air preheaters used are recuperative type and the other is regenerative type.

1.3.3 Steam Turbines

The dry and superheated steam from the supeheater is supplied to the turbine. The hat energy of the steam is converted to the mechanically energy as steam passes over the turbine blades. There are two types of steam prime movers available, steam engine and steam turbine. The steam turbine is practically used because of the following advantages,

i) High efficiency ii) Simple construction iii) Low maintenance
iv) High speed v) Less floor area vi) No flywheel required
vii) Less problems of vibrations

The steam turbines are classified into two types as impulse turbine and reaction turbine.

In the impulse turbine, the steams expands completely in the nozzle and pressure over the moving blades remaining constant. While doing so, the steam attains very high velocity and impacts on moving blades giving rise to an impulsive force on them. Thus the turbines starts rotating.

In the reaction turbine, steam is partially expanded in the stationary nozzle and remaining expansion takes place on the moving blades. This causes reaction force on the moving blades and the turbine stats rotating.

The commercial turbines nowadays use series combination of impulse and reaction turbines, due to which steam can be used more efficiently.

1.3.4 Alternator

The alternator shaft is coupled to the turbine. When the turbine shaft rotates, the alternator shaft rotates and converts the mechanical energy into an electrical energy. The electrical energy from the alternator is given to the busbar through transformer, circuit breakers and isolators.

1.3.5 Feed Water Circuit

The condensate leaving the condenser is used as the feed water. Because it goes to the boiler, It is first heated in a closed feed water heater. Then it is passed to economizer where it is further heated and then passed to the boiler. This increases the overall efficiency of the plant.

The feed water source is generally river or a canal. It contains suspended and dissolved impurities. The boilers needs clean and soft water for loner life and better efficiency. Hence the feed water is purified. It is stored in the tanks and by the different actions like sedimentation, filtration etc., it is made soft and pure. Such a pure feed water is used for the steam generation in the boiler.

1.3.6 Cooling Water Circuit

For improving the plant efficiency, the expanded steam coming out of the turbine, passes through the condenser where it is condensed into water. The condenser is very important as it creases a very low pressure at the exhaust of the turbine thus helps in the expansion of steam in the turbine at low pressure.

For condensation of steam, a flow of natural cold water is circulated through the condenser. This takes the heat from the exhaust steam and gets heated. This hot water is discharged at a suitable location or is passed through a cooling tower so that it is again converted to cold water. Then it is recirculated through the condenser by a pump. The condensed steam can be used as a feed water to the boiler.

The two types of condensers used are jet condenser and surface condenser.

Advantages

1. The fuel used is a coal, which is cheap.
2. The initial cost is less compared to other power station.
3. It requires less floor space area compared to hydro-electric power station.
4. The fuel is easily available.
5. The fuel can be easily transported top the site hence site can be anywhere ad not always near the coal mines.
6. The cost of the generation is less than the diesel.

Disadvantages

1. Due to the smoke and fume, pollutes the surrounding atmosphere.
2. Running cost is higher than hydro-electric power palnt

3.11. Efficiency

For a steam power station, two efficiencies are defined which are thermal efficiency and the overall efficiency.

The thermal efficiency is the ratio of heat equivalent of the mechanical energy transmitted to the turbine shaft to the heat of the combustion of coal.

$$\eta_{thermal} = \frac{\left[\text{Heat equivalent of mechanical energy transmitted to turbine}\right]}{\text{Heat of coal combustion}}$$

The overall efficiency is the ratio of heat equivalent of electrical output from alternator to the heat of coal combustion. The overall efficiency pf steam power station is very low about 20 to 25%.

$$\eta_{overall} = \frac{\text{Heat equivalent of electrical output}}{\text{Heat of combustion of coal}}$$

The overall efficiency depends on number of factors and hence can be expressed as,

$$\eta_{overall} = \eta_{thermal} \times \eta_{electrical} \times \eta_{boiler}$$

Where,
$\eta_{electrical}$ = Electrical efficiency of an alternator which is practically high, above 90%.
η_{boiler} = Boiler efficiency considering the effect of economizer and air preheater, which is about 85%.

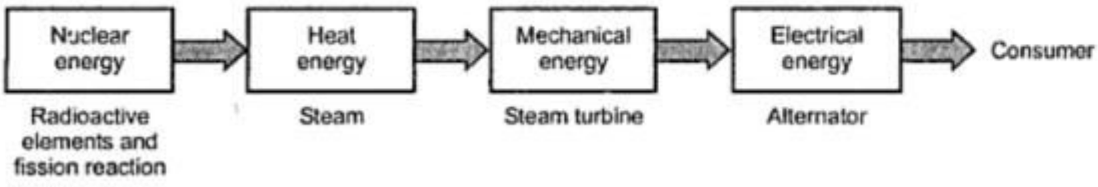
Nuclear Power Station

A generating station which converts the nuclear energy into an electrical energy is called nuclear power station.

In such a power station, heavy radioactive elements like uranium (U^{235}), Thorium (Th^{232}), are subjected to the nuclear fission. The fission is breaking of nucleus of heavy atom into the parts by bombarding neutrons. This is carried out in a special nuclear reactor. During the nuclear fission, huge amount of energy is released.

The heat energy that released is used in rising the steam at high pressure and temperature. The steam turbines are operated using the high temperature steam. The turbines converts the heat energy into a mechanical energy. The turbine drives the alternator which converts mechanical energy into an electrical energy.

The energy conversion involved in the nuclear power station is shown in the Fig.1.



Conversion of Nuclear Energy

According to Einstein's hypothesis, the relation between the energy released by the nuclear reaction of the mass given by,

$$E = mc^2$$

where E = Energy released in jouls
m = Actual mass converted into energy in kg
c = Velocity of light = 3×10^8 m/s

There are three types of nuclear reaction, radioactive decay, fission and fusion. Out of this, only fission is used to produce the energy.

The fission reaction is achieved by bombarding an electrically neutral neutron, on the positively charged nucleus of radioactive element. This results in the sustained reaction to release two or three neurons for eacj one absorbed in fission.

The immediate products of fission reaction such as xenon (Xe^{140}) and strontim (Sr^{94}) are fission fragments and are the decay products. The complete fission of 1 gm of U^{235} nucleus produces 0.948 MW energy per day.

Factors selection of site

The following factors are to be considered for the selection of site for the nuclear power station.

1. **Availability of water** : Water is a secondary working fluid and used as a coolant for the cooling purpose, in the nuclear power station. A huge amount of water is necessary for this purpose. Hence site must be near the river or canal so that abundant quantity of cooling water is availabe.
2. **Disposal of waste** : The immediate products of fission reaction are the waste products which are radioactive in nature. These can cause problems to the health of the people and hence must be disposal quickly. Such a waste is either burried in deep pits or disposal off in the sea. Hence the site should be selected so that their is sufficient arrangement for disposal of such radioactive waste products.
3. **Distance from populated area** : The radioactive elements are hazardous to the health of the people around. There is always danger of presence of radioactivity in the atmosphere near the plant. Hence as a safety measure the site itself must selected to far away from the populated area. Practically a dome is used in the plant, which restricts radioactivity to spread in the atmosphere.
4. **Transportation facilities** : For transporting the equipments and the machinery required, there must be adequate transportation facilities. The site must accessible by a rail or road so that it is easy for the movement of the workers, working in the plant.
5. **Nearness to the load centres** : Though the site should be away from the populated area near the river or sea, it should not be too large distance, due to which transmission cost may increase tremendously.
6. Cost and type of land : The land price must be reasonable and the bearing capacity of the land should be good enough to withstand the forces due to heavy equipments of the plant.

All these factors affects the selection of site for the nuclear power station.

General Arrangement of Nuclear Power Plant

The Fig. 2 shows the schematic arrangement of a nuclear power plant.

The entire arrangement can be divided into following stages.

1.Nuclear reactor 2. Heat exchange (Steam generator)
3. Steam turbine 4. Alternator 5. Cooling water circuit.

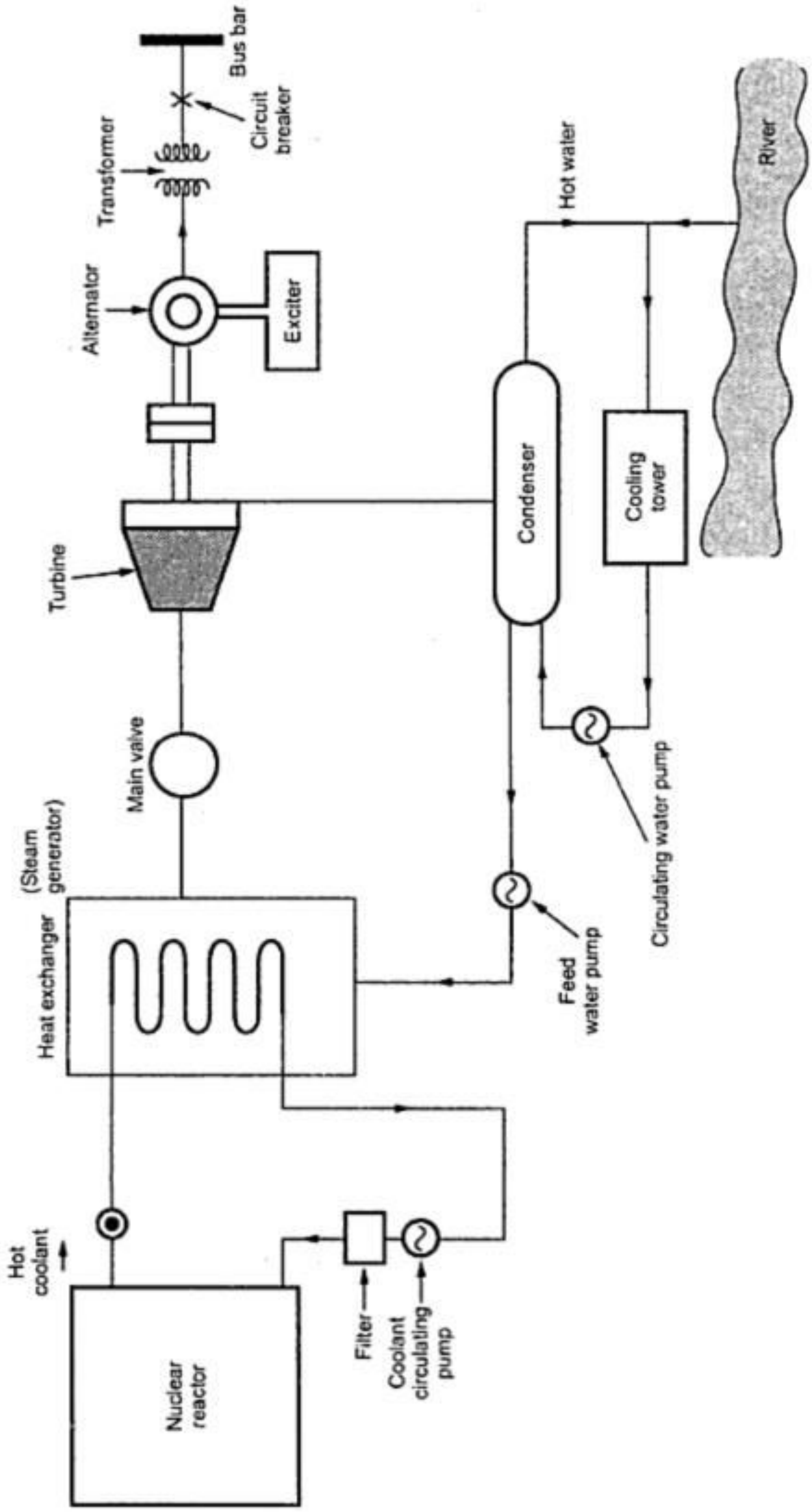


Fig.2 Schematic arrangement of nuclear power station

Nuclear Reactor

This represents that part of a nuclear power plant where U fuel is subjected to a controlled fission chain reaction, during which tremendously energy is generated.

The Fig. 3 shows the various components of a nuclear reactor and a heat exchanger.

The following are the components of the nuclear reactor.

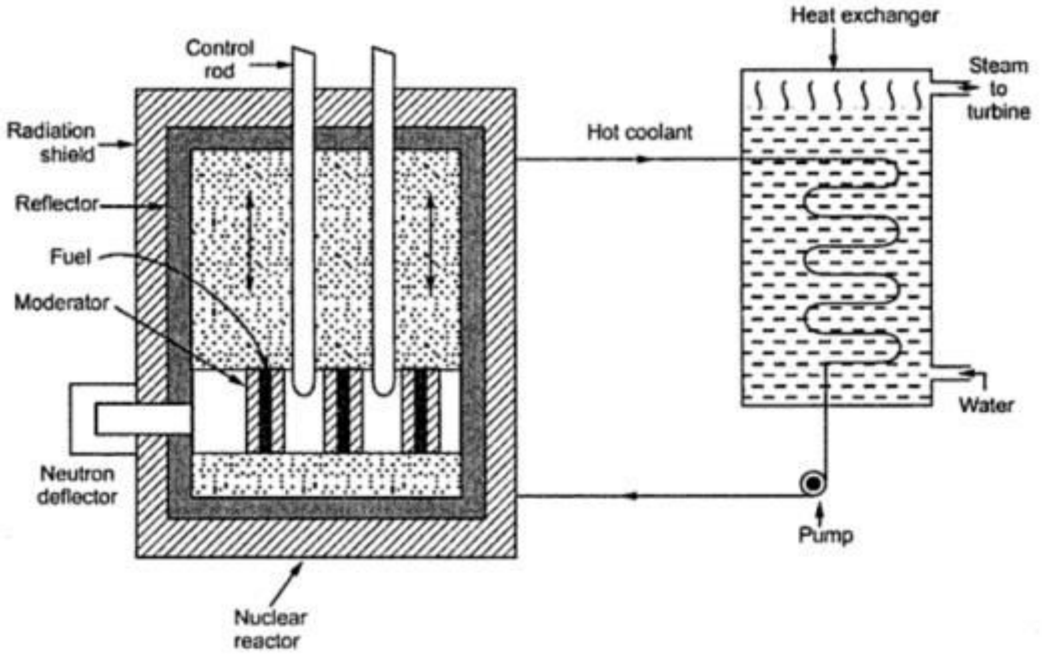


Fig. 3 Nuclear reactor and heat exchanger

1. Fuel : The commonly used fuel is uranium containing 0.7 % U^{235} or enriched uranium containing 1.5 - 2.5 U^{235}. The fuel is used in the form of rods or plates which are surrounded by the moderators. The fuel rods are arranged in cluster and the entire assembly is called core. The minimum amount of the fuel required to maintain the chain reaction is called the critical mass.

2. Moderators : The main function of the moderators is to reduce the energy of neutrons evolved during fission. By slowing down the high energy neutron, the possibility of escape of neutrons is reduced while possibility of absorption of neutrons by fuel to cause further fission is increased. This also educes the amount of fuel required for the chain reaction. The commonly used moderators are graphite, beryllium and heavy water. Some other functions of moderators include prevention of corrosion of fuel element, retain the radioactivity and to provide structural support.

3. Reflector : The reflector is placed around the core to reflect back some of the neutrons which may leak out from the surface of the core, without taking part in the fission. A blancket of reflector can reduce the critical mass required.

4. Control rods : The cadmium rods are used as control rods which are strong neutron absorber. Thus control rods can regulate the supply of neutrons for chain reaction. If the number of neutrons are not controlled, there is a possibility of explosion due to large amount of energy released. By pushing or pulling out of these rods, the rate of chain reaction and hence the heat produced can be controlled. The control rods are operated automatically as per the next requirement. The other material used for the control rods is boron or hafinium.

5. Coolant : The main purpose of the coolant is to transfer heat generated in the reactor core and use it for the system generation. he coolant in the reactor keeps the temperature of fuel below safe level by continuous removable of the energy from the core. The liquid metals like sodium or potassium are used as coolants.

6. Radiation shield : The radiation of a radioactive substances are harmful to the human life. Hence radiation shield is used to prevent the escape of these radiations to the atmosphere. Generally 50 to 60 cm thick steel plate and few meters of the concrete outside are used as the radiation shield.

1.5 Heat exchanger

It is a device which is used to exchange the heat from the primary circuit to the secondary circuit. The coolant carries the heat in the reactor to the exchanger where it is exchanged to the water, to convert water to steam. Thus the heat exchanger is nothing but a steam generator. Once the heat exchanged, the coolant is fed back to the reactor, using the coolant recirculating pump.

1.6 Steam turbine

The steam generated from the water in the secondary circuit is taken to the steam turbine through a main valve, where it is expanded. Due to this, turbine starts rotating and thus the heat energy is converted to a mechanical energy.

1.7 Alternator

The shaft of an alternator is coupled to the turbine shaft. Thus when the turbine rotates, the alternator starts rotating. The alternator converts mechanical energy into an electrical energy. The energy output of an alternator is given to the bus bars through transformer, circuit breakers and isolators.

1.8 Cooling Water Circuit

The expanded steam from the turbine is the exhausted steam which is taken to the condenser. In the condenser, the steam is condensed into water. For the condensation of steam , a flow of natural cold water is circulated through the condenser. This water takes heat from the exhaust steam. This hot water is passed through cooling tower, where it is again converted to cold water. The it is recirculated through the condenser by pump. The condensed steam is then recirculated through the secondary circuit of exchanger, using the feed water pump.

