1 Power Generation

1.1 Introduction

The energy is neither be created nor be destroyed but it can be converted from one form to another. The generation of an electrical energy is nothing but the conversion of various other forms of energy into an electrical energy. The various energy sources which are used to generate an electrical energy on the large scale are steam obtained by burning coal, oil, natural gas, water stored in dams, diesel oil, nuclear power and other nonconventional energy sources. The electrical power is generated in bulk at the generating stations which are also called power stations. Depending upon the source of energy used, these stations are called thermal power station, hydroelectric power station, diesel power station, nuclear power station etc.

This generated electrical energy is demanded by the consumers. Hence the generated electrical power is to be supplied to the consumers. Generally the power stations are located too far away from the town and cities where electrical energy is demanded. Hence there exists a large network of conductors between the power stations and the consumers. This network is broadly classified into two parts.

1. Transmission 2. Distribution

In this chapter, let us discuss the basic elements of a typical transmission and distribution scheme. The chapter also includes the various distribution systems and related calculations. At the end it includes discussion on EHV AC and HVDC transmission.

1.2 Structure of Electrical Power System

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. Generating 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. 1.1.

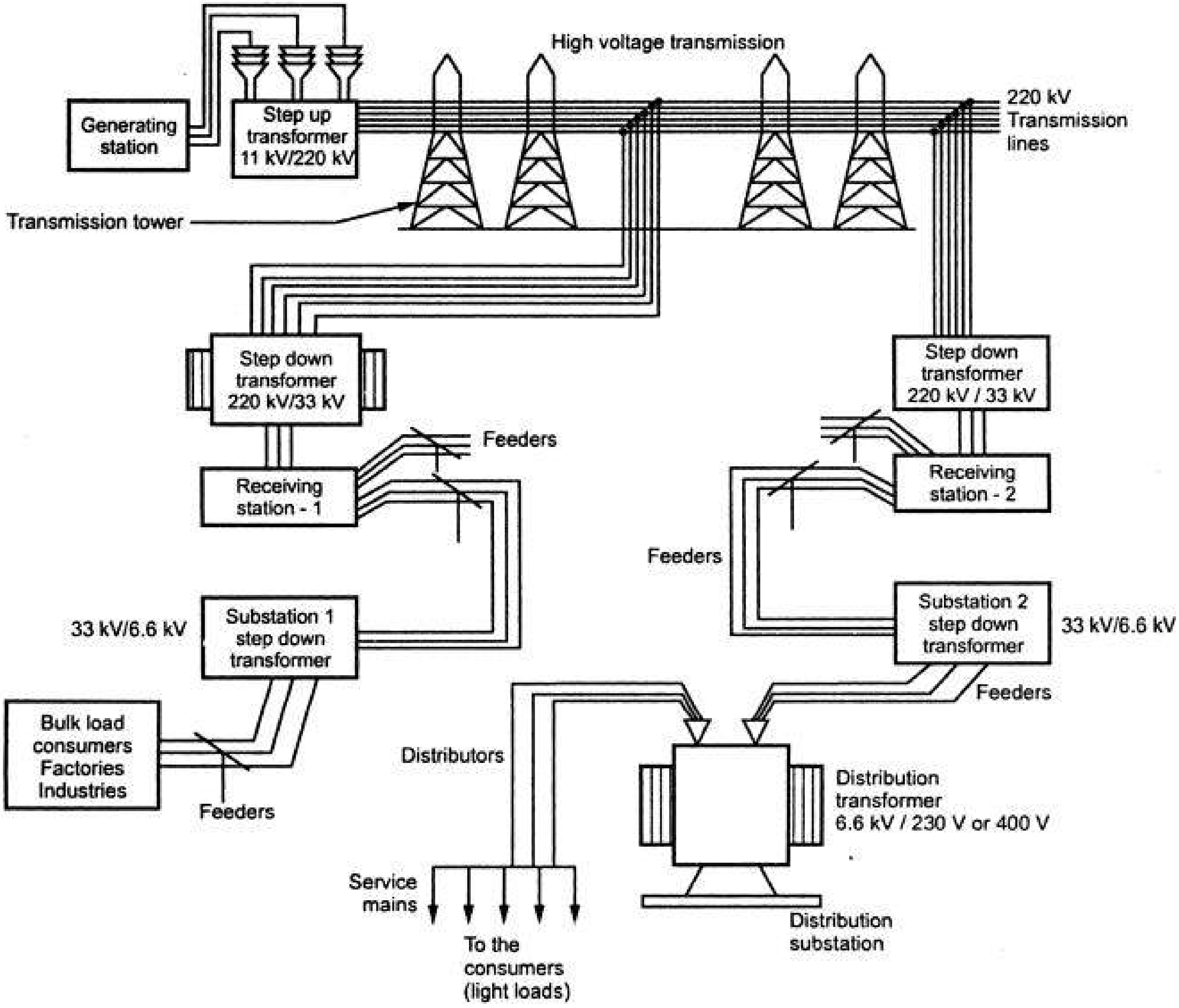

Fig. 1.1 Schematic representation of a typical transmission distribution scheme

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 areas like cities, overhead system of bare conductors 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**.