Advantages

1. The amount of fuel required is very small
2. Three is saving in the transportation cost of fuel as fuel required is less.
3. It requires less space compared to any other type of the power plant.
4. The running cost per unit energy generated is lower than the thermal power plant.
5. It is very much economical.
6. There is a lake of environmental problems which are associated with the thermal power plant.
7. Large deposits of nuclear fuels are available so such plants can ensure continued supply of the fuel.
8. It ensures reliability of the operation.

. *Disadvantages*

1. The fuel is very expensive.
2. The fuel is difficult to recover.
3. The capital cost is very high compared to other types.
4. The waste products are radioactive and can cause pollution.
5. The waste disposal problem is severe.
6. The maintenance charges are very high.
7. It is not suitable for the varying load conditions, as the reactor can not respond instantly to the load fluctuations.
8. The fuel may be misused in weapons.

Solar Power Plant

The surface of the earth receives from sun about kW of solar energy. The amount of solar energy reaching the earth is not easily convertible. There are two obvious obstacles in harnessing solar energy. First it is not constantly available on earth and secondly the energy is diffused. Therefor it requires a large capital investment for conversion apparatus.

Flat Plate Solar Collector

Fig. 1 shows a flat plate collector which consists of following components.

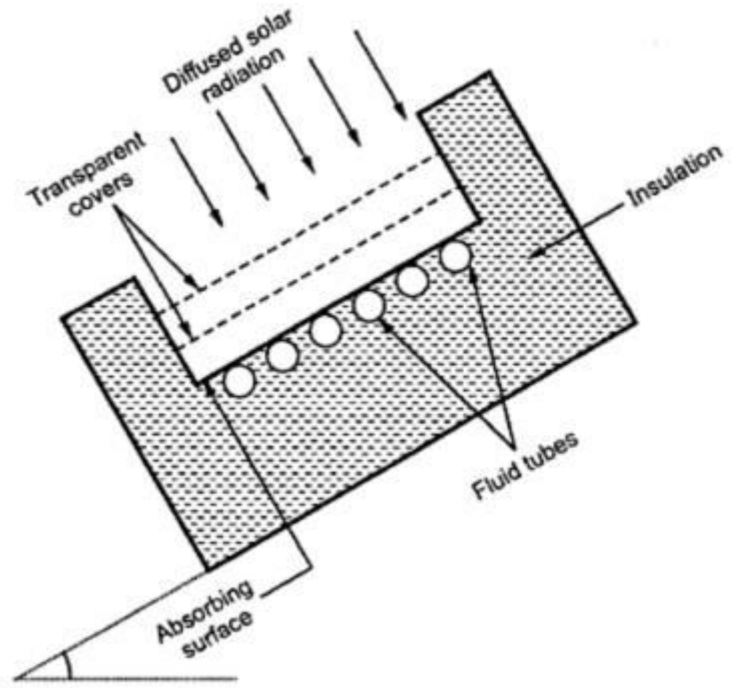


Fig. 1 Flat plate solar collector

i) An absorber plate : It intercepts and absorbs solar radiations.
ii) Transparent covers : These are one or more sheets of solar radiation transmitting materials and are placed above the absorber plate. They allow solar energy to reach absorber plate while reducing convection, conduction and re-radiation heat losses.

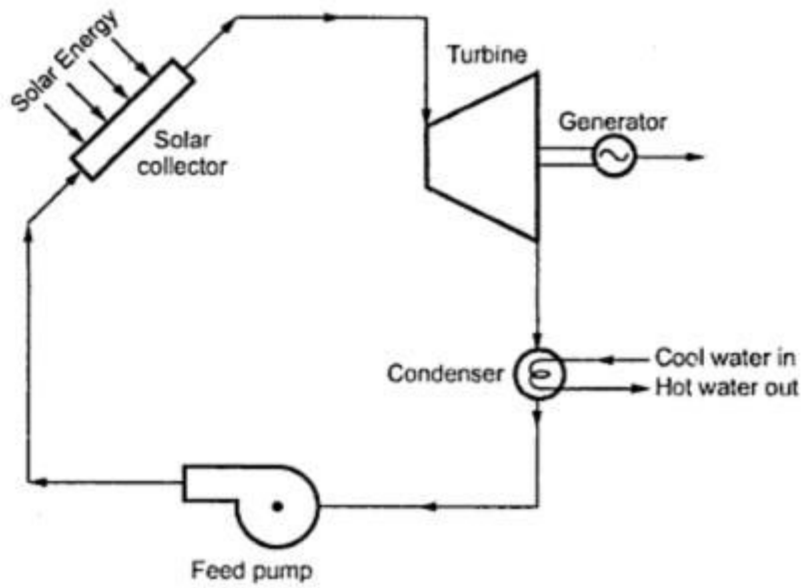


Fig.. 2 solar power plant

Solar Power Plant Fig. 2 represents a schematic diagram of solar power plant.

The basic components of solar power plant are also exactly identical to thermal power plant except boiler is replaced by a flat plate solar collector.

The energy from solar radiation is collected and utilized to generate a steam to run steam turbines. For obtaining reasonably high efficiency, concentration type of collectors are used when steam is used as working fluid. The cost of concentrating collector is more than flat plate collector. Therefor, new working fluid whose saturation temperature is lower than that of water at considerably high pressures are normally used in this type of power plant. But the thermal efficiency of the plant will be low due to low temperature range.

This is more suitable in rural areas for house lighting and water pumping for irrigation purpose

1.1 Advantages

Solar energy has following advantages.

1) Solar radiation does not disturb ecological balance.
2) It is available freely in nature.
3) It is non-depleting source.
4) It is easily available all over the wind.

1.2 Disadvantages

Following are disadvantages of solar energy.

1) Collections and conversion of solar energy into useful forms must be carried out over a large area which requires a large capital investment for comversion.
2) Such power plants require direct light and are not operative when the sun is even partly covered with clouds.
3) Reflecting surface undergo deterioration with passage of time.
4) These power plants are uneconomical.

Transmission of electric power

The flow of electrical power from the generating station to the consumer is called an electrical power system or electrical supply system. It consists of the following important components :

1. Generation station
2. Transmission network
3. Distribution network

All these important networks are connected with the help of conductors and various step up and step down transformers. A typical transmission and distribution scheme is shown in the Fig. 1.

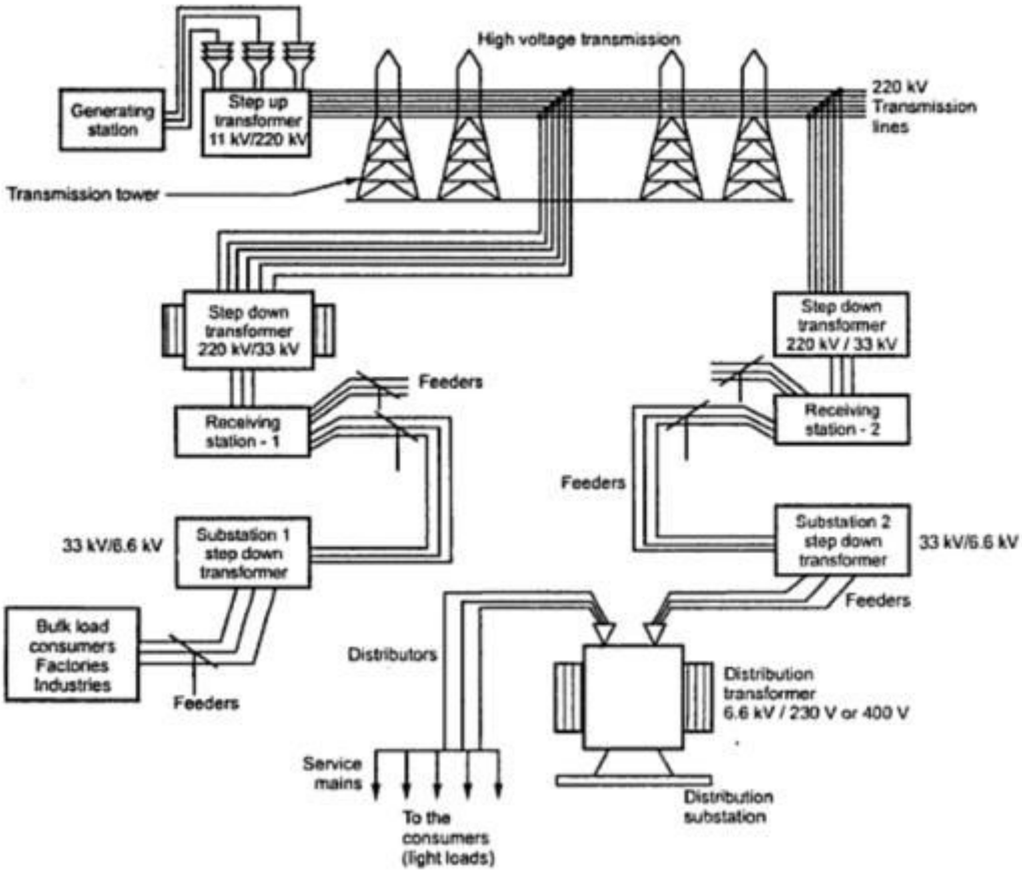


Fig. 1 Schematic representation of a typical transmission distribution scheme

A scheme shows a generating station which is located too far away from cities and towns. It is generating an electrical power at 11 KV. It is required to increase this level for the transmission purpose. Hence a step up transformer is used which steps up the voltage level to 220 KV. This level may be 132 KV, 220 KV or more as per the requirement.

Then with the help of transmission lines and the towers, the power is transmitted at very long distances. Design of the transmission lines is based on the factors like transmission voltage levels, constants like resistance, reactance of the lines, line performance, interference with the neighbouring circuits etc. Its mechanical features are strength of the supports, sag calculations, tension etc. Transmission of power by the overhead lines is very much cheaper. Similarly the repairs also can be carried out comparatively more easily. The transmission is generally along with additional lines in parallel. These lines are called duplicate lines. Thus two sets of three phase lines work in parallel. This ensures the continuity during maintenance and also can be used to satisfy future demand. The power is then transmitted to the receiving station via step down transformer. This transformer is 220/33 KV or 220/22 KV transformer.

The power is then transmitted to the substations. A substation consists of a step down transformer of rating 33 KV to 6.6. KV or 3.3 KV. The transfer of power from receiving station to the substation is with the help of conductors called feeders. This is called secondary transmission.

From the substations, power is distributed to the local distribution centres with the help of distributors. Sometimes for bulk loads like factories and industries, the distributors transfer power directly. For the light loads, there are distribution centres consisting of distribution transformers which step down the voltage level to 230 V or 400 V. This is called primary distribution. In the crowded area like cities, overhead system of bar conductor is not practicable. In such cases insulated conductors are used in the form of underground cables, to give supply to the consumers. These cables are called service mains. This is called secondary distribution.

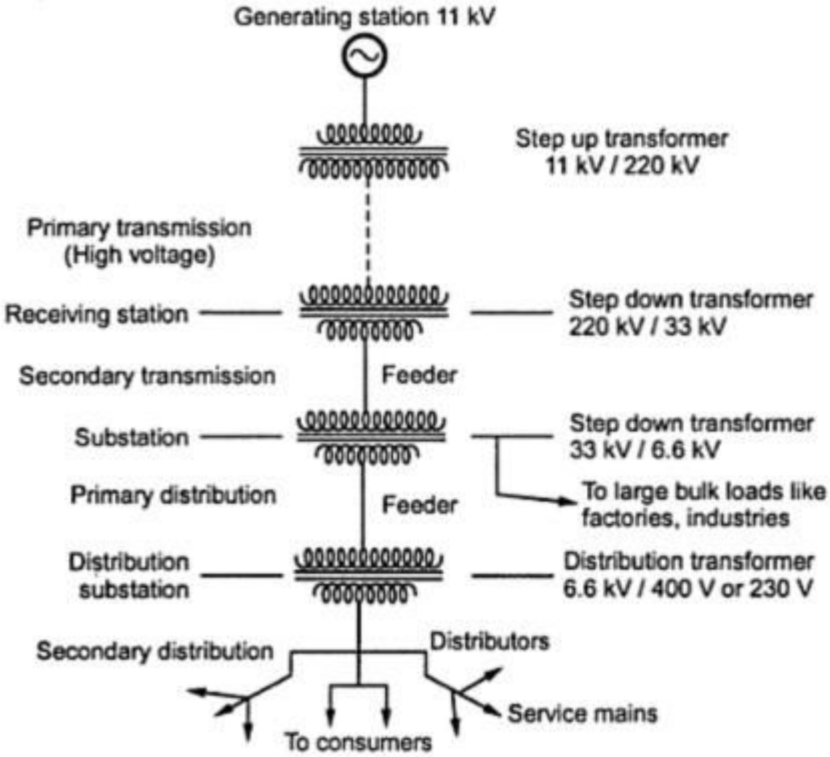


Fig. 2 Line diagram of a typical transmission distribution scheme

1. Primary transmission : It is basically with the help of overhead transmission lines. For the economic aspects, the voltage level is increased to 132 KV, 22 KV or more, with the help of step up transformer. Hence this transmission is also called high voltage transmission. The primary transmission. The primary transmission uses 3 phase 3 wire system.
2. Secondary transmission : The primary transmission line continues via transmission towers till the receiving stations. At the receiving stations, the voltage level is reduced to 22 KV or 33 KV using the step down transformer. There can be more than one receiving stations. Then at reduced voltage level of 22 KV or 33 KV, the power is then transmitted to various substations using overhead 3 phase 3 wire system. This is secondary transmission. The conductors used for the secondary transmission are called feeders.
3. Primary distribution : At the substation the voltage level is reduced to 6.6 KV, 3.3 KV or 11 KV with the help of step down transformers. It uses three phase three wire underground system. And the power is further transmitted to the local distribution. For the large consumers like factories and industries, the power is directly transmitted to such loads from a substation. Such big loads have their own substations.
4. Secondary distribution : At the local distribution centres, there are step down distribution transformers. The voltage level of 6.6 KV, 11 KV is further reduced to 400 V using distribution transformers. Sometimes it may be reduced to 230 V. The power is then transmitted using distributors and service mains to the consumers. This is secondary distribution, also called low voltage distribution. This uses 3 phase 3 wire system. The voltage between any two lines is 400 V while the voltage between any of the three lines and a neutral is 230 V. The single phase lighting loads are supplied using a line and neutral while loads like motors are supplied using three phase lines.

Kelvin's law for economical size of conductor.

The cost of conductor material is generally a very considerable part of the total cost of a transmission line. Therefore, the determination of proper Conductor Size 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 first 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.

(I) 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 he 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 Conductor Size. Therefore, annual charge on an overhead' transmission line can be expressed as :

$$\text{Annual charge} = P_1 + P_2 a \qquad \ldots(i)$$

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

(ii) Annual cast of energy wasted. This is on account of energy lost mainlyt 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 Size, 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 :

$$\text{Annual cost of energy wasted} = P_3/a \qquad \ldots(ii)$$

where P_3 is a constant.

$$\begin{aligned} \text{Total annual cost, } C &= \text{exp. } (i) + \text{exp. } (ii) \\ &= (P_1 + P_2 a) + P_3/a \\ C &= P_1 + P_2 a + P_3/a \qquad \ldots(iii) \end{aligned}$$

In exp. (iii), 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.

$$\begin{aligned} \frac{d}{da}(C) &= 0 \\ \text{or} \quad \frac{d}{da}(P_1 + P_2 a + P_3/a) &= 0 \\ \text{or} \quad P_2 - \frac{P_3}{a^2} &= 0 \\ \text{or} \quad P_2 &= P_3/a^2 \\ \text{or} \quad P_2 a &= \frac{P_3}{a} \end{aligned}$$

i.e.Variable part of animal charge = Annual cost of energy wasted

Therefore Kelvin's Law can also be stated in an 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

Graphical illustration of Kelvin's law. Kelvin's law can also be illustrated graphically by plotting annual cost against X-sectional area 'a'of the conductor as shown in Fig. 7.28. In the diagram, the straight line (1) shows the relation between the annual charge (i.e., $P_1 + P_2a$) and area of X-section a of the conductor. Similarly, the rectangular hyperbola (2) gives the relation between 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 ($P_1+P_2a+P_3/a$) 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.

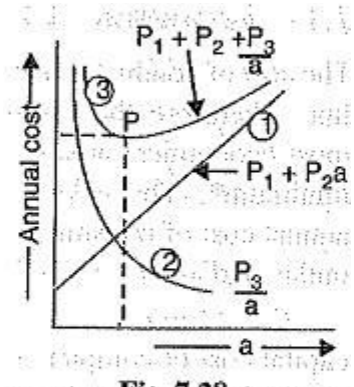


Fig. 7.28

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 surrounded 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

Factors Affecting Corona Effect in Power System

As mentioned earlier, the line voltage of the conductor is the main determining factor for corona in transmission lines, at low values of voltage (lesser than critical disruptive voltage) the stress on the air is too less to dissociate them, and hence no electrical discharge occurs. Since with increasing voltage corona effect in a transmission line occurs due to the ionization of atmospheric air surrounding the cables, it is mainly affected by the conditions of the cable as well as the physical state of the atmosphere. Let us look into these criterion now with greater details :

Atmospheric Conditions for Corona in Transmission Lines

It has been physically proven that the voltage gradient for di-electric breakdown of air is directly proportional to the density of air. Hence in a stormy day, due to continuous air flow the number of ions present surrounding the conductor is far more than normal, and hence its more likely to have electrical discharge in transmission lines on such a day, compared to a day with fairly clear weather. The system has to designed taking those extreme situations into consideration.

Condition of Cables for Corona in Transmission Line.

This particular phenomena depends highly on the conductors and its physical condition. It has an inverse proportionality relationship with the diameter of the conductors. i.e. with the increase in diameter, the effect of corona in power system reduces considerably.

Also the presence of dirt or roughness of the conductor reduces the critical breakdown voltage, making the conductors more prone to corona losses. Hence in most cities and industrial areas having high pollution, this factor is of reasonable importance to counter the ill effects it has on the system.

Spacing between Conductors

As already mentioned, for corona to occur effectively the spacing between the lines should be much higher compared to its diameter, but if the length is increased beyond a certain limit, the dielectric stress on the air reduces and consequently the effect of corona reduces as well. If the spacing is made too large then corona for that region of the transmission line might not occur at all.

Advantages and Disadvantages of Corona

Corona has many advantages and disadvantages. In the correct design of a high voltage overheadline, a balance should be struck between the advantages and disadvantages.

Below are the Advantages and disadvantages of Corona.

Advantages

∟ Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the conductor is increased. The increased diameter reduces the electrostatic stresses between the conductors.

∟ Corona reduces the effects of transients produced by surges.

Disadvantages

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

∟ Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.

∟ 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 neighboring Communication lines.

OVER HEAD LINES

Insulators

Electrical Insulator must be used in electrical system to prevent unwanted flow of current to the earth from its supporting points. The **insulator** plays a vital role in electrical system. **Electrical Insulator** is a very high resistive path through which practically no current can flow. In transmission and distribution system, the overhead conductors are generally supported by supporting towers or poles. The towers and poles both are properly grounded. So there must be **insulator** between tower or pole body and current carrying conductors to prevent the flow of current from conductor to earth through the grounded supporting towers or poles.

Insulating Material

The main cause of failure of overhead line insulator, is flash over, occurs in between line and earth during abnormal over voltage in the system. During this flash over, the huge heat produced by arcing, causes puncher in insulator body. Viewing this phenomenon the materials used for electrical insulator, has to posses some specific properties.

Properties of Insulating Material

The materials generally used for insulating purpose is called **insulating material**. For successful utilization, this material should have some specific properties as listed below-

1. It must be mechanically strong enough to carry tension and weight of conductors.
2. It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.
3. It must possesses high Insulation Resistance to prevent leakage current to the earth.
4. The **insulating material** must be free from unwanted impurities.
5. It should not be porous.
6. There must not be any entrance on the surface of electrical insulator so that the moisture or gases can enter in it.
7. There physical as well as electrical properties must be less affected by changing temperature.

There are mainly three **types of insulator** used as **overhead insulator** likewise

1. **Pin Insulator**
2. **Suspension Insulator**
3. **Strain Insulator**

In addition to that there are other two **types of electrical insulator** available mainly for low voltage application i.e. **Stray Insulator** and **Shackle Insulator**.

Pin Insulator

Pin Insulator is earliest developed **overhead insulator**, but still popularly used in power network up to 33KV system. Pin type insulator can be one part, two parts or three parts type, depending upon application voltage. In 11KV system we generally use one part type insulator where whole pin insulator is one piece of properly shaped porcelain or glass. As the leakage path of insulator is through its surface, it is desirable to increase the vertical length of the insulator surface area for lengthening leakage path. In order to obtain lengthy leakage path, one, tower or more rain sheds or petticoats are provided on the insulator body. In addition to that rain shed or petticoats on an insulator serve another purpose. These rain sheds or petticoats are so designed, that during raining the outer surface of the rain shed becomes wet but the inner surface remains dry and non-conductive. So there will be discontinuations of conducting path through the wet pin insulator surface.

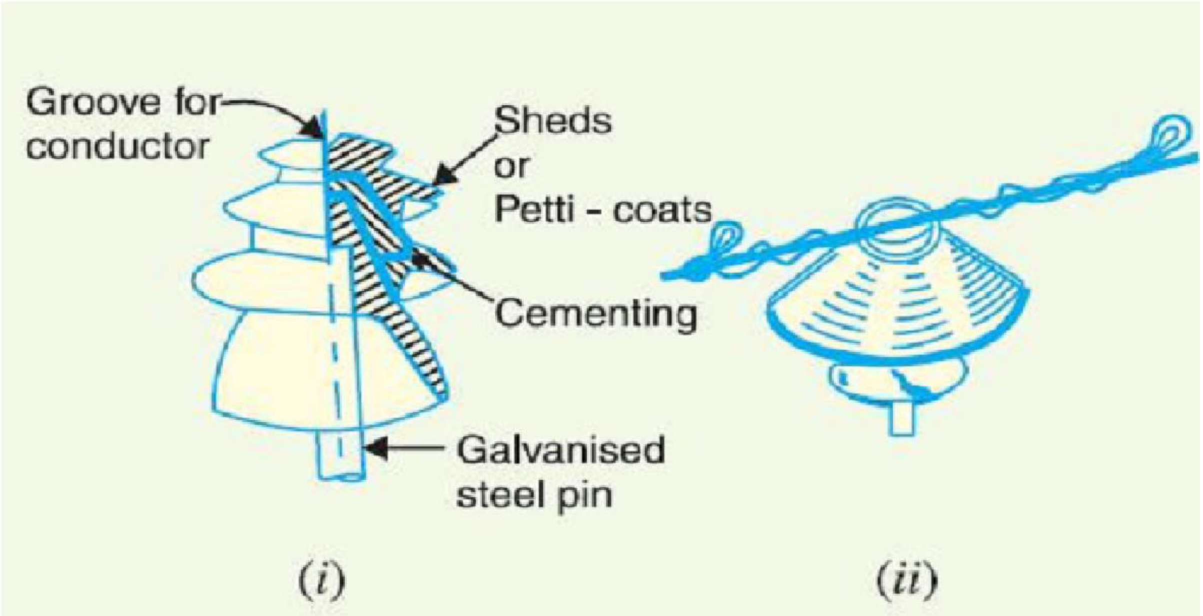


Fig 2.1- Pin Insulator

In higher **voltage** like 33KV and 66KV manufacturing of one part porcelain pin insulator becomes difficult. Because in higher voltage, the thickness of the insulator become more and a quite thick single piece porcelain insulator cannot manufactured practically. In this case we use multiple part pin insulator, where a number of properly designed porcelain shells are fixed together by Portland cement to form one complete insulator unit. For 33KV tow parts and for 66KV three parts pin insulator are generally used.

Designing Consideration of Electrical Insulator

The live conductor attached to the top of the pin insulator is at a potential and bottom of the insulator fixed to supporting structure of earth potential. The insulator has to withstand the potential stresses between conductor and earth. The shortest distance between conductor and earth, surrounding the insulator body, along which electrical discharge may take place through air, is known as flash over distance.

Suspension Insulator

In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of the insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming these difficulties, **suspension insulator** was developed.
In **suspension insulator** numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their disc like shape.

Advantages of Suspension Insulator

(i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.
(ii) Each unit or disc of suspension type insulator is designed for low voltage,usually 11 kV. Depending upon the working voltage, the desired number of discs 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

Strain Insulator

When suspension string is used to sustain extraordinary tensile load of conductor it is referred as **string insulator**. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A **strain insulator** must have considerable mechanical strength as well as the necessary electrical insulating properties

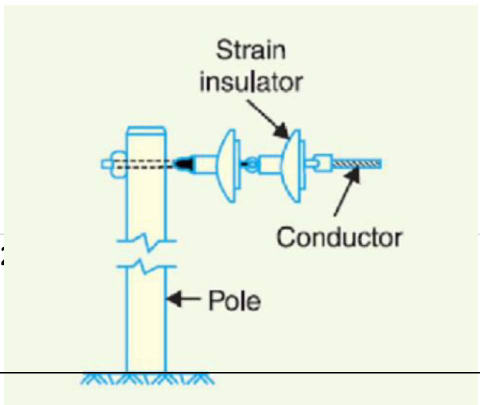


Fig 2.2- Strain Insulator

Shackle Insulator

The **shackle insulator** is usually used in low voltage distribution network. It can be used both in horizontal and vertical position. The use of such insulator has decreased recently after increasing the using of underground cable for distribution purpose.

Conductor Material

The most common conductor in use for transmission today is aluminum conductor steel reinforced (ACSR). Also seeing much use is all-aluminum-alloy conductor (AAAC). Aluminum is used because it has about half the weight of a comparable resistance copper cable (though larger diameter due to lower fundamental conductivity), as well as being cheaper. Copper was more popular in the past and is still in use, especially at lower voltages and for grounding. Bare copper conductors are light green.

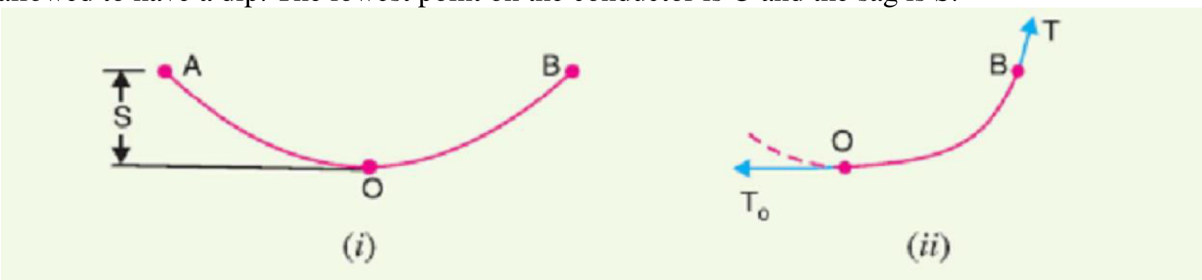
While larger conductors may lose less energy due to lower electrical resistance, they are more costly than smaller conductors. An optimization rule called *Kelvin's Law* states that the optimum size of conductor for a line is found when the cost of the energy wasted in the conductor is equal to the annual interest paid on that portion of the line construction cost due to the size of the conductors. The optimization problem is made more complex by additional factors such as varying annual load, varying cost of installation, and the discrete sizes of cable that are commonly made. **BUNDLE CONDUCTORS**

For higher amounts of current, **bundle conductors** are used for several reasons. Due to the skin effect, for larger conductors, the current capacity does not increase proportional to the crosssectional area; instead, it is only with the linear dimension. Also, reactance decreases only slowly with size. But the cost and weight do increase with area. Due to this, several conductors in parallel become more economical.

Bundle conductors consist of several parallel cables connected at intervals by spacers, often in a cylindrical configuration. The optimum number of conductors depends on the current rating, but typically higher-voltage lines also have higher current. There is also some advantage due to lower corona loss. American Electric Power is building 765 kV lines using six conductors per phase in a bundle. Spacers must resist the forces due to wind, and magnetic forces during a shortcircuit.

Sag in Overhead Transmission Line:

While erecting an overhead line, it is very important that conductors are under safe tension. 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 tension 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. Following Fig. 8.1 shows a conductor suspended between two equal level 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.



The following points may be noted:

(i) When the conductor is suspended between two supports at the same level, it takes the shape of catenary. However, if the sag is very small compared with the span, then sag-span curve is like a parabola.

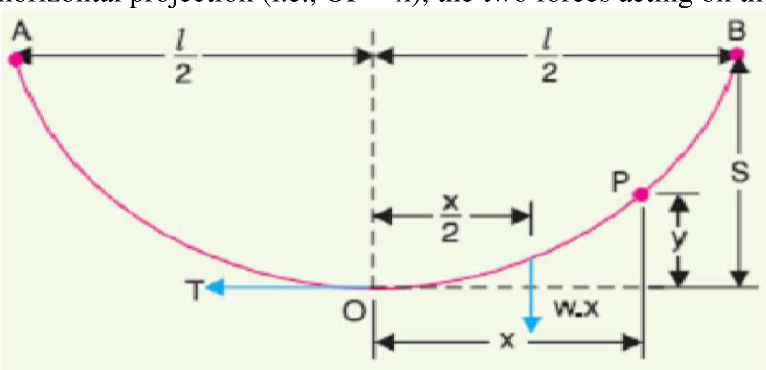
(ii) The tension at any point on the conductor acts tangentially. Thus tension T_0 at the lowest Point O acts horizontally as shown in Fig. (ii).

(iii) The horizontal component of tension is constant throughout the length of the wire.
(iv) The tension at supports is approximately equal to the horizontal tension acting at any point on the wire. Thus if T is the tension at the support B, then $T = T_0$.

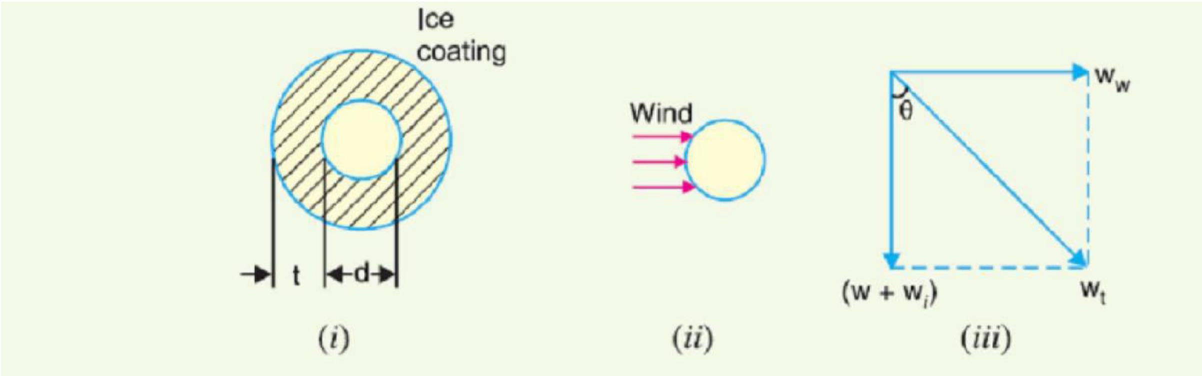
Conductor sag and tension. This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level. It is also desirable that tension in the conductor should be low to avoid the mechanical failure of conductor and to permit the use of less strong supports. However, low conductor tension

and minimum 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 in made between the two.

Calculation of Sag: In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, effects of wind, ice loading and temperature variations. It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength i.e., minimum factor of safety in respect of conductor tension should be 2. We shall now calculate sag and tension of a conductor when (i) supports are at equal levels and (ii) supports are at unequal levels. **When supports are at equal levels.** Consider a conductor between two equilevel supports A
and B with O as the lowest point as shown in Fig.2.5. It can be proved that lowest point will be at a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig. 2.5. It can be proved that lowest point will be at the mid-span.
conductor between two equilevel supports A and B with O as the lowest point as shown in Fig. 2. It can be proved that lowest point will be at the mid-span.
Let l = Length of span
w = Weight per unit length of conductor
T = Tension in the conductor.
Consider a point P on the conductor. Taking the lowest point O as the origin, let the co-ordinates of point P be x and y. Assuming that the curvature is so small that curved length is equal to its horizontal projection (i.e., OP = x), the two forces acting on the portion OP



Effect of wind and ice loading- The above formulae 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 as shown in



Q2) A transmission line has 150m betn level supports the Conductor has a Crossection area of $2cm^2$ the tension in the Conductor is 2000 kg The specific gravity of the Conductor is 9.9 g/cm³ & wind pressure is 1.5 kg/m Calculate the sag.

<u>Given</u>

$L = 150m$

$T = 2000\ kg$

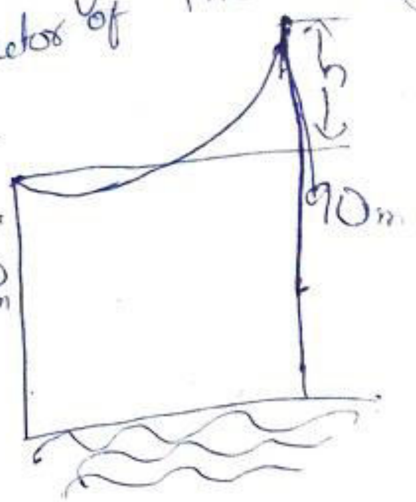
$S.G = 9.9 g/cm^2$

wind pressure = 1.5 kg/m

$W = S.P \times$ volum of Conducor

$= 9.9 \times 100 \times 2 = 1980\ gm = 1.98\ kg$

Q) ~~A span~~ The towers of height 30m & 90m suppt in a river Crossing. The horizontal distance is 500 m. If the tension is ~~10kg~~ 1600 kg the calcula minimum Clearance of the conductor of the level. weigh of Conductor is 1.5 kg/m



<u>Given</u>

$L = 500\,m$

$h = 90 - 30 = 60$

$T = 1600\,kg$

$\omega = 1.5\,kg/m$

$$x_1 = \frac{L}{2} - \frac{Th}{\omega L}$$

$$= \frac{500}{2} - \frac{1600 \times 60}{1.5 \times 500} = 122$$

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

$$= \frac{1.5 \times (122)^2}{2 \times 1600} = 6.97\,m$$

$30 - 6.97 = 23.03\,m$

Q1) 132 kV transmission line has following data length of span 260 m, weight of Conductor 680 kg/km of safty factor = 2 ultimate strength = 3100 kg. Calculate the height of above the ground at which the Conductor should be supported. Ground Clearance is 10m.