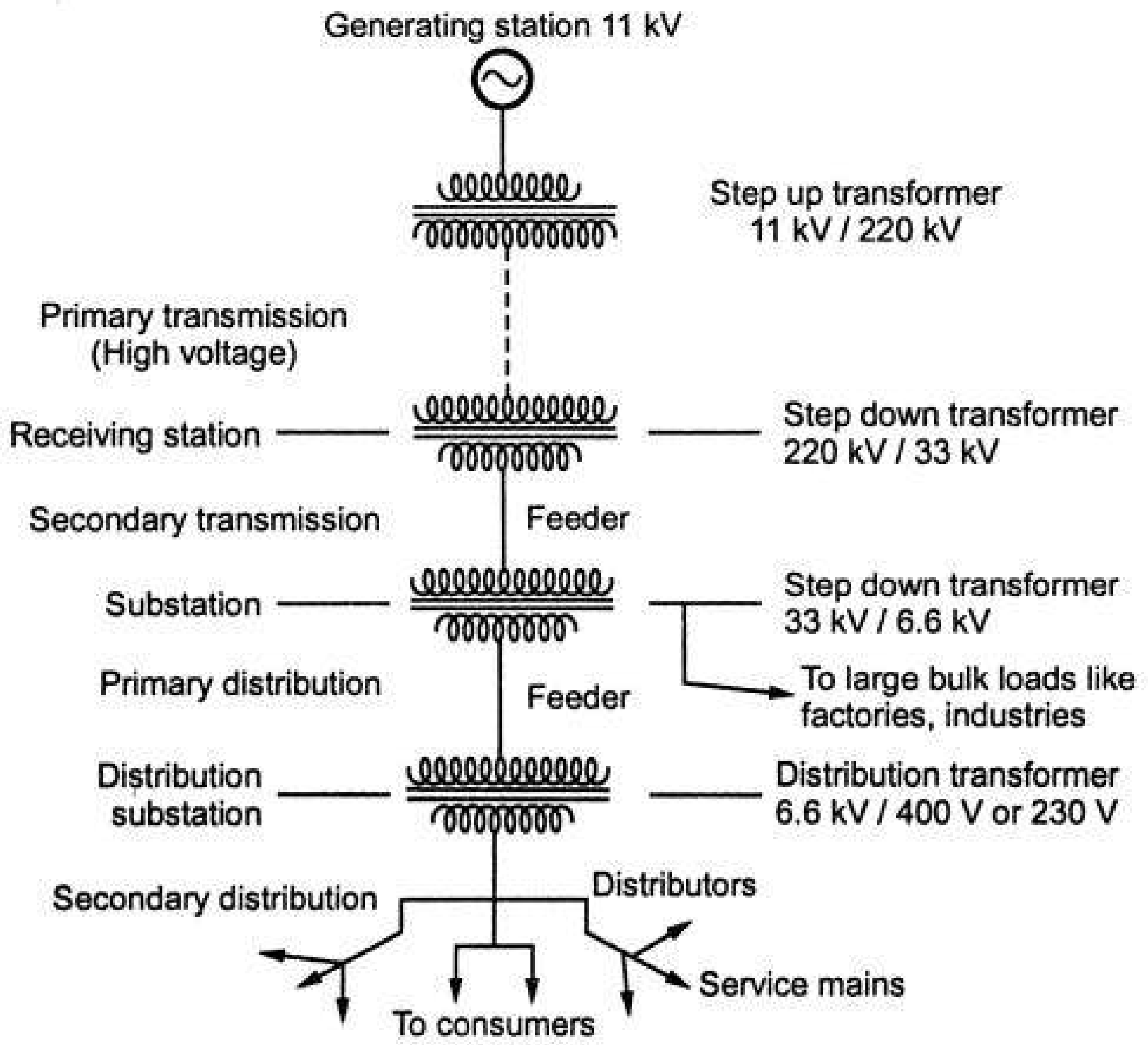

Fig. 1.2 Line diagram of a typical transmission distribution scheme

This is the complete flow of an electrical power from the generating station to the consumer premises.

Let us study the line diagram of such a typical scheme of transmission and distribution and discuss the various components and voltage levels at the various stages in detail. The Fig. 1.2 shows the line diagram of a typical transmission and distribution scheme.

At the generating station, an electrical power is generated with the help of three phase alternators running in parallel. In the scheme shown, the voltage level is 11 kV but the voltage level may be 6.6 kV, 22 kV or 33 kV depending upon the capacity of the generating station. After the generating station, actual transmission and distribution starts. The overall scheme can be divided into four sections which are,

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, 220 kV or more, with the help of step up transformer. Hence this transmission is also called **high voltage 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 centres. This is primary distribution, also called high voltage 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 4 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.

1.2.1 Components of Distribution

The distribution scheme consists of following important components.

1. **Substation :** Transmission lines bring the power upto the substations at a voltage level of 22 kV or 33 kV. At the substation the level is reduced to 3.3 kV or 6.6 kV. Then using feeders, the power is given to local distribution centres.

2. **Local distribution station :** It consists of distribution transformer which steps down the voltage level from 3.3 kV, 6.6 kV to 400 V or 230 V. Then it is distributed further using distributors. This is also called **distribution substation.**
3. **Feeders :** These are the conductors which are of large current carrying capacitor. The feeders connect the substation to the area where power is to be finally distributed to the consumers. No tappings are taken from the feeders. The feeder current always remains constant. The voltage drop along the feeder is compensated by compounding the generators.
4. **Distributors :** These are the conductors used to transfer power from distribution centre to the consumers. From the distributors, the tappings are taken for the supply to the consumers. The voltage drop along the distributors is the main criterion to design the distributors.
5. **Service mains :** These are the small cables between the distributors and the actual consumer premises.

The interconnection of feeders, distributors and service mains is shown in the Fig. 1.3.

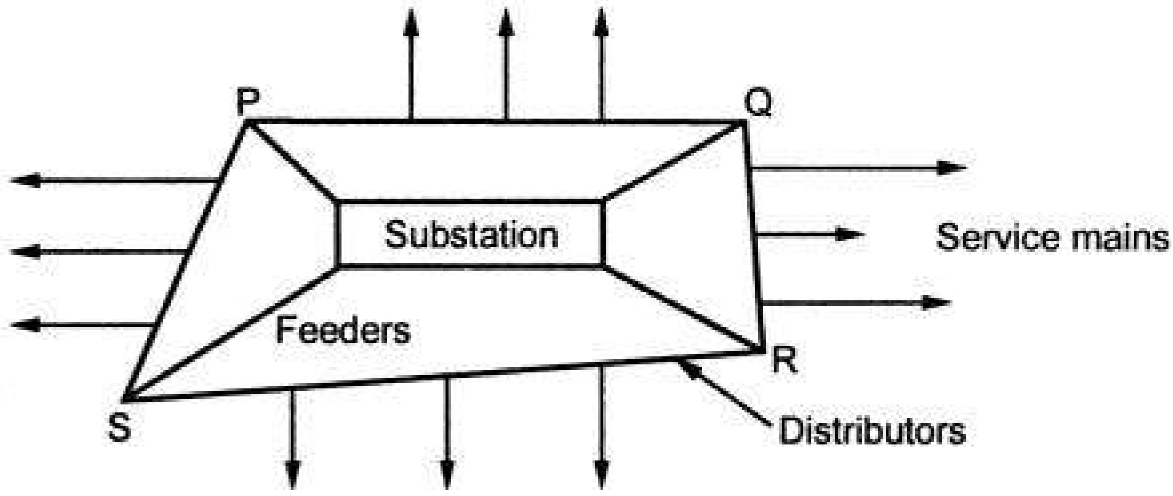

Fig. 1.3

There is no tapping on feeders. PQ, QR, RS and PS are the distributors which are supplied by the feeders. No consumer is directly connected to the feeder. The service mains are used to supply the consumers from the distributors. Tappings are taken from the distributors.

1.3 Single Line Diagram of Power System

The different elements of power systems are always required to be connected with each other so that the complete power system can be modelled. The supply system is normally three phase balanced system so while representing the system one of the three lines is shown with return through neutral. The representation of all three lines with neutral return is rarely required in practice. The representation of all power system elements along with their interconnections is done with the help of single line diagram of the system.

The single line diagram can still be simplified by excluding the completed circuit through the neutral and the components are represented by their standard symbols rather

As shown in the Fig. 1.6, there are 5 sections. With the help of isolators, each section can be disconnected for repair and maintenance. If it is required to do maintenance in section 4, then the circuit breaker in that section is to be opened first and then open the isolators 3 and 4. Thus section 4 is open for maintenance. After maintenance, the isolators 3 and 4 are to be closed first and then circuit breaker is closed.

In some cases, isolators are used as circuit breaking devices. But it is limited by particular conditions such as power rating of given circuit. The isolators are of two types viz single pole and three pole isolators.

1.5 Sources of Electric Energy

The various energy sources are classified into two main groups.

a) Non-conventional or renewable energy sources.

b) Conventional or non-renewable energy sources.

1.5.1 Non-conventional or Renewable Energy Sources

These energy sources are available abundantly in nature and can be reused again.

The various non-conventional energy sources are as follows.

i) Solar energy	ii) Wind energy
iii) Hydraulic energy	iv) Tidal energy
v) Wave energy	vi) Geothermal energy
vii) Ocean thermal energy	viii) Biogas energy
ix) Biomass energy	x) Fuel cells

1.5.1.1 Advantages of Non-conventional Energy Sources

The leading advantages of non-conventional energy sources are

1) They are abundantly available in nature.
2) They do not pollute the atmosphere.
3) They are available in large quantities.
4) They are well suited for decentralized use.
5) The plants using these sources have very less (theoretically no) maintenance cost.

1.5.1.2 Disadvantages of Non-conventional Energy Sources

The disadvantages of non-conventional energy sources are

1) They are available at very low intensities.
2) These sources are available in nature during particular periods which is uncertain.
3) Less efficiency of the power plants.
4) High initial cost.

1.5.2 Conventional or Non-renewable Energy Sources

These are the energy sources which once used cannot be recovered any more. They are depleting in nature.

The various non-renewable energy sources are

i) Thermal energy from a) Coal coke b) Petroleum products like petrol, Diesel, Kerosene etc. c) Natural gas.

ii) Nuclear energy.

1.5.2.1 Advantages of Conventional Energy Sources

Following are the advantages of conventional energy sources.

1) Their efficiency is more.

2) Their initial cost is comparatively less.

3) Their intensities are high.

1.5.2.2 Disadvantages of Conventional Energy Sources

The disadvantages of conventional energy sources are

1) Their running and maintenance cost is high.

2) They are depleting in nature.

3) They cause pollution to atmosphere by different means.

Comparison between renewable and non-renewable energy sources

Sr. No	Renewable energy sources	Non-renewable energy sources
1.	They don't cause pollution to atmosphere.	They cause pollution to atmosphere.
2.	Their efficiency is comparatively less.	Their efficiency is comparatively high.
3.	They are available at low intensities.	They are available at high intensities.
4.	Their initial cost is comparatively less.	Their initial cost is comparatively high.
5.	Their running cost is less.	Their running cost is more.

.6 Electrical Equipments used in Power Station

A power station generates an electrical energy by using one of the energy sources. modern power station contains number of electrical equipments. The important electrical quipments are,

. **Alternator :** This is most important equipment. It is always coupled to the turbine, hichever type of the station it may be i.e. steam, gas, nuclear etc. The turbine acts as a rime mover of alternator. The alternator converts the mechanical energy received from e turbine into an electrical energy.

Alternators are generally hydrogen cooled or air cooled. The necessary excitation to the alternators is provided by the main and pilot exciters directly connected to the alternator shaft.

2. Transformer : This is another important electrical equipment which is used to raise or lower the available voltage levels as per the requirement. In a power station, different types of transformers are used, which are :

i) Main step up transformer which steps up the generated voltage for the further transmission.

ii) Station transformer which is used for the general service in the power station itself.

iii) Auxiliary transformers which supply to individual auxiliary unit.

3. Switchgear : This includes such a equipment which locates the fault on the power system and isolates the faulty part from the system. It contains circuit breakers, relays, isolating switches, fuses and other controlling devices.

Alternator gives its output to the bus bar through the transformer and proper switchgear equipments.

1.7 Steam Power Station

A generating station which converts the heat energy of coal 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 coal 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. 1.7.

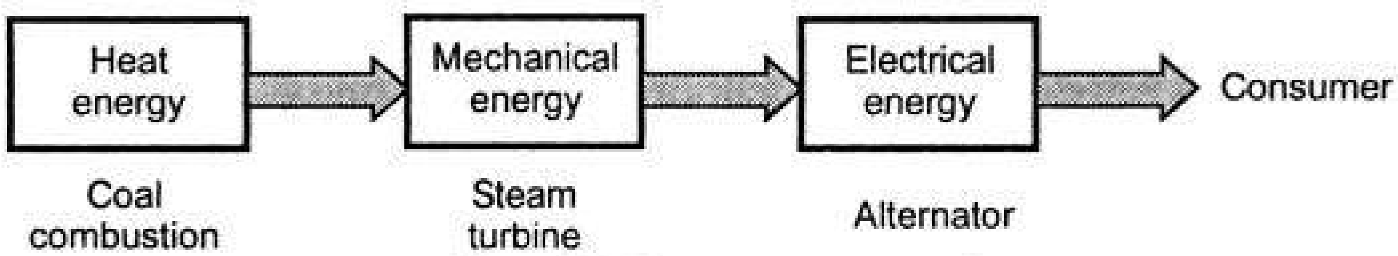

Fig. 1.7 Energy conversion

1.7.1 Factors for 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 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 be near 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, the 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 voltages 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 factors affect the selection of site for the steam power station.

1.7.2 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. 1.8 shows the schematic arrangement of steam power station. (See Fig. 1.8 on next page)

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 bus bar 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 called condensate. Using the condensate extraction pump, the condensate is taken to economizer. The economizer again transfers the heat from flue gases to the condensate and then transfers the heated water to the boiler. Thus the cycle is completed. The exhaust flue gases are released to the atmosphere through the chimney.