Given

Length of span = 260m

weight of Conductor = 680 kg/km = $\frac{680}{1000} = 0.680$

Safty factor = 2

ultimate strength = 3100kg

Ground Clearance = 10m

$$S = \frac{Wl^2}{8T}$$

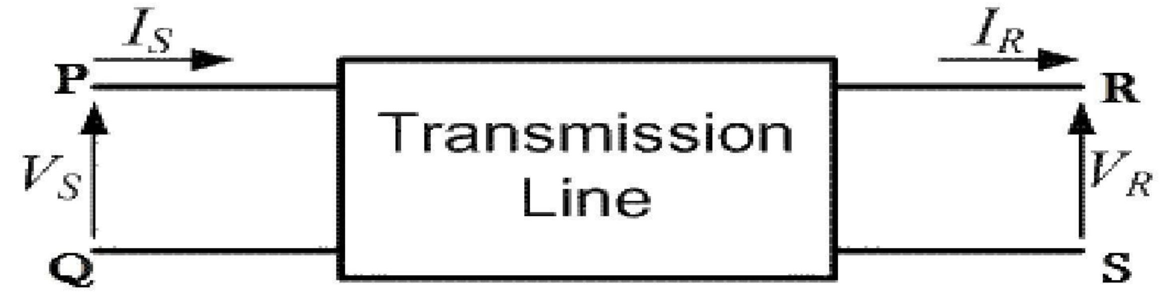
$$T = \frac{U.S}{S.F} = \frac{3100}{2} = 1550\,kg$$

$$S = \frac{680 \times 260}{8 \times 1550} = 3.7\,m$$

= Sag + ground = 10 + 3.7 = 13 m

PERFORMANCE OF SHORT & MEDIUM LINES

Classification of Overhead Transmission Lines



A transmission line has *three constants *R*, *L* and *C* distributed uniformly along the whole length of the line. The resistance and inductance form the series impedance. The capacitance existing between 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 :

(***i***) *Short transmission lines.* When the length of an overhead transmission line is upto 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. Therefore, while studying the performance of a short transmission line, only resistance and inductance of the line are taken into account.
(***ii***) *Medium transmission lines.* When the length of an overhead transmission line is about 50-150 km and the line voltage is moderatly 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. For purposes of calculations, the distributed capacitance of the line is divided and lumped in the form of condensers shunted across the line at one or more points.
(***iii***) *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. For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line and rigorous methods are employed for solution.

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 (*VR*) of the line is generally less than the sending end voltage (*VS*). This voltage drop (*VS* −*VR*) in the line is expressed as a percentage of receiving end voltage *VR* 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.

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*

Short Transmission Line

The transmission lines which have length less than 80 km are generally referred as **short transmission lines**.

For short length, the shunt capacitance of this type of line is neglected and other parameters like electrical resistance and inductor of these short lines are lumped, hence the equivalent circuit is represented as given below, Let's draw the vector diagram for this equivalent circuit, taking receiving end current Ir as reference. The sending end and receiving end voltages make angle with that reference receiving end current, of φs and φr, respectively.

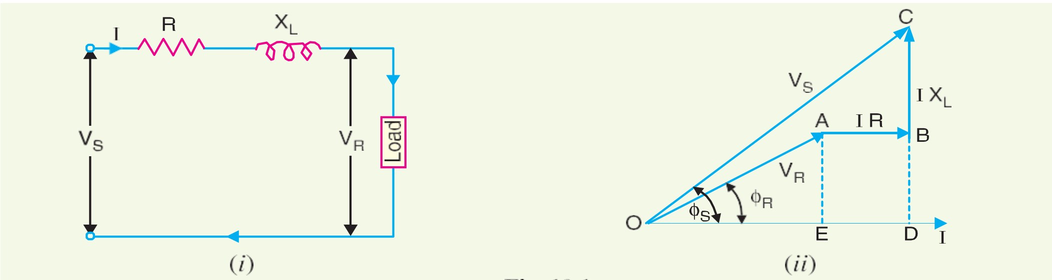


Fig. 10.1

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

Solution in complex notation. It is often convenient and profitable to make the line calculations in complex notation.

Taking *VR* as the reference phasor, draw the phasor diagram as It is clear that *VS* is the phasor sum of *VR* and *I Z*

$VR = VR + j\,0$

$I = I(\cos \phi_R - j\sin \phi_R)$

$Z = R + jXL$

$VS = VR\ I\ Z$

Example . *A single phase overhead transmission line delivers 1100 kW at 33 kV at 0·8 p.f. lagging. The total resistance and inductive reactance of the line are 10 Ω and 15 Ω respectively. Determine :* (*i*) *sending end voltage* (*ii*) *sending end power factor and* (*iii*) *transmission efficiency.*

(i) Soln

Load power factor, $\cos\phi_R = 0.8$ lagging

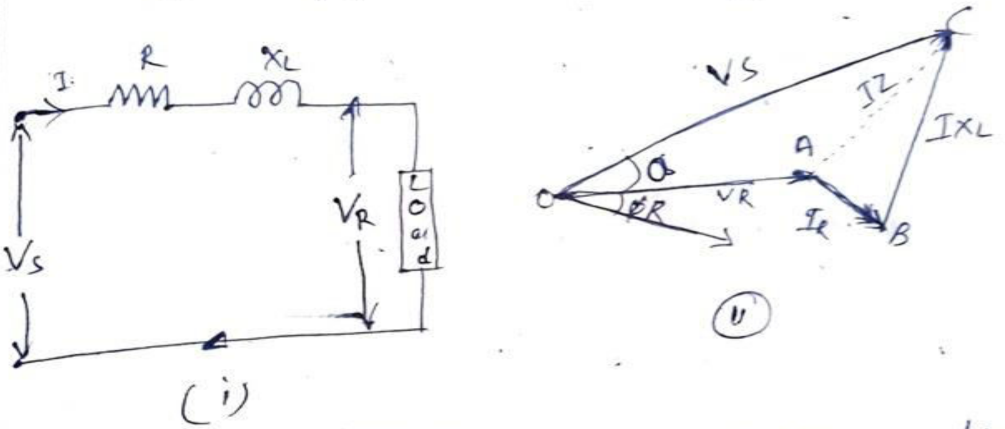
Total line impedance, $\vec{Z} = R + jX_L = 10 + j15$

Receiving end voltage, $V_R = 33kV = 33,000V$

$\therefore$ Line current, $I = \dfrac{kW \times 10^3}{V_R \cos\phi_R} = \dfrac{1100 \times 10^3}{33,000 \times 0.8}$

$= 41.67$ A

As $\cos\phi_R = 0.8$ $\therefore$ $\sin\phi_R = 0.6$



The equivalent circuit and phasor diagram of the line are shown in fig (i) and (ii) respectively. Taking receiving end voltage $\vec{V_R}$ as the reference phasor.

$\vec{V_R} = V_R + j0 = 33000V$

$\vec{I} = I(\cos\phi_R - j\sin\phi_R)$

$= 41.67(0.8 - j0.6) = 33.33 - j25$

(i) Sending end voltage, $\vec{V_S} = \vec{V_R} + \vec{I}\vec{Z}$

$$= 33000 + (33.33 - j25.0)(10 + j15)$$

$$= (33,708.3 + j250)$$

Magnitude of $|\vec{V_S}| = \sqrt{(33708.3)^2 + 250^2}$

$$= 33709 \text{ V}$$

(ii) Angle bet^n $\vec{V_S}$ and $\vec{V_R}$ is

$$\alpha = \tan^{-1}\left(\frac{250}{33708.3}\right) = 0.42^\circ$$

$$\phi_S = \phi_R + \alpha = 36.87 + 0.42 = 37.29^\circ.$$

Sending end power factor= cos φ_s=cos(37.29)=0.7956 lagging.
(iii) Line losses I^2R= $41.67^2 \times 10$=17364 W= 17.364 KW.
Output delivered = 11000kw
Power sent=1100+17.364=1117.364kw
Transmission efficiency = $\frac{\textit{Power delivered}}{\textit{Power sent}} \times 100 = \frac{11000}{1117.364} \times 100$=98.44%

Example . *An overhead 3-phase transmission line delivers 5000 kW at 22 kV at 0·8 p.f. lagging. The resistance and reactance of each conductor is 4 ∧ and 6 ∧ respectively. Determine :* (*i*) *sending end voltage* (*ii*) *percentage regulation* (*iii*) *transmission efficiency.*

Sol^n

Load power factor, $\cos\phi_R = 0.8$ lagging

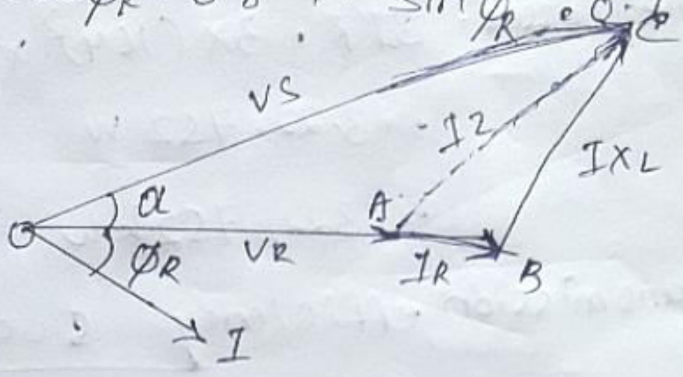
Receiving end voltage / phase, $V_R = 22{,}000/\sqrt{3}$

$= 12{,}700\ V$

Impedance / phase $\vec{Z} = 4 + j6$.

Line current, $I = \dfrac{5000 \times 10^3}{3 \times 12700 \times 0.8} = 164\ A$

As $\cos\phi_R = 0.8 \quad \therefore \sin\phi_R = 0.6$



Taking $\vec{V_R}$ as the reference phasor

$$\vec{V_R} = V_R + j0 = 12700\ V$$

$$\vec{I} = I(\cos\phi_R - j\sin\phi_R) = \cancel{164}$$

$$164(0.8 - j0.6) = 131.2 - j98.4$$

(i) Sending end voltage per phase is

$$\vec{V_S} = \vec{V_R} + \vec{I}\vec{Z} = 12700 + (131.2\ j98.4)(4+j6)$$

$$= 12700 + 524.8 + j787.2 - j393.6 + 590.4$$

$$= 13815.2 + j393.6$$

Magnitude of $V_S = \sqrt{(13815.2)^2 + (393.6)^2} = 13820.8\ V$

Line value of $V_S = \sqrt{3} \times 13820.8 = 23938\ V$

$= 23.938\ kV$

(ii) $\%age\ Regulation = \frac{V_S - V_R}{V_R} \times 100$

$= \frac{13820.8 - 12700}{12700} \times 100 = 8.825\%$

(iii) $Line\ losses = 3I^2R = 3 \times 164^2 \times 4 = 322752\ W$

$= 322.752\ kW$

$Transmission\ efficiency = \frac{5000}{5000 + 322.752} \times 100$

$= 93.94\%$

Medium Transmission Lines

In short transmission line calculations, the effects of the line capacitance are neglected because such lines have smaller lengths and transmit power at relatively low voltages (< 20 kV). However, as the length and voltage of the line increase, the capacitance gradually becomes of greater importance. Since medium transmission lines have sufficient length (50-150 km) and usually operate at voltages greater than 20 kV, the effects of capacitance cannot be neglected. Therefore, in order to obtain reasonable accuracy in medium transmission line calculations, the line capacitance must be taken into consideration.

The most commonly used methods (known as *localised capacitance methods*) for the solution of medium transmissions lines are :

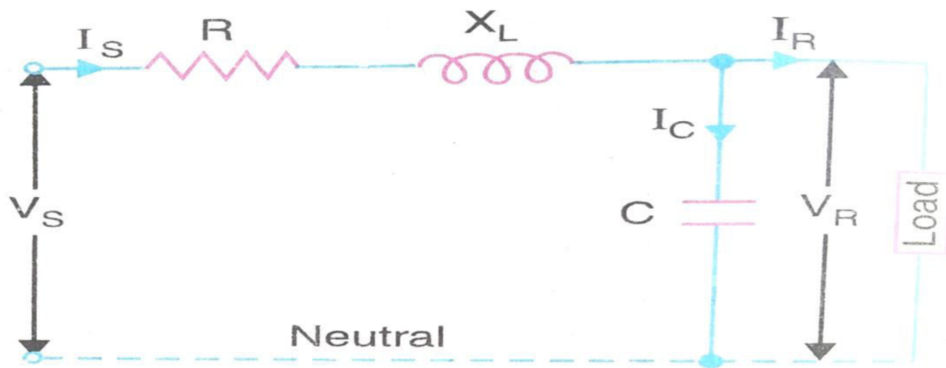
(i) End condenser method
(ii) Nominal *T* method
(iii) Nominal π method.

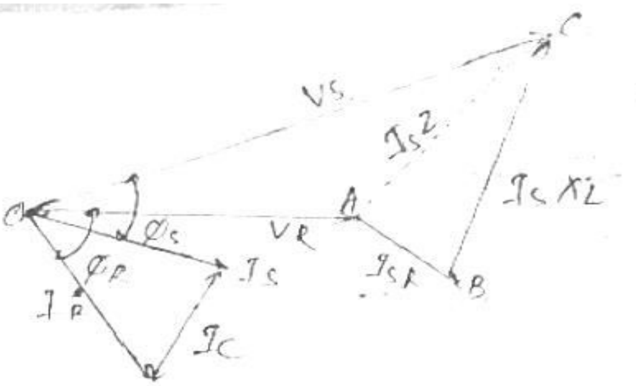
End Condenser Method

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. In Fig. 10.8, one phase of the 3-phase transmission line is shown as it is 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 φ_R= receiving end power factor (*lagging*)





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 phasor 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.

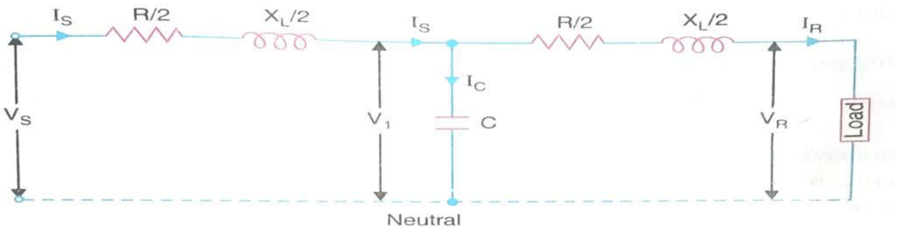
$$\%\ \text{voltage regulation} = \frac{V_S - V_R}{V_R} \times 100$$

% voltage transmission efficiency =

$$\frac{\text{power delivered / phase}}{\text{power delivered / phase + losses / phase}} \times 100$$

Nominal T Method

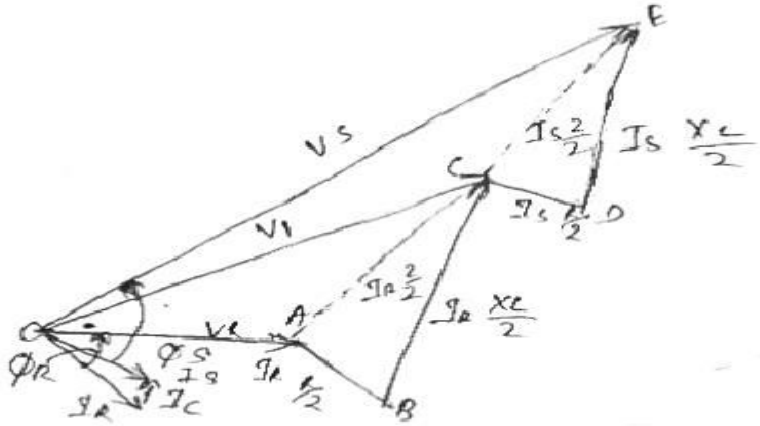
In this method, the whole line capacitance is assumed to be concentrated at the middle point of the line and half the line resistance and reactance are lumped on its either side as shown in Fig. 10.11. Therefore, in this arrangement, full charging current flows over half the line. In Fig., one phase 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
X_L = inductive reactance per phase ;
C = capacitance per phase
Cos φ_R= receiving end power factor (*lagging*) ;
V_S = sending end voltage/phase
V_1 = voltage across capacitor C

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 $\vec{V_1} = \vec{V_R} + \vec{I_R}\vec{Z}/2$

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

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

Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C}$

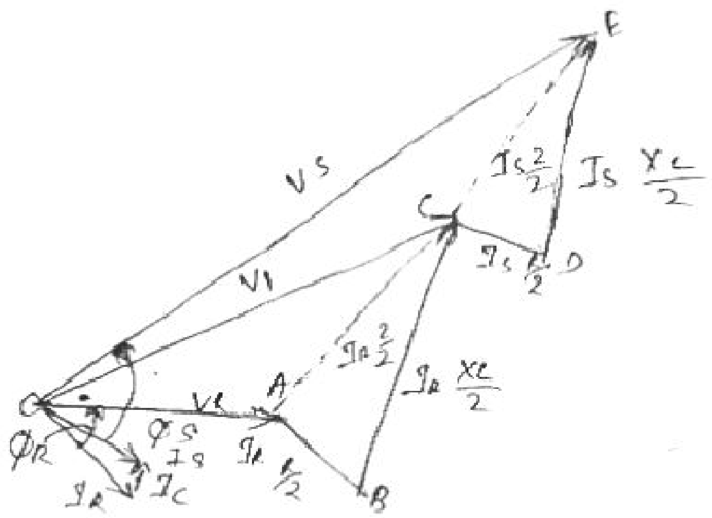
Sending end voltage- $\vec{V_S} = \vec{V_1} + \vec{I_S}\frac{\vec{Z}}{2}$

$= \vec{V_1} + \vec{I_S}(\frac{R}{2} + j\frac{X_L}{2})$

For pi model the phasor diagram

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 $\vec{I_C} = j\omega C\vec{V_1} = j2\pi f C\vec{V_1}$

Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C}$

Sending end voltage $\vec{V_S} = \vec{V_1} + \vec{I_S}\frac{\vec{Z}}{2}$

$$= \vec{V_1} + \vec{I_S}\left(\frac{R}{2} + j\frac{X_L}{2}\right)$$

$\vec{V_R} = V_R + j0$

Load current $\vec{I_L} = \vec{I_R} + \vec{I_{C1}}$

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

$$\vec{I_{C2}} = j\omega(C/2)\vec{V_S} = j\pi f C\vec{V_S}$$

$\therefore$ Sending end current, $\vec{I_S} = \vec{I_L} + \vec{I_{C2}}$

Example *A 3-phase, 50Hz, 150 km line has a resistance, inductive reactance and capacitive shunt admittance of 0·1 Ω, 0·5 Ω and 3×10*$^{-6}$ *S per km per phase. If the line delivers 50 MW at 110 kV and 0·8 p.f. lagging, determine the sending end voltage and current. Assume a nominal π circuit for the line.*

Solution

Total resistance / Phase, $R = 0.1 \times 150 = 15\,\Omega$

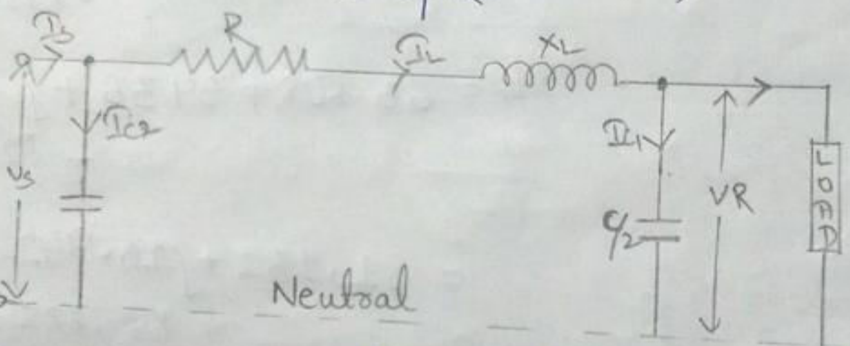
Total reactance / Phase, $X_L = 0.5 \times 150 = 75\,\Omega$

Capacitive admittance / phase, $Y = 3 \times 10^{-6} \times 150 = 45 \times 10^{-5}\,S$

Receving end voltage / Phase, $V_R = 110 \times 10^3 / \sqrt{3} = 63.508\,V$

Load Current $I_R = \dfrac{50 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.8} = 328\,A$

$\cos\phi_R = 0.8$; $\sin\phi_R = 0.6$



Taking receving end voltage as the reference phasor, we have,

$\Rightarrow \vec{V_R} = V_R + j0 = 63.508V$

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

$= 328(0.8 - j0.6)$

Load current, $= 262.4 - j196.8$

Charging Current at the load end is

$$I_{C1} = \vec{V_R}\, j\frac{Y}{2} = 63{,}508 \times j\frac{45\times10^{-5}}{2}$$

$$= j14.3$$

Line current, $\vec{I_L} = \vec{I_R} + I_{C1} = (262.4 - j196.8) + j14.3 = 262.4 - j182.5$

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

$$= 63{,}508 + (262.4 - j182.5)(15 + j75)$$

$$= 63.508 + 3936 + j19{,}680 - j2737.5 + 13{,}687$$

$$= 81{,}131 + j16.94205$$

$$= 82{,}881 \angle 11^\circ 47' V$$

$\therefore$ Line to line sending end voltage

$$= 82{,}881 \times \sqrt{3} = 1{,}43{,}550V$$

$$= 143.55kV$$

Charging the current at the sending end is;

$$I_{C2} = j\vec{V_s}\,Y/2 = (81{,}131 + j16{,}942.5)\, j\frac{45\times10^{-5}}{2}$$

$$= -3.81 + j18.25$$

Sending end current, $\vec{I_s} = I_L + I_{C2} = (262.4 - j182.5) + (-3.81 + j18.25)$

$$= 258.6 - j164.25$$

$$= 306.4 \angle -32.4^\circ A$$

$\therefore$ Sending current

$$= 306.4A.$$

EHV TRANSMISSION

EHV AC TRANSMISSION

Industrial-minded countries of the world require a vast amount of energy of which electrical energy forms a major fraction. There are other types of energy such as oil for transportation and industry, natural gas for domestic and industrial consumption, which form a considerable proportion of the total energy consumption. Thus, electrical energy does not represent the only form in which energy is consumed but an important part nevertheless. It is only 150 years since the invention of the dynamo by Faraday and 120 years since the installation of the first central station by Edison using dc. But the world has already consumed major portion of its natural resources in this short period and is looking for sources of energy other than hydro and thermal to cater for the rapid rate of consumption which is outpacing the discovery of new resources

ADVANTAGES

1. Reduction in the current.
2. Reduction in the losses.
3. Reduction in volume of conductor material required.
4. Decrease in voltage drop & improvement of voltage regulation.
5. Increase in Transmission Efficiency.
6. Increased power handling capacity.
7. The no. of circuits & the land requirement reduces as transmission voltage increases.
8. The total line cost per MW per km decreases considerably with the increase in line voltage

Problems involved in EHV transmission

Power-frequency voltage is impressed on a system continuously as compared to transients caused by faults, lightning, and switching operations. Certain abnormal conditions arise when over voltages of a sustained nature can exist in systems which have to be guarded against. Insulation levels will be governed by these, and it is very important to know all the factors which contribute to such over voltages. E.H.V. lines are longer than and their surge impedance lower than lines at 345 kV and lower voltages. Also, e.h.v. lines are used more for point-to point transmission so that when load is dropped, a large portion of the system is unloaded and voltage rise could be more severe than when there is a vast interconnected network. Due also to the high capacitance of e.h.v. lines possibility of self-excitation of generators is quite serious.
Shunt reactors are employed to compensate the high charging current, which not only prevent over voltages during load dropping but also improve conditions for load flow, and the risk of self excitation can also be counteracted. In order to improve conditions, variable static VAR systems can also be employed as well as switched capacitors which introduce harmonics into the system.

HVDC

The massive transmission of electricity in the form of DC over long distances by means of submarine cables or overhead transmission line is the high voltage direct current transmission. This type of transmission is preferred over HVAC transmission for very long distance when considering the cost, losses and many other factors. The names Electrical superhighway or Power superhighway are often used for **HVDC**.

Advantages of the HVDC transmission system

1) ***Economical transmission of the bulk power***

In a conventional transmission line, the distance cannot be more than the breakeven distance. But in the HVDC transmission line, the distance can be more than the breakeven distance.

2) ***Decrease in the number of conductors***

In the HVAC system, the power transmitted in the form of three-phase AC power. Therefore, three or four conductors need as per the type of transmission line. But in the case of HVDC transmission lines, only two conductors required. Hence, the cost of the conductor decreased.

3) ***Corona***

Corona effect appears in both HVAC and HVDC systems. But, in an HVDC system, the effect of the corona is very less compared to the HVAC system. And there is no disturbance to the nearby communication line.

4) ***Size of tower***

In the HVDC transmission line, phase-phase and phase-ground clearance required is less compared to the HVAC line. Therefore, the height and width of the tower required is less.

The number of conductors required in this system is less. So, the size of the tower is less which results in less cost of the tower.

5) Earth return

For the monopolar HVDC transmission system, earth return can be used. That means, only one conductor required to transmit the power. This is not possible in the HVAC transmission line.

6) Charging current

In the DC transmission line, the capacitance is not produced between two phases or between the phase and ground. Therefore, the charging current is absent in the HVDC system.

7) Skin effect

The current density is uniform throughout the line. Hence, there is no skin effect in the HVDC system.

And it utilizes an entire cross-section area of the conductor. So, the resistance of the line is not increasing and the power loss is less.

8) Reduction in line loss

The line loss reduced due to the absence of the reactive power in the HVDC transmission line. This increases the efficiency of the system.

9) Reduction in size of the conductor

When equal power transmitted for the same distance, less volume of conductor required for the HVDC two-wire system compared to the HVAC three-phase three-wire system.

Disadvantages/Limitations

1) Cost of terminal equipment

In the HVDC transmission line, the **rectifier** used at the sending end and the inverter used at the receiving end. The smoothing filters need at receiving end. The cost of this equipment is very high.

2) DC circuit breaker

The DC circuit breaker is still under development and the cost is high compared to the AC circuit breaker.

3) Additional equipment

This system needs some additional equipment like converter transformer, electrical and mechanical auxiliaries, pole control, valve control, and many more. All this equipment is of high technology and the cost of this equipment is high.

4) Complicated control

The converter used to control the transmission line. But it is difficult to control the converter under certain abnormal conditions.

5) Change the voltage level

In the AC system, with the help of a transformer, the voltage can be easily stepped up and stepped down. Therefore, this system cannot use for low voltage transmission.

6) System failure

There is some abnormal operating condition in which the system may fail to operate.

7) Harmonic filter

In the input side, the AC supply is given to the rectifiers. To mitigate these harmonics, a large amount of filter required. And the cost of this equipment is high.

Distribution System

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

(*i*) *Feeders.* A feeder is a conductor which connects 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. 12.1, *AB*, *BC*, *CD* and *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.

Connection Schemes of Distribution System

(*i*) Radial System. In this system, separate feeders radiate from a single substation and feed the distributors at one end only. Fig. 12.8 (*i*) 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 this case. Fig. (*ii*) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.

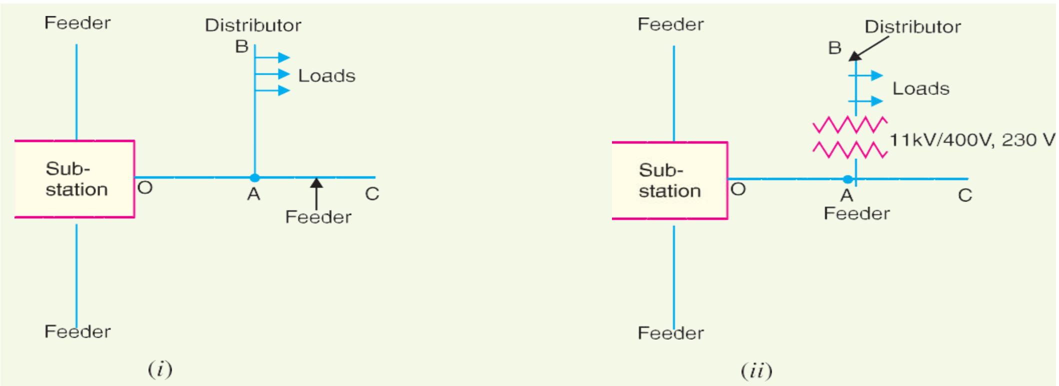


Fig. 12.8

Ring main system.

In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Fig. 12.9 shows the single line diagram of ring main
system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points *M*, *O* and *Q* of the feeder through distribution transformers

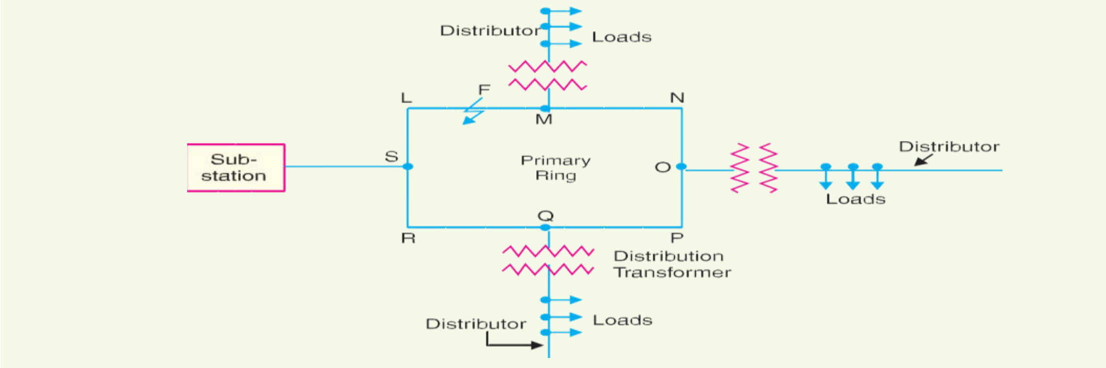


Fig. 12.9

Interconnected system.

When the feeder ring is energised by two or more than two generating stations or substations, it is called inter-connected system. Fig. 12.10 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

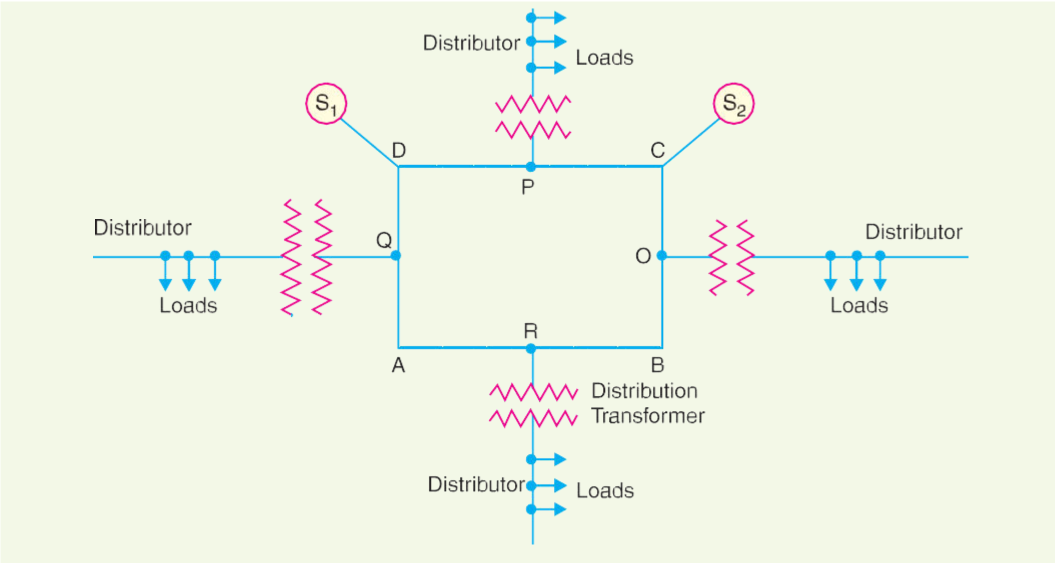


Fig. 12.10

D.C. Distribution

Types of D.C. Distributors

The most general method of classifying d.c. 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

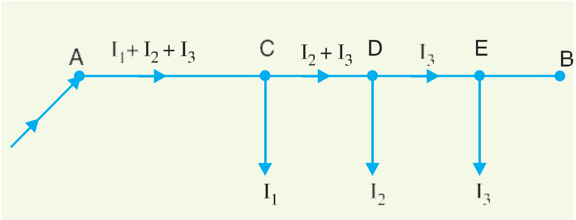


Fig. 13.1

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. 13.1 shows the single line diagram of a d.c. distributor *AB* fed at the end *A* (also known as *singly distributor*) and loads *I*1, *I*2 and *I*3 tapped off at points *C*, *D* and *E* respectively

Distributor fed at both ends.

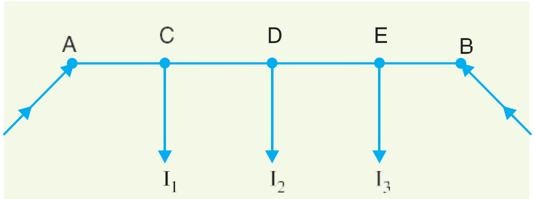


Fig. 13.2

In this type of feeding, the distributor is connected to the supply mains at both ends and loads are tapped off at different points along the length of the distributor. The voltage at the feeding points may or may not be equal. Fig. 13.2 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. Here, the load voltage goes on decreasing as we move away from one feeding point *say A*, reaches minimum value and then again starts rising and reaches maximum value when we reach the other feeding point *B*. The minimum voltage occurs at some load point and is never fixed. It is shifted with the variation of load on different sections of the distributor

Distributor fed at the centre. In this type of feeding, the centre of the distributor is connected to the supply mains as shown in Fig. 13.3. It is equivalent to two singly fed distributors, each distributor having a common feeding point and length equal to half of the total length.