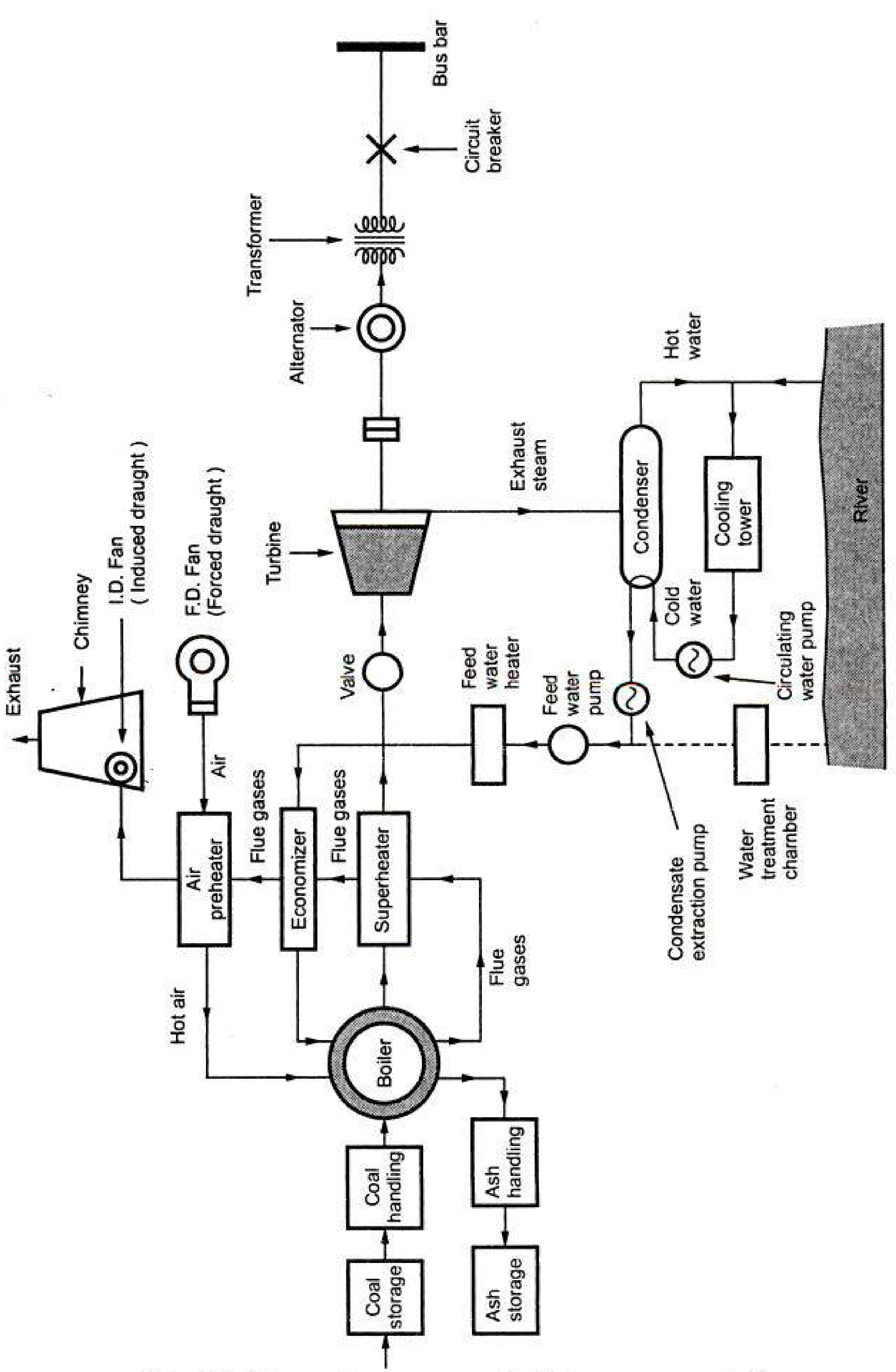

Fig. 1.8 Schematic arrangement of steam power station

1.7.3 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. Cooling water circuit

1.7.3.1 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 coal 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.

1.7.3.2 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 coal 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 coal 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 metre of the boiler surface.

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

1.7.3.3 Steam Turbine

The dry and superheated steam from the superheater is supplied to the turbine. The heat energy of the steam is converted to the mechanical 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 steam 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 turbine 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.

1.7.3.4 Alternator

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

1.7.3.5 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 boiler needs clean and soft water for longer 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.

1.7.3.6 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 creates 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.

1.7.4 Advantages

1. The fuel used is a coal, which is cheap.
2. The initial cost is less compared to other power stations.
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 to the site hence site can be anywhere and not always near the coal mines.
6. The cost of the generation is less than the diesel.

1.7.5 Disadvantages

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

1.7.6 Efficiency

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

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.

$$\eta_{thermal} = \frac{\begin{bmatrix}\text{Heat equivalent of mechanical energy} \\ \text{transmitted to turbine}\end{bmatrix}}{\text{Heat of coal combustion}}$$

The **overall efficiency** is the ratio of heat equivalent of electrical output from alternator to the heat of coal combustion. The overall efficiency of 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 %.

1.8 Hydro-electric Power Station

A power generating 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. 1.9.

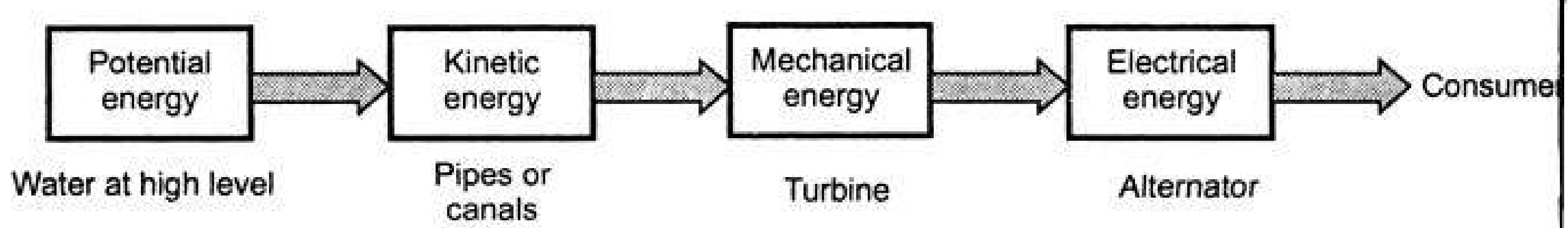

Fig. 1.9 Energy conversion

1.8.1 Factors for Selection of Site

The water reservoir like dam cannot be constructed anywhere. There are number of factors 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 is 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 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.

1.8.2 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. 1.10 shows the schematic arrangement of hydro-electric power station which uses water supply from an artificially constructed dam.

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

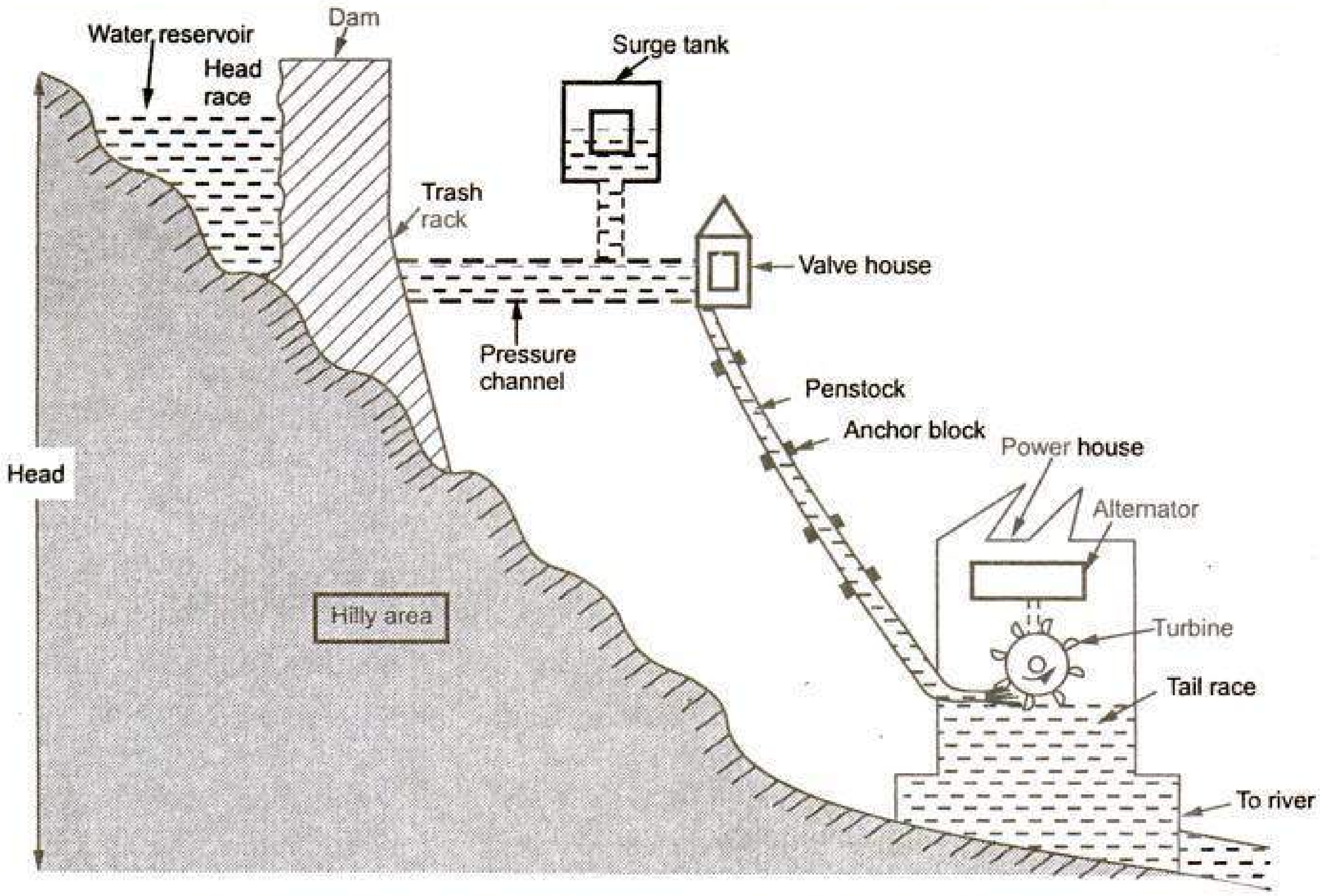

Fig. 1.10 Schematic arrangement of hydro-electric power plant

pass to the turbine. The pressure channel 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 penstocks 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.

1.8.3 Constituents of Hydro-electric Power Station

Let us discuss the constituents and their functions in the operation of the hydro-electric power station.

1.8.3.1 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 is selected according to the topography of the site and economical aspects.

1.8.3.2 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.

1.8.3.3 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 the 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.

1.8.3.4 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.

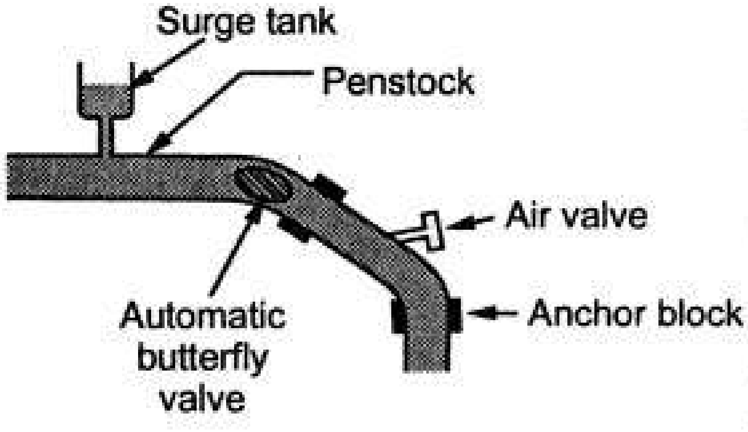

Fig. 1.11 Protecting devices of penstock

There are certain protective devices attached to the penstocks. These devices are shown in the Fig. 1.11.

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.

1.8.3.5 Water Turbines

The main two types of water turbines are,

i) Impulse and ii) Reaction

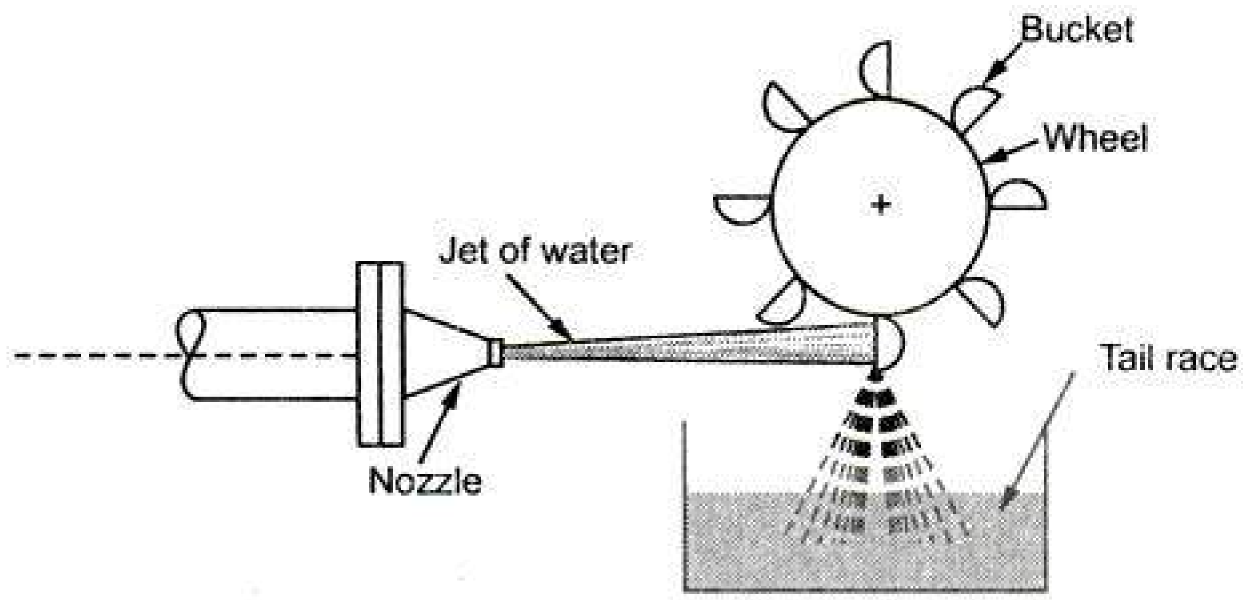

Fig. 1.12 Impulse turbine

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 with a large velocity which drives the wheel. The pelton wheel is an example of impulse turbine which is shown in the Fig. 1.12.