Ring mains. In this type, the distributor is in the form of a closed ring as shown in Fig.13.4. It is equivalent to a 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

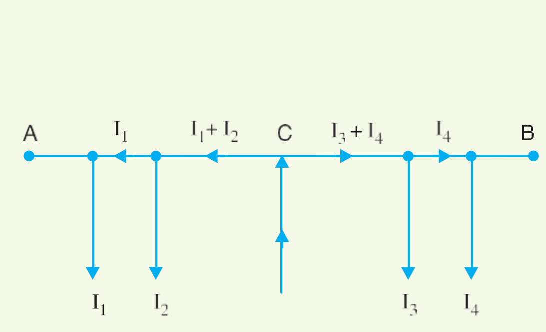


Fig. 13.3

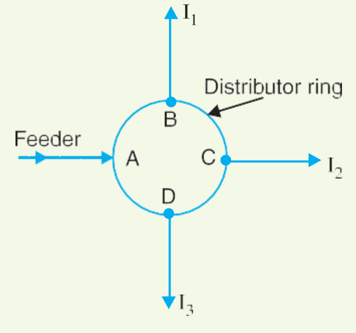


Fig. 13.4

Example *A 2-wire d.c. distributor cable AB is 2 km long and supplies loads of 100A, 150A,200A and 50A situated 500 m, 1000 m, 1600 m and 2000 m from the feeding point A. Each conductor has a resistance of 0·01 Ω per 1000 m. Calculate the p.d. at each load point if a p.d. of 300 V is maintained at point A.*

Resistance per 1000m of distributor $= 2 \times 0.01 = 0.02\ \Omega$

Resistance of section AC, $R_{AC} = 0.02 \times 500/1000 = 0.01\ \Omega$

Resistance of section CD, $R_{CD} = 0.02 \times 500/1000 = 0.01\ \Omega$

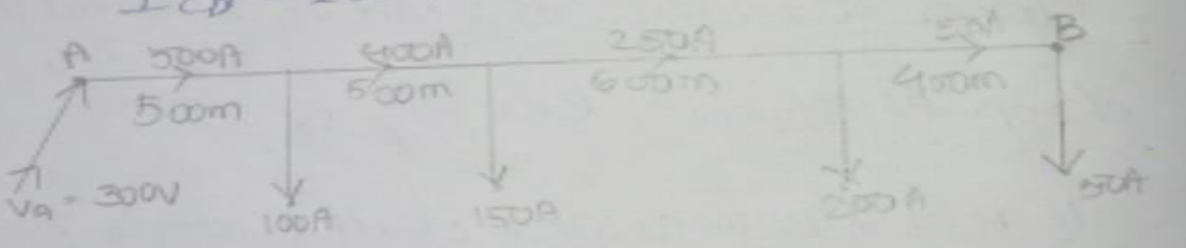
Resistance of section DE, $R_{DE} = 0.02 \times 600/1000 = 0.012\ \Omega$

Resistance of section EB, $R_{EB} = 0.02 \times 400/1000 = 0.008\ \Omega$

Referring to fig A, the currents in the various sections of the distributor are:

$I_{EB} = 50A$; $I_{DE} = 50 + 200 = 250A$

$I_{CD} = 250 + 150 = 400A$; $I_{AC} = 400 + 100 = 500A$



P.D at load point C, V_C = Voltage at A − Vol drop in AC.

$= V_A - I_C R_{AC}$; $300 - 500 \times 0.01 = 295V$

PD at load point E ; $V_D = V_C - I_D R_{CD}$

$= 295 - 400 \times 0.01 = 291V$

PD at load point E, $V_E = V_D - I_{DE} R_{DE}$

$= 291 - 250 \times 0.012 = 288\ V$

PD at load point B, $V_B = V_E - I_{EB} R_{EB}$

$= 288 - 50 \times 0.08 = 287.6\ V$

A.C. Distribution Calculations

A.C. distribution calculations differ from those of d.c. distribution in the following respects :

(*i*) In case of d.c. system, the voltage drop is due to resistance alone. However, in a.c. system, the voltage drops are due to the combined effects of resistance, inductance and capacitance.

(*ii*) In a d.c. system, additions and subtractions of currents or voltages are done arithmetically but in case of a.c. system, these operations are done vectorially.

(*iii*) In an a.c. system, power factor (p.f.) has to be taken into account. Loads tapped off form the distributor are generally at different power factors. There are two ways of referring power factor *viz*

(*a*) It may be referred to supply or receiving end voltage which is regarded as the reference vector.

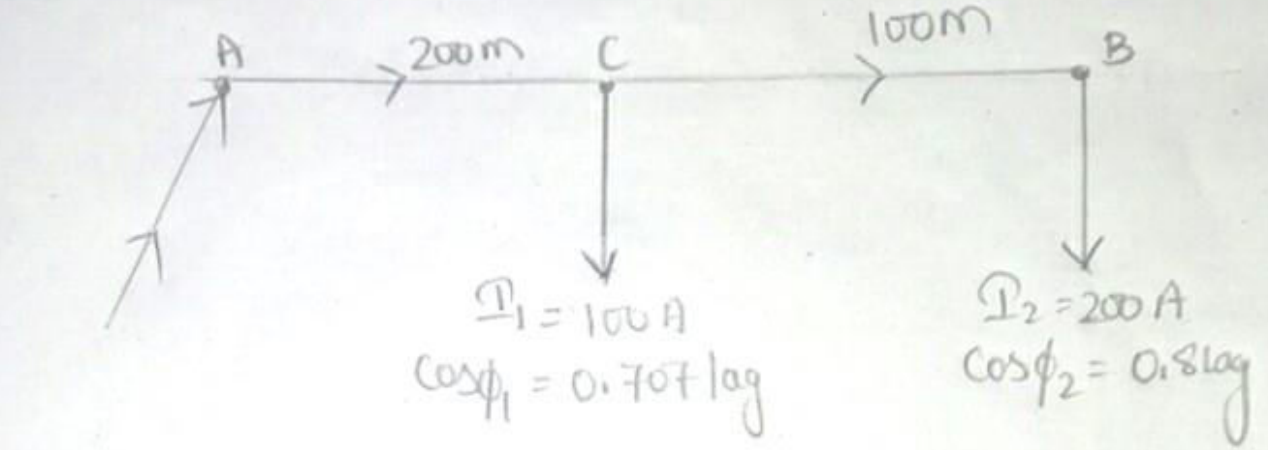
(*b*) It may be referred to the voltage at the load point itself

Example 14.1. *A single phase a.c. distributor AB 300 metres long is fed from end A and is loaded as under :*

(*i*) *100 A at 0·707 p.f. lagging 200 m from point A*

(*ii*) *200 A at 0·8 p.f. lagging 300 m from point A*

The load resistance and reactance of the distributor is 0·2Ω and 0·1 Ωper kilometre. Calculate the total voltage drop in the distributor. The load power factors refer to the voltage at the far end



Impedance of section AC,

$$\vec{Z_{AC}} = (0.2 + j0.1) \times 200/1000 = (0.04 + j0.02)\,\Omega$$

Impedance of section CB,

$$\vec{Z_{CB}} = 0.2 + j0.1) \times 100/1000 = (0.02 + j0.01)\,\Omega$$

Taking voltage at the far end B as the reference vector, we have,

Load current at point B, $I_2 = I_2(\cos\phi_2 - j\sin\phi_2)$

$$= 200\,(0.8 - j0.6)$$

$$= (160 - j120)\,A$$

$$\vec{I_1} = I_1(\cos\phi_1 - j\sin\phi_1) = 100(0.707 - j0.707)$$

$$= (70.7 - j70.7)\,A$$

$$\vec{I_{CB}} = \vec{I_2} = (160 - j120)\,A$$

$$\vec{I_{AC}} = \vec{I_1} + \vec{I_2} = (70.7 - j70.7) + (160 - j120)$$

$$= (230.7 - j190.7)\,A$$

$$\vec{V_{CB}} = \vec{I_{CB}}\,Z_{CB} = (160 - j120)(0.02 + j0.01)$$

$$= (4.4 - j0.8)\text{ volts.}$$

$$\vec{V_{AC}} = \vec{I_{AC}}\,\vec{Z_{AC}} = (230.7 - j190.7)(0.04 + j0.02)$$

$$= (13.04 - j3.01)\text{ volts.}$$

Voltage drop in the distributor $= \vec{V_{AC}} + \vec{V_{CB}}$

$$= (13.04 - j3.01) + (4.4 - j0.8)$$

$$= (17.44 - j3.81)\text{ volts.}$$

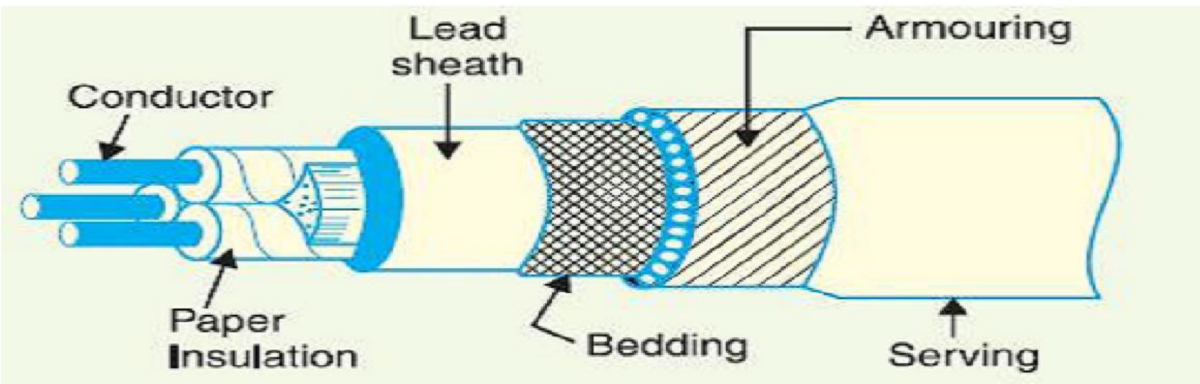
Magnitude of drop $= \sqrt{17.44^2 + 3.81^2} = 17.85$

=17.85 volt

UNDERGROUND CABLES

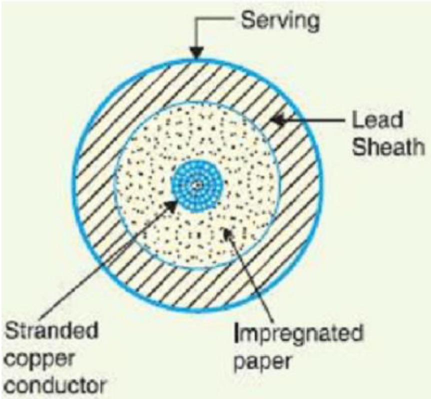
Electric power can be transmitted or distributed either by overhead system or by underground cables. The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chance of faults, smaller voltage drop and better general appearance. However, their major drawback 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. Such locations may be thickly populated areas where municipal authorities prohibit overhead lines for reasons of safety, or around plants and substations or where maintenance conditions do not permit the use of overhead construction. The chief use of underground cables for many years has been for distribution of electric power in congested urban areas at comparatively low or moderate voltages. However, recent improvements in the design and manufacture have led to the development of cables suitable for use at high voltages. This has made it possible to employ underground cables for transmission of electric power for short or moderate distances. In this chapter, we shall focus our attention on the various aspects of underground cables and their increasing use in power system.

Underground Cables:-An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover. Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements. In general, a cable must fulfill the following necessary requirements:
(i) The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. Stranding is done so that conductor may become flexible and carry more current.
(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:-Figure shows the general construction of a 3-conductor cable



Cores or Conductors. A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. For instance, the 3 conductor cable shown in Figure is used for 3-phase service. The conductors are made of tinned copper or aluminum 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 upon 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 (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminum is provided over the insulation as shown in Fig.
(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 galvanized steel wire or steel tape. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling. Armouring may not be done in the case of some cables.
(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. It may not be out of place to mention here that bedding, armouring and serving are only applied to the cables for the protection of conductor insulation and to protect the metallic sheath from mechanical injury.

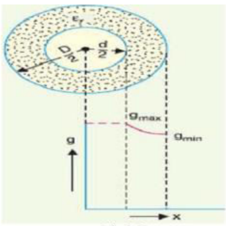


(i) Low-tension (L.T.) cables — upto 1000 V
(ii) High-tension (H.T.) cables — upto 11,000 V
(iii) Super-tension (S.T.) cables — from 22 kV to 33 kV
(iv)Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
(iv) Extra super voltage cables — beyond 132 kV

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. Fig. 11.2 shows the constructional details of a single-core low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (up to 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into the inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of larger copper section.

Cable for 3-phase
In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used. For voltages upto 66 kV, 3-core cable (i.e., multi-core construction) is preferred due to economic reasons. However, for voltages beyond 66 kV, 3-core-cables become too large and unwieldy and, therefore, single-core cables are used. The following types of cables are generally used for 3-phase service:

1. Belted cables — upto 11 kV
2. Screened cables — from 22 kV to 66 kV
3. Pressure cables — beyond 66 kV

Dielectric Stress in Cable 

Under operating conditions, the insulation of a cable is subjected to electrostatic forces. This is known as dielectric stress. The dielectric stress at any point in a cable is in fact the potential gradient (or electric intensity) at that point

Loop Tests For Location of Faults in Underground Cables

There are several methods for locating the 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-circuit 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-circuit fault in underground cables.

Earth fault : Fig. shows the circuit 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 occuring 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 resistances *P* and *Q* are joined to ends *A* and *C* (See Fig. 11.22) respectively and serve as the ratio arms of the Wheatstone bridge.

Let R = resistance of the conductor loop upto the fault from the test end

X = resistance of the other length of the loop

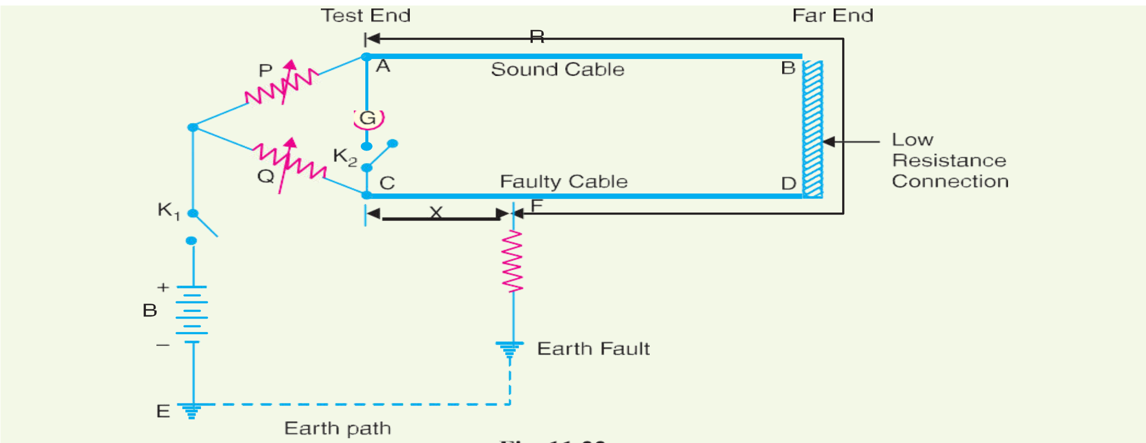


Fig. 11.22

Note that P, Q, R and X are the four arms of the Wheatstone bridge. The resistances P and Q are varied till the galvanometer indicates zero deflection. In the balanced position of the bridge, we have,

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

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

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

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

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

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

Distance of fault point from test end is

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

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

Short-circuit fault :

Fig. shows the circuit diagram for locating the short-circuit 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 circuit and not in the bridge circuit. The bridge in balanced by adjusting the resistances P and Q. In the balanced position of the bridge

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

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

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

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

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

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

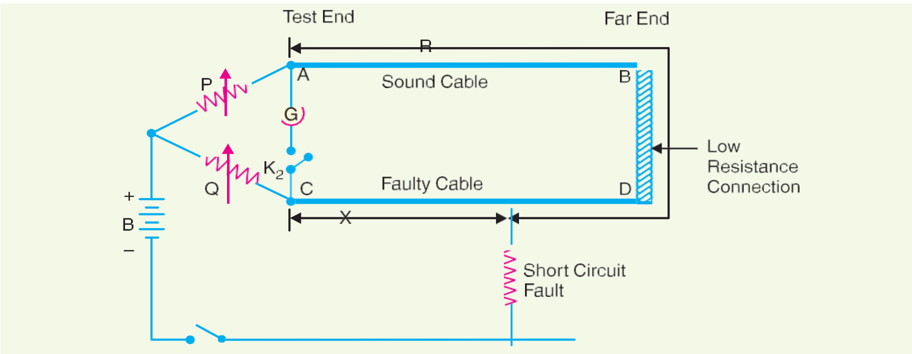


Fig. 11.23

Thus the position of the fault is located

Varley Loop Test

The Varley loop test is also used to locate earth fault or short-circuit fault in underground cables. This test also employs Wheatstone bridge principle. It differs from Murray loop test in that here the ratio arms P and Q are fixed resistances. Balance is obtained by adjusting the variable

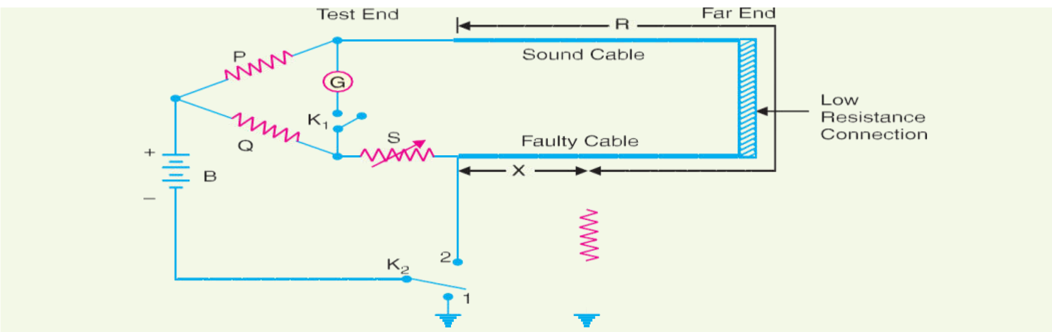


Fig. 11.24 Varley Loop Test (Earth Fault)

resistance S connected to the end of the faulty cable .