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 spear at the tip of the nozzel. 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.

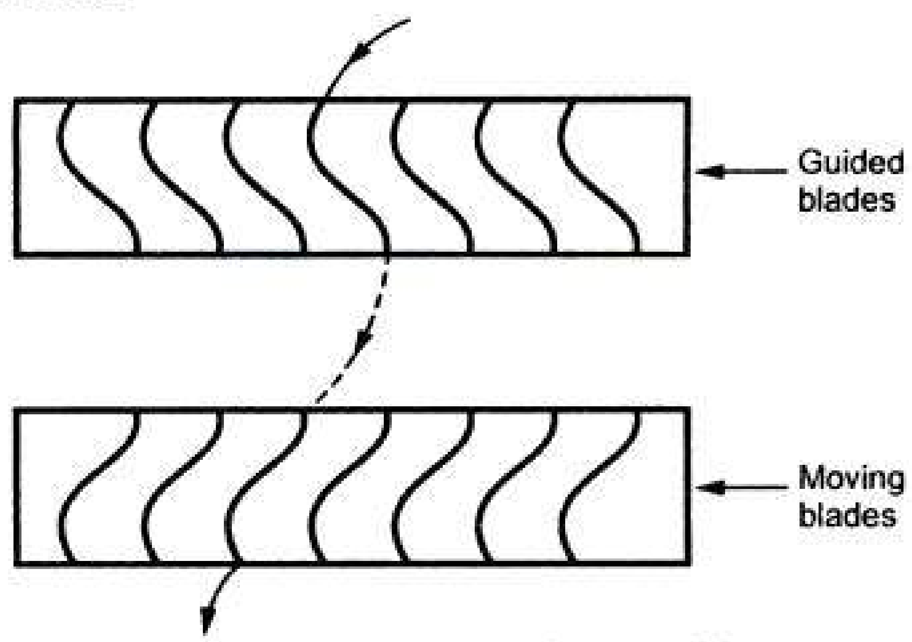

Fig. 1.13 Reaction turbine

In the reaction turbines, the water enters the runner, partly with pressure and partly with velocity head. There are two types of reaction turbines.

i) Francis and ii) Kalpan

The Fig. 1.13 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.

1.8.4 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 these 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 requirement is low.

.8.5 Disadvantages

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.

.9 Nuclear Power Station

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

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

The heat energy thus released is used in raising 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. 1.14.

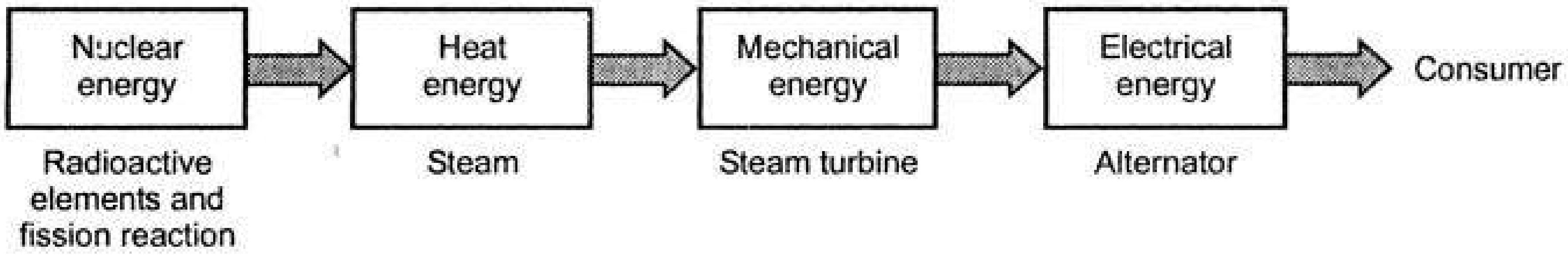

Fig. 1.14 Energy conversion

1.9.1 Conversion of Nuclear Energy

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

$$E = mc^2$$

where E = Energy released in joules

m = Actual mass converted into energy in kg

c = Velocity of light = 3×10^8 m / s

There are three types of nuclear reactions, 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 neutrons for each one absorbed in fission.

The immediate products of fission reactions such as xenon (Xe^{140}) and strontium (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.

1.9.2 Factors for 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 available.

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 disposed quickly. Such a waste is either burried in deep pits or disposed 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 affect the selection of site for the nuclear power station.

1.9.3 General Arrangement of Nuclear Power Plant

The Fig. 1.15 shows the schematic arrangement of a nuclear power plant.

The entire arrangement can be divided into following stages.

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

1.9.4 Nuclear Reactor

This represents that part of a nuclear power plant where U^{235} fuel is subjected to a controlled fission chain reaction, during which tremendous energy is generated.

The Fig. 1.16 shows the various components of a nuclear reactor and a heat exchanger.