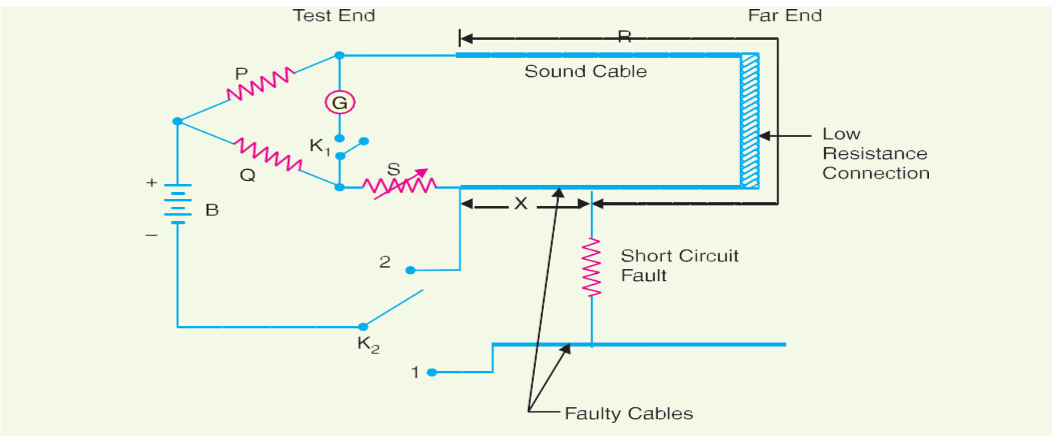


Fig. 11.25 Varley Loop Test (Short Circuit Test)

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

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

$$\text{or } X = \frac{Q(R+X) - PS_1}{P+Q} \quad \ldots\ldots (i)$$

Now Key K_2 at position 2

$$\frac{P}{Q} = \frac{R+X}{S_2} \quad \ldots\ldots (ii)$$

$$(R+X)Q = PS_2$$

From eqn (i) and (ii), we get

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

Since the values of P,Q,S_1,S_2 are known , the value of x can be determined and the distance of fault from the test end is d=X/r meters

ECONOMIC ASPECTS

Power factor:

The cosine of the angle between voltage and current is called power factor.

Consider an inductive circuit taking a lagging current I from sup- ply voltage V; the angle of lag being ϕ. The phasor diagram of the circuit is shown in Fig. 6.1. The circuit current I can be resolved into two perpendicular components, namely ;

(a) $I \cos \phi$ in phase with V

(b) $I \sin \phi$ 90° out of phase with V

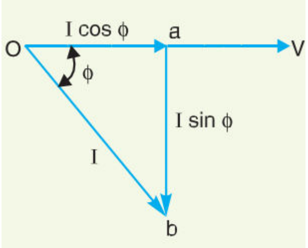


Fig. 6.1

Causes of Low Power Fa ctor

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system in lower than 0·8. The following are the causes of low power factor:

(i) Most of the a.c. 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 to 0·8 or 0·9 at full load.

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

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

The low power factor is mainly due to the fact that most of the power loads are inductive and, there- fore, take lagging currents. In order to improve the power factor, some device taking leading power should be connected in parallel with the load. One of such devices can be a capacitor. The capacitor draws a leading current and partly or

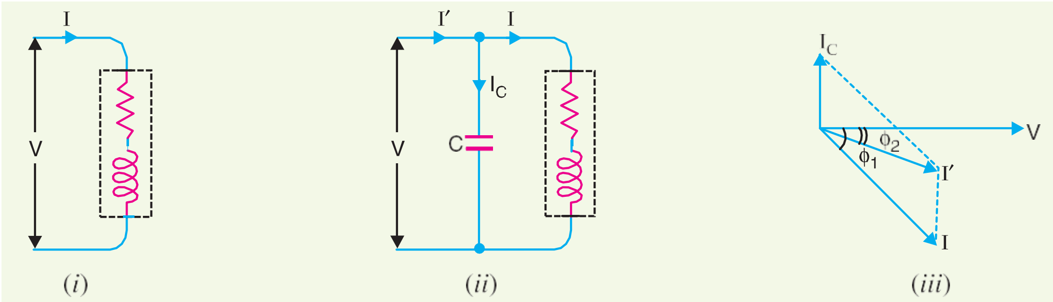


Fig. 6.3

completely neutralises the lagging reactive component of load current. This raises the power factor of the load.

Power Factor Improvement Equipment

Normally, the power factor of the whole load on a large generating station is in the region of 0·8 to 0·9. However, sometimes it is lower and in such cases it is generally desirable to take special steps to improve the power factor. This can be achieved by the following equipment :

1. Static capacitors. **2.** Synchronous condenser. **3.** Phase advancers.

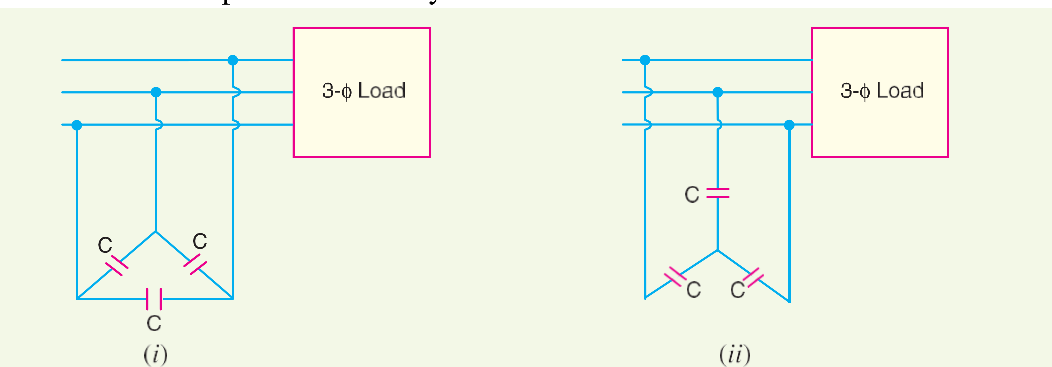


Fig. 6.4

Static capacitor.

The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor.

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

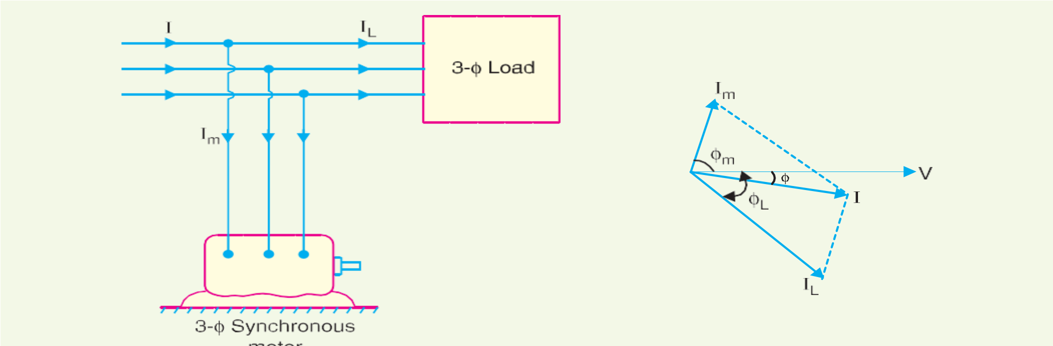


Fig. 6.5

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.

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^o. If the exciting amp turns can be provided from some other a.c. source the phase advancer which is simply an a.c. exciter. The phase advancer is mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor it provides exciting ampere turns to the rotor circuit at slip frequency. By providing more ampere turns than required, the induction motor can be made to operate on leading power factor like an over-excited synchronous motor

Calculations of Power Factor Correction

Consider an inductive load taking a lagging current *I* at a power factor cos ϕ_1. In order to improve the power factor of this circuit, the remedy is to connect such an equipment in parallel with the load which takes a leading reactive component and partly cancels the lagging reactive component of the load. Fig. 6.6 (*i*) shows a capacitor connected across the load. The capacitor takes a current I_C which
leads the supply voltage V by 90^o. The current *I* partly cancels the lagging reactive component of
the load current as shown in the phasor diagram in Fig. 6.6 (*ii*). The resultant circuit current becomes *I*and its angle of lag is ϕ_2. It is clear that ϕ_2 is less than $\phi_1$so that new p.f. cos ϕ_2 is more than the previous p.f. cos ϕ_1.

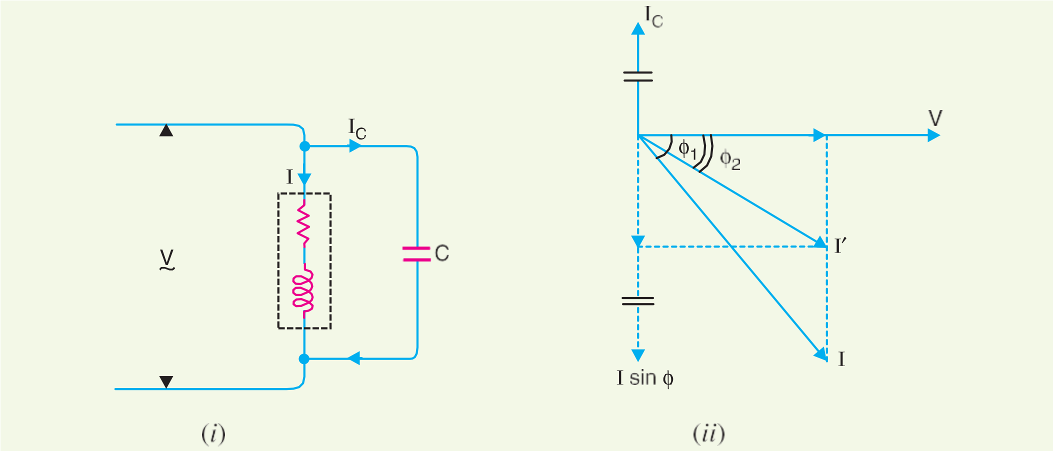


Fig. 6.6

From the phasor diagram, it is clear that after p.f. correction, the lagging reactive component of the load is reduced to $I' \sin \phi_2$.

Obviously, $I' \sin \phi_2 = I \sin \phi_1 - I_C$

or $I_C = I \sin \phi_1 - I' \sin \phi_2$

Example

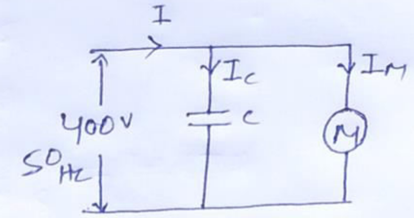
A single phase motor connected to 400 V, 50 Hz supply takes 31·7A at a power factor of 0·7 lagging. Calculate the capacitance required in parallel with the motor to raise the power factor to 0·9 lagging

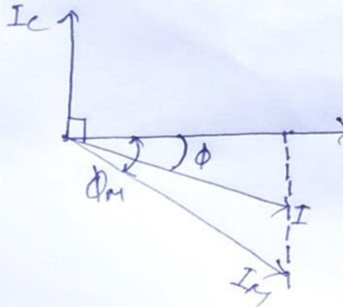
Sol^n

Given Motor current $I_M = 31.7A$.

$V = 400\,V$

$f = 50\,Hz$





Active component of $I_M = I_M \cos\phi_M$

$= 31.7 \times 0.7 = 22.19\,A$

Active component of $I = I\cos\phi = I \times 0.9$

$$I = \frac{22.19}{0.9} = 24.65\,A$$

Reactive component of $I_M = I_M \sin\phi_M$

$= 31.7 \times 0.714 = 22.6\,A$

Reactive component of $I = I\sin\phi$

$= 24.65\sqrt{1-0.9^2}$

$= 10.75\,A$

$I_c = I_M \sin\phi_M - I\sin\phi$

$= 22.6 - 10.75 = 11.85\,A$

$$I_c = \frac{V}{X_c} = V \times 2\pi f C$$

$11.85 = 400 \times 2\pi \times 50 \times C$

$C = 94.3 \times 10^{-6}\,F = 94.3\,\mu F.$

Load Curves

The curve showing the variation of load on the power station with respect to (w.r.t) time is known as Load curves.

The load on a power station is never constant; it varies from time to time during the whole day (i.e., 24 hours) are recorded half-hourly or hourly and are plotted against time graph The curve thus obtained is known as daily load curve as it shows the variations of load w.r.t. time during the day

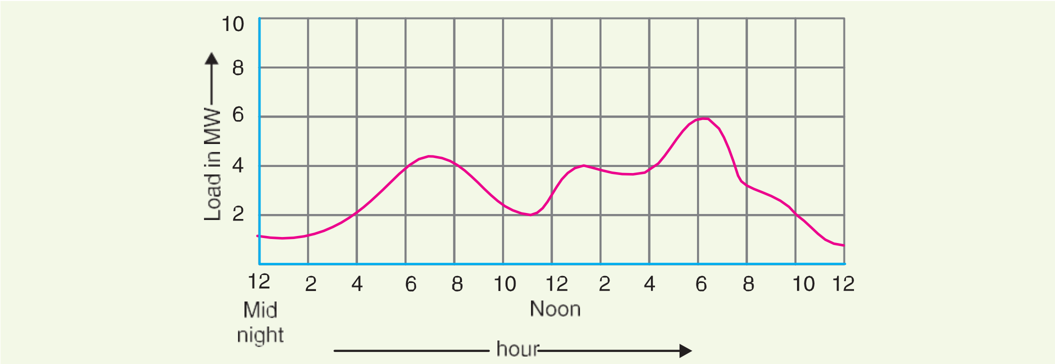


Fig. 3.2

Important Terms and Factors

Connected load:

It is the sum of continuous ratings of all the equipments connected to supply system.

Maximum demand:

It is the greatest demand of load on the power station during a given period

The load on the power station varies from time to time. The maximum of all the demands that have occurred during a given period (say a day) is the maximum demand

Demand factor.

It is the ratio of maximum demand on the power station to its connected load

Demand factor = $\frac{Maximum\ Demand}{Connected\ Loads}$

The value of demand factor is usually less than 1

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**

Load factor.

The ratio of average load to the maximum demand during a given period is ***known as*** **load factor**

Load factor = $\frac{Average\ Loads}{Maximum\ Demand}$

Diversity factor.

The ratio of the sum of individual maximum demands to the maximum

Diversity factor = $\frac{Sum\ of\ individual\ Max\ Demand}{Maximum\ Demand\ on\ Power\ station}$

Units Generated per Annum

It is often required to find the kWh generated per annum from maximum demand and load factor.The procedure is as follows

Load factor = $\frac{Average\ Loads}{Maximum\ Demand}$

Average load = Max. demand × L.F

Units generated/annum = Average load (in kW) × Hours in a year

= Max. demand (in kW) × L.F. × 8760

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

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

Example *The maximum demand on a power station is 100 MW. If the annual load factor is 40% , calculate the total energy generated in a year.*

Solution.

$$\textit{Energy generated/year} = \textit{Max. demand} \times \textit{L.F.} \times \textit{Hours in a year}$$

$$= (100 \times 10^3) \times (0{\cdot}4) \times (24 \times 365) \text{ kWh}$$

$$= 3504 \times 10^5 \text{ kWh}$$

Example *A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being 61·5 × 10*^{6} *per annum. Calculate* (*i*) *the demand factor and* (*ii*) *load factor.*

Solution.

(i) $$\text{Demand factor} = \frac{\text{Max. demand}}{\text{Connected load}} = \frac{20}{43} = \mathbf{0{\cdot}465}$$

(ii) $$\text{Average demand} = \frac{\text{Units generated / annum}}{\text{Hours in a year}} = \frac{61{\cdot}5 \times 10^6}{8760} = 7020 \text{ kW}$$

(iii) $$\text{Load factor} = \frac{\textit{Average Loads}}{\textit{Maximum Demand}} = \frac{7020}{20000} = 0.351 = 35.1\%$$

Base Load and Peak Load on Power Station

Base load.

The unvarying load which occurs almost the whole day on the station is known as **base load**

Peak load.

The various peak demands of load over and above the base load of the station is known as **peak load**

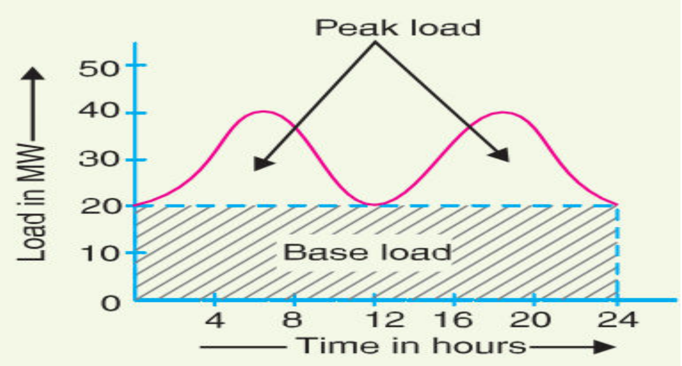


Fig. 3.13

Tariff

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

Types of Tariff

There are several types of tariff. However, the following are the commonly used 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.**

In this type of tariff, the price charged per unit is constant *i.e.*, it does not vary with increase or decrease in number of units consumed. The consumption of electrical energy at the consumer's terminals is recorded by means of an energy meter. This is the simplest of all tariffs and is readily understood by the consumers.

Disadvantages

(i) There is no discrimination between 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 a* **flat rate tariff**.

In this type of tariff, the consumers are grouped into different classes and each class of consum- ers is charged at a different uniform rate. For instance, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less† (say 55 paise per kWh) for power load. The different classes of consumers are made taking into account their diversity and load factors. The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

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 expen- sive 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**.

In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest** and it is progressively reduced for the succeeding blocks of energy. For example, the first 30 units may be charged at the rate of 60 paise per unit ; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced. However, its principal defect is that it lacks a measure of the consumer's demand. This type of tariff is being used for majority of residential and small commercial consumers.

4. **Two-part tariff.** *When the rate of electrical energy is charged on the basis of maximum 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. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer. Thus, the consumer is charged at a certain amount per kW of maximum†† demand plus a certain amount per kWh of energy consumed *i.e*

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

where, b = charge per kW of maximum demand

c = charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages

(i) It is easily understood by the consumers.

(ii) It recovers the fixed charges which depend upon the maximum 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 assessing the maximum demand of the consumer.