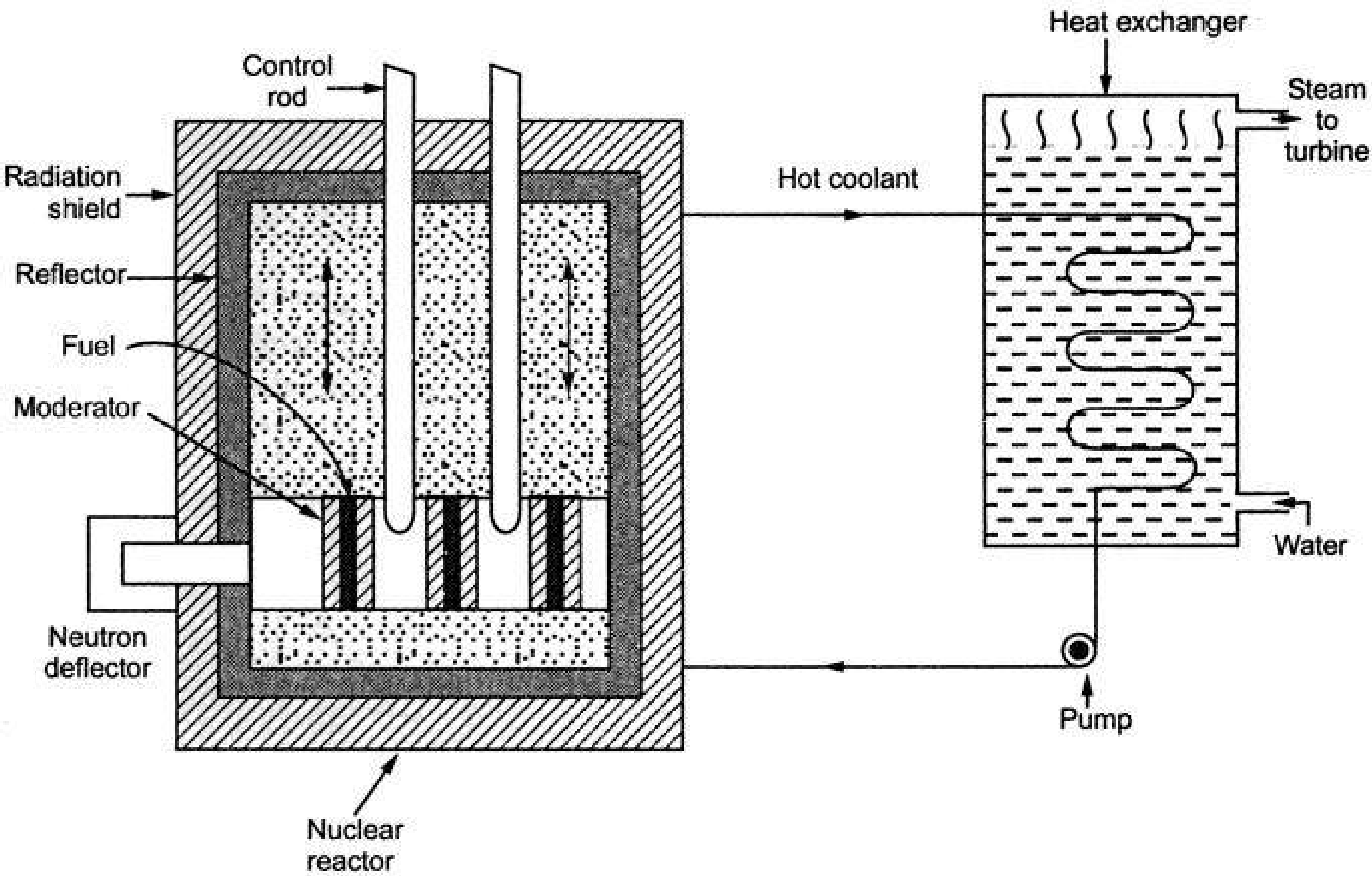

Fig. 1.16 Nuclear reactor and heat exchanger

The following are the components of the nuclear reactor.

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 reduces 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 steam generation. The coolant in the reactor keeps the temperature of fuel below safe level by continuous removal of the energy from the core. The liquid metals like sodium or potassium are used as coolants.

6. Radiation shield : The radiations 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 metres of the concrete outside are used as the radiation shield.

1.9.5 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 into steam. Thus the heat exchanger is nothing but a steam generator. Once the heat is exchanged, the coolant is fed back to the reactor, using the coolant recirculating pump.

1.9.6 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.

1.9.7 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.

1.9.8 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. Then 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.

1.9.9 Advantages

1. The amount of fuel required is very small.
2. There 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 lack 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.

1.9.10 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 cannot respond instantly to the load fluctuations.
8. The fuel may be misused in weapons.

1.10 Gas Turbine Power Station

A power station which uses the gas turbine as the prime mover for the alternator, to produce an electrical energy is called gas turbine power station.

In a gas turbine power plant, air is used as a working fluid. The compressor is used to compress the air. The compressed air is taken to the combustion chamber. This adds heat to the air. This increases the temperature of the air. The air is heated either by burning the fuel or using the air heaters.

The hot and high pressure air is then transferred to the gas turbine. Here the air is expanded and drives the turbine. Thus the heat energy is converted to the mechanical

1.17 Solar Power Plant

The surface of the earth receives from sun about 10^{14} 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. Therefore it requires a large capital investment for conversion apparatus.

Flat Plate Solar Collector

Fig. 1.25 shows a flat plate collector which consists of following components.