5. **Maximum demand tariff.** It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rateable value. This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer

6. Power factor tariff. *The tariff in which power factor of the consumer's load is taken into consideration is known as* **power factor tariff**.

In an a.c. system, power factor plays an important role. A low* power factor increases the rating of station equipment and line losses. Therefore, a consumer having low power factor must be penalised. The following are the important types of power factor tariff :

(i) *k VA maximum demand tariff* : It is a modified form of two-part tariff. In this case, the fixed charges are made on the basis of maximum demand in kVA and *not* in kW. As kVA is inversely proportional to power factor, therefore, a consumer having low power factor has to contribute more towards the fixed charges. This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved power factor.

(ii) *Sliding scale tariff* : This is also know as average power factor tariff. In this case, an average power factor, say 0·8 lagging, is taken as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer.

(iii) *kW and kVAR tariff* : In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately. A consumer having low power factor will draw more reac- tive power and hence shall have to pay more charges.

7. Three-part tariff. *When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a* **three-part tariff**. *i.e.*,

$$\text{Total charge} = \text{Rs } (a + b \times \text{kW} + c \times \text{kWh})$$

where a = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribu- tion and labour cost of collecting revenues,

b = charge per kW of maximum demand,

c = charge per kWh of energy consumed

Example . *A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is Rs. 100 per kW of maximum demand plus 10 paise per kWh, find the overall cost per kWh*

$$\text{Units consumed/year} = \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}$$
$$= (200) \times (0{\cdot}4) \times 8760 = 7{,}00{,}800 \text{ kWh}$$
$$\text{Annual charges} = \text{Annual M.D. charges} + \text{Annual energy charges}$$
$$= \text{Rs } (100 \times 200 + 0{\cdot}1 \times 7{,}00{,}800)$$
$$= \text{Rs } 90{,}080$$
$$\therefore \quad \text{Overall cost/kWh} = \text{Rs}\frac{90{,}080}{7{,}00{,}80} = \text{Re } 0{\cdot}1285 = \mathbf{12{\cdot}85 \text{ paise}}$$

Sub-Station

The assembly of apparatus used to change some characteristic (*e.g. voltage, a.c. to d.c., frequency,*

p.f. etc.) *of electric supply is called a* **sub-station.**

Sub-stations are important part of power system. The continuity of supply depends to a consid- erable extent upon the successful operation of sub-stations. It is, therefore, essential to exercise utmost care while designing and building a sub-station. The following are the important points which must be kept in view while laying out a sub-station :

(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. For reliability, consider- ation must be given for good design and construction, the provision of suitable protective gear *etc.*

(iii) It should be easily operated and maintained.

(iv) It should involve minimum capital cost.

1. A sub-station has many components (*e.g.* circuit breakers, switches, fuses, instruments etc.) which must be housed properly to ensure continuous and reliable service. According to constructional features, the sub-stations are classified as :

(*i*) Indoor sub-station **(*ii*)** Outdoor sub-station

(iii) Underground sub-station **(*iv*)** Pole-mounted sub-station

(i) **Indoor sub-stations.** For voltages upto 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 upto 66 kV.

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

(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. The reader may find further discussion on underground sub-stations in Art. 25.6.

Pole-mounted sub-stations. This is an outdoor sub-station with equipment installed over- head on *H*-pole or 4-pole structure. It is the cheapest form of sub-station for voltages not exceeding 11kV (or 33 kV in some cases). Electric power is almost distributed in localities through such sub- stations.

(i) Step-up sub-station. The generation voltage (11 kV in this case) is stepped up to high voltage (220 kV) to affect economy in transmission of electric power. The sub-stations which ac- complish this job are called step-up sub-stations. These are generally located in the power houses and are of outdoor type.

(ii) Primary grid sub-station. From the step-up sub-station, electric power at 220 kV is trans- mitted by 3-phase, 3-wire overhead system to the outskirts of the city. Here, electric power is re- ceived by the primary grid sub-station which reduces the voltage level to 66 kV for secondary trans- mission. The primary grid sub-station is generally of

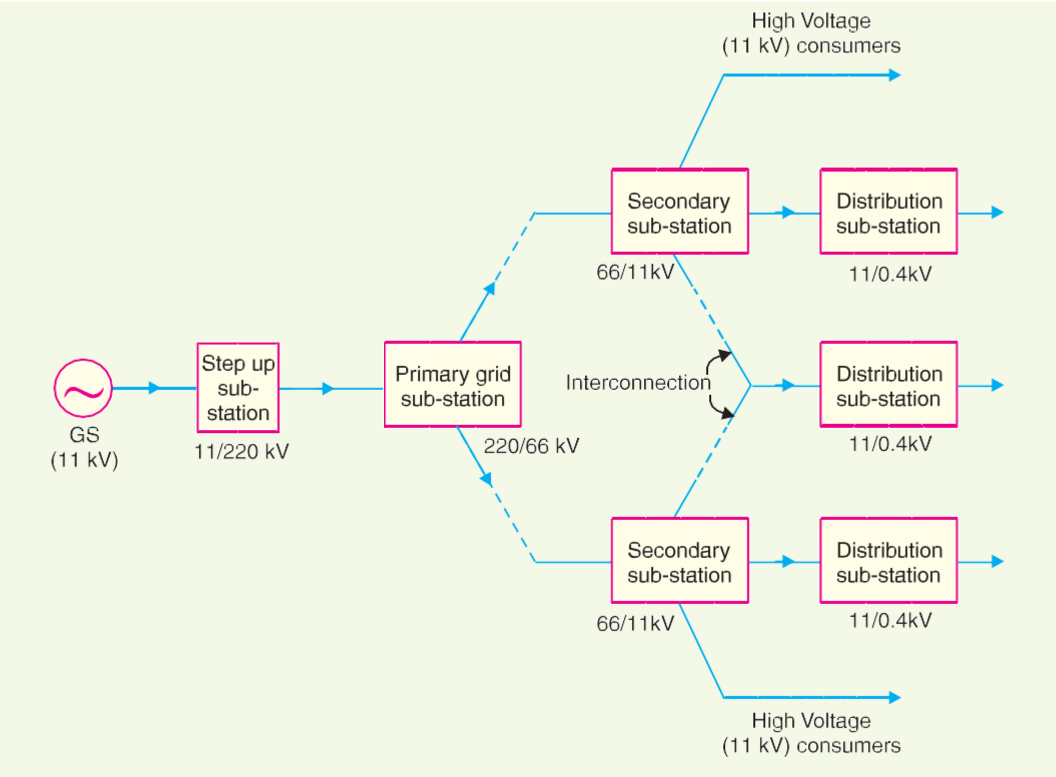


Fig. 25.1

(iii) Secondary sub-station. From the primary grid sub-station, electric power is transmitted at 66 kV 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 11 kV. The 11 kV lines run along the important road sides of the city. It may be noted that big consumers (having demand more than 50 kW) are generally supplied power at 11 kV for further handling with their own sub-

(iv) stations. The secondary sub-stations are also generally of outdoor type.

(v) **Distribution sub-station.** The electric power from 11 kV lines is delivered to distribution sub-stations. These sub-stations are located near the consumers localities and step down the voltage to 400 V, 3-phase, 4-wire for supplying to the consumers. The voltage between any two phases is 400V and between any phase and neutral it is 230 V. 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. It may be worthwhile to mention here that majority of the distribution sub- stations are of pole-mounted type

Pole-Mounted Sub-Station

main equipment:

1. **Bus-bars.** When a number of lines operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical component. Bus-bars are copper or aluminium bars (generally of rectangular *x*-section) and operate at constant voltage. The incoming and outgoing lines in a sub-station are connected to the bus-bars. The most commonly used bus-bar arrangements in sub-stations are:

(i) Single bus-bar arrangement

(ii) Single bus-bar system with sectionalisation

(iii) Double bus-bar arrangement

A detailed discussion on these bus-bar arrangements has already been made in Art. 16.3. However, their practical applications in sub-stations are discussed in Art. 25.9.

Insulators. The insulators serve two purposes. They support the conductors (or bus-barsand confine the current to the conductors. The most commonly used material for the manufacture of insulators is porcelain. There are several types of insulators (*e.g.* pin type, suspension type, post insulator etc.) and their use in the sub-station will depend upon the service requirement. For ex- ample, post insulator is used for bus-bars. A post insulator consists of a porcelain body, cast iron cap and flanged cast iron base. The hole in the cap is threaded so that bus-bars can be directly bolted to the cap

A small correction in the figure input is 11kv not 400v.

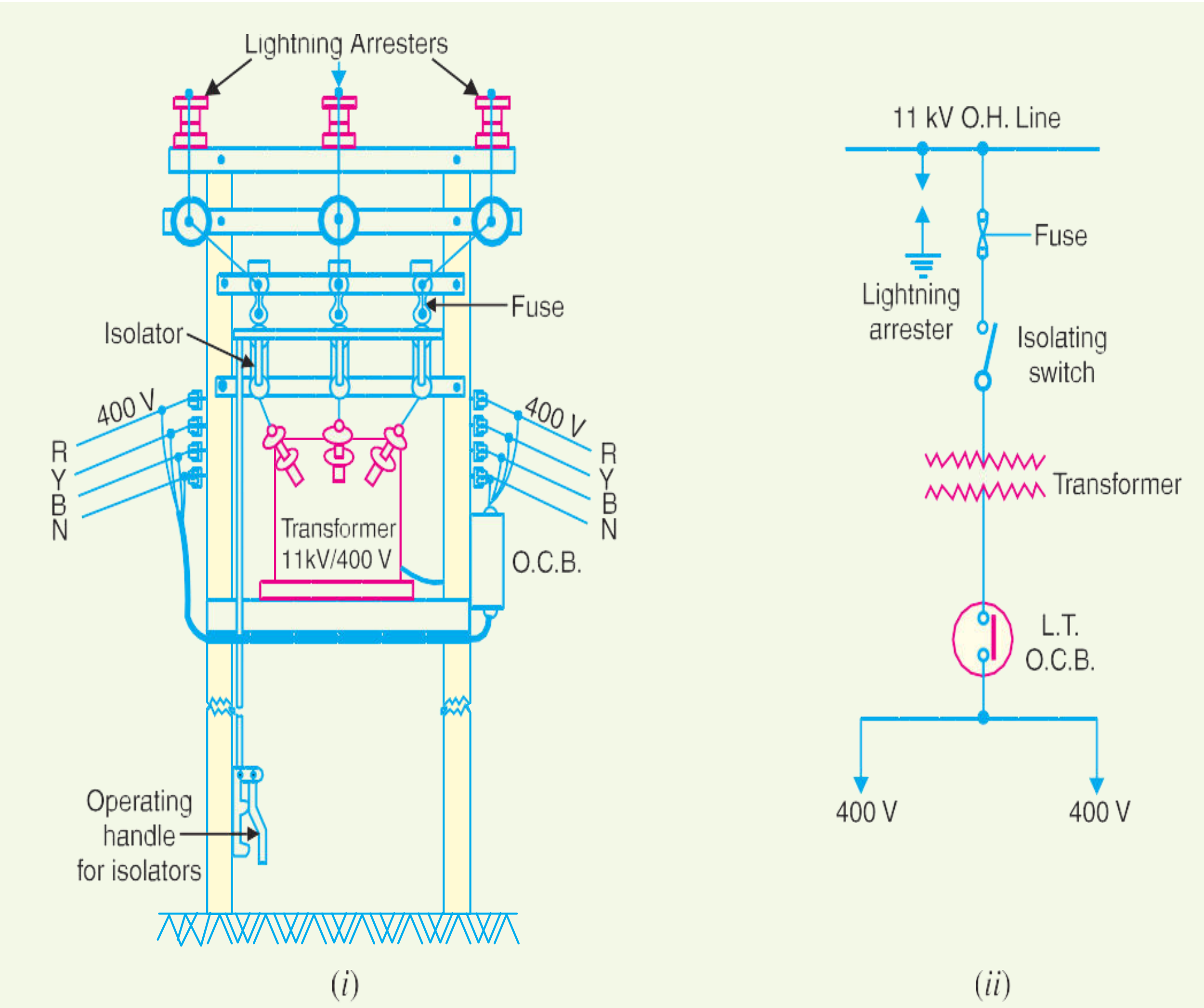


Fig. 25.2

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2. Isolating switches. In sub-stations, it is often desired to disconnect a part of the system for general maintenance and repairs. This is accomplished by an isolating switch or isolator. An isolator is essentially a knife switch and is designed to open a circuit under *no load.* In other words, isolator switches are operated only when the lines in which they are connected carry *no

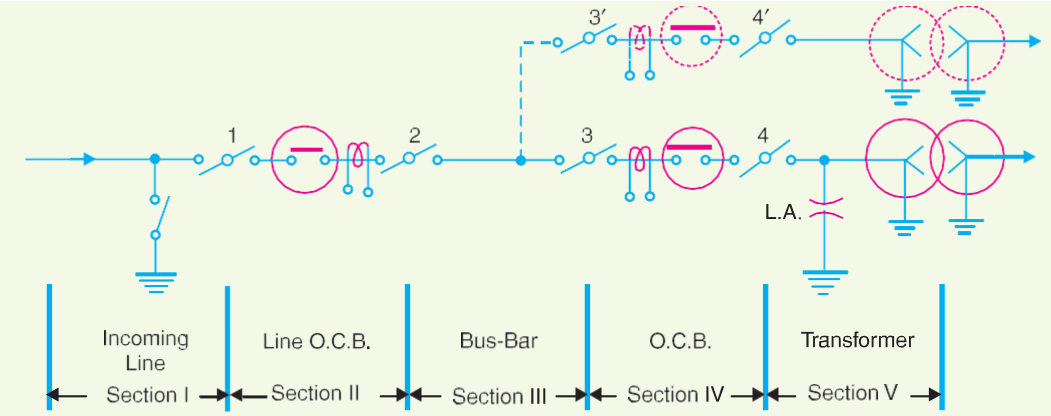

Fig. 25.4

current.

Fig. 25.4 shows the use of isolators in a typical sub-station. The entire sub-station has been divided into V sections. Each section can be disconnected with the help of isolators for repair and maintenance. For instance, if it is desired to repair section No. II, the procedure of disconnecting this section will be as follows. First of all, open the circuit breaker in this section and then open the isolators 1 and 2. This procedure will disconnect section II for repairs. After the repair has been done, close the isolators 1 and 2 first and then the circuit breaker.

3. Circuit breaker. A circuit breaker is an equipment which can open or close a circuit under **normal as well as fault conditions. It is so designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions. For the latter operation, a relay circuit is used with a circuit breaker. Generally, bulk oil circuit breakers are used for voltages upto 66kV while for high (>66 kV) voltages, low oil circuit breakers are used. For still higher voltages, air-blast, vacuum or SF_6 circuit breakers are used. For detailed discussion of these breakers, the reader may refer to chapter 19.

4. Power Transformers. A power transformer is used in a sub-station to step-up or step-down the voltage. Except at the ***power station, all the subsequent sub-stations use step-down transform- ers to gradually reduce the voltage of electric supply and finally deliver it at utilisation voltage. The modern practice is to use 3-phase transformers in sub-stations ; although 3 single phase bank of

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transformers can also be used. The use of 3-phase transformer (instead of 3 single phase bank of transformers) permits two advantages. Firstly, only one 3-phase load-tap changing mechanism can be used. Secondly, its installation is much simpler than the three single phase transformers.

The power transformer is generally installed upon lengths of rails fixed on concrete slabs having foundations 1 to 1·5 m deep. For ratings upto 10 MVA, naturally cooled, oil immersed transformers are used. For higher ratings, the transformers are generally air blast cooled.

5. **Instrument transformers.** The lines in sub-stations operate at high voltages and carry current of thousands of amperes. The measuring instruments and protective devices are designed for low voltages (generally 110 V) and currents (about 5 A). Therefore, they will not work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing *instrument trans- formers* on the power lines. The function of these instrument transformers is to transfer voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays. There are two types of instrument transformers *viz.*

(*i*) Current transformer (C.T.) (*ii*) Potential transformer (P.T.)

(i) **Current transformer (C.T.).** A current transformer in essentially a step-up transformer which steps down the current to a known ratio. The primary of this transformer consists of one or more turns of thick wire connected in series with the line. The secondary consists of a large number of turns of fine wire and provides for the measuring instruments and relays a current which is a constant fraction of the current in the line. Suppose a current transformer rated at 100/5 A is con- nected in the line to measure current. If the current in the line is 100 A, then current in the secondary will be 5A. Similarly, if current in the line is 50A, then secondary of C.T. will have a current of 2·5 A. Thus the C.T. under consideration will step down the line current by a factor of 20.

(ii) **Voltage transformer.** It is essentially a step down transformer and steps down the voltage to a known ratio. The primary of this transformer consists of a large number of turns of fine wire connected across the line. The secondary winding consists of a few turns and provides for measuring instruments and relays a voltage which is a known fraction of the line voltage. Suppose a potential transformer rated at 66kV/110V is connected to a power line. If line voltage is 66kV, then voltage across the secondary will be 110 V.

6. **Metering and Indicating Instruments.** There are several metering and indicating instru- ments (*e.g.* ammeters, voltmeters, energy meters etc.) installed in a sub-station to maintain watch over the circuit quantities. The instrument transformers are invariably used with them for satisfactory operation.

7. **Miscellaneous equipment.** In addition to above, there may be following equipment in a sub-station :

(i) fuses
(ii) carrier-current equipment
(iii) sub-station auxiliary supplies