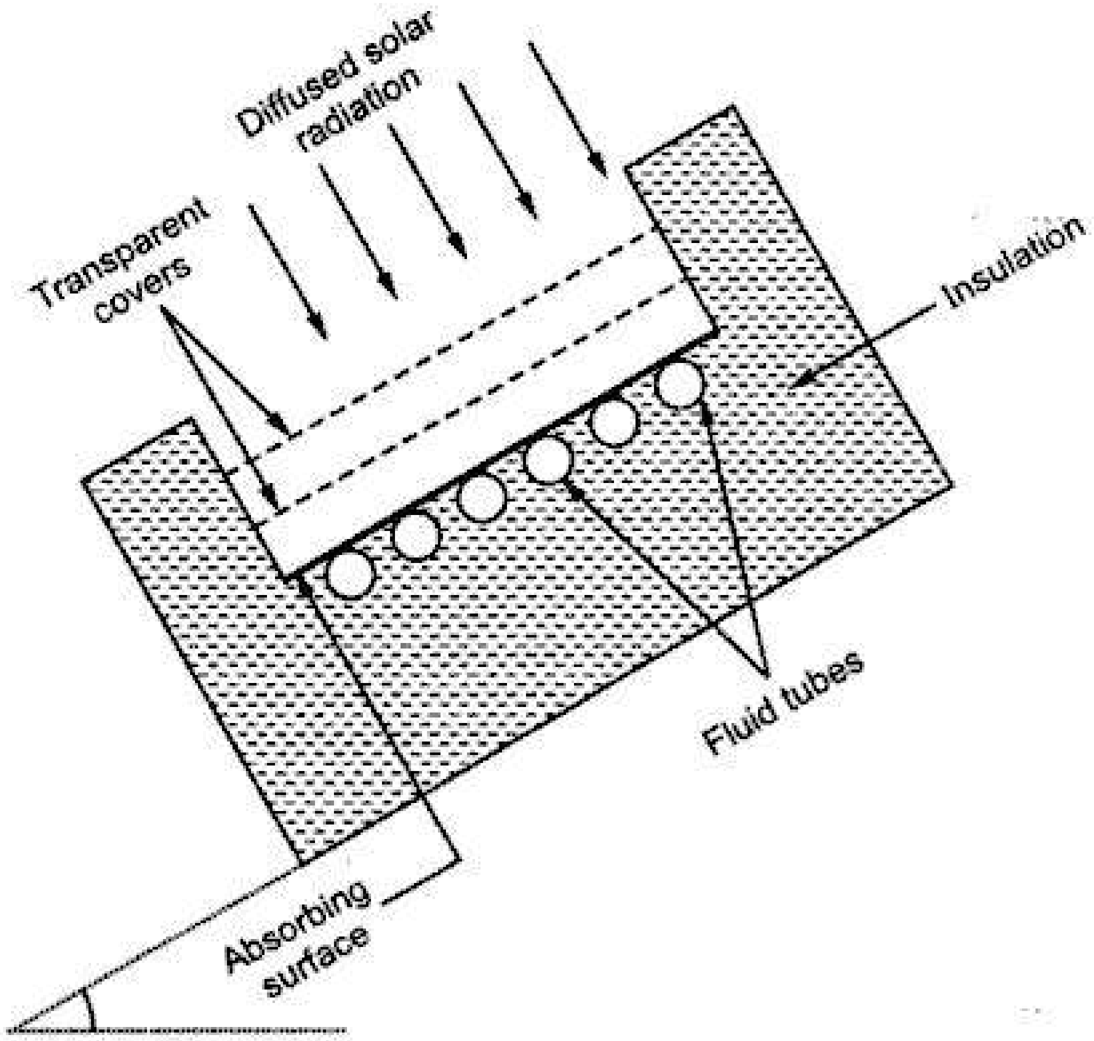

Fig. 1.25 Flat plate solar collector

i) An absorber plate : It intercepts and absorbs solar radiations.

iii) 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.

iv) Insulation : It is placed beneath absorber plate. It minimises and protects absorbing surface from heat losses.

Solar Power Plant

Fig. 1.26 represents a schematic diagram of solar power plant.

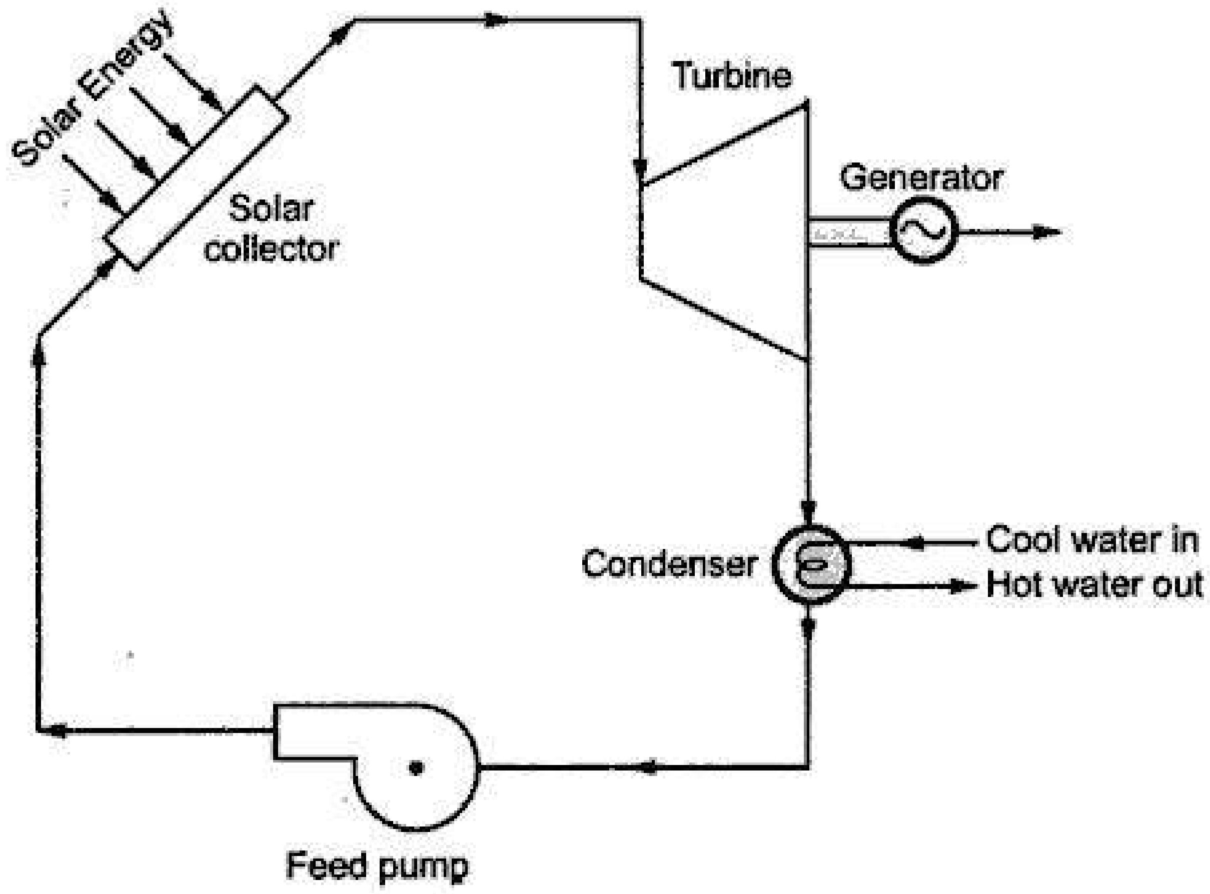

Fig. 1.26 Solar power plant

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 utilised 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. Therefore, 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.

Energy Conversions

Heat Energy ⇒ Mechanical Energy ⇒ Electrical Energy

1.17.1 Advantages

Solar energy has following advantages.

1) **Solar radiation doesn't 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.

1.17.2 Disadvantages

Following are disadvantages of solar energy.

1) Collections and conservation of solar energy into useful forms must be carried out over a large area which requires a large capital investment for conversion.

2) Such power plants require direct light and are not operative when the sun is even partly covered with clouds.

3) Reflecting surfaces undergo deterioration with passage of time.

4) These power plants are uneconomical.

1.18 Wind Power Plant

Wind flow is created as an effect of solar energy which creates low and high pressure regions on the earth due to the heating. This wind is used to run a wind mill which in turn drives a generator to produce electricity. In India, high wind speeds are available in coastal areas of Sourashtra, Western Rajsthan and some parts of central India. In Maharashtra wind mills are erected at various places like Brahmanwel in Dhule district, near Supa in Ahmednagar district and chalkewadi, Thoseghar in Satara district.

Fig. 1.27 shows a schematic arrangement of a horizontal axis wind-electric generating power plant. The various parts of this power plant are -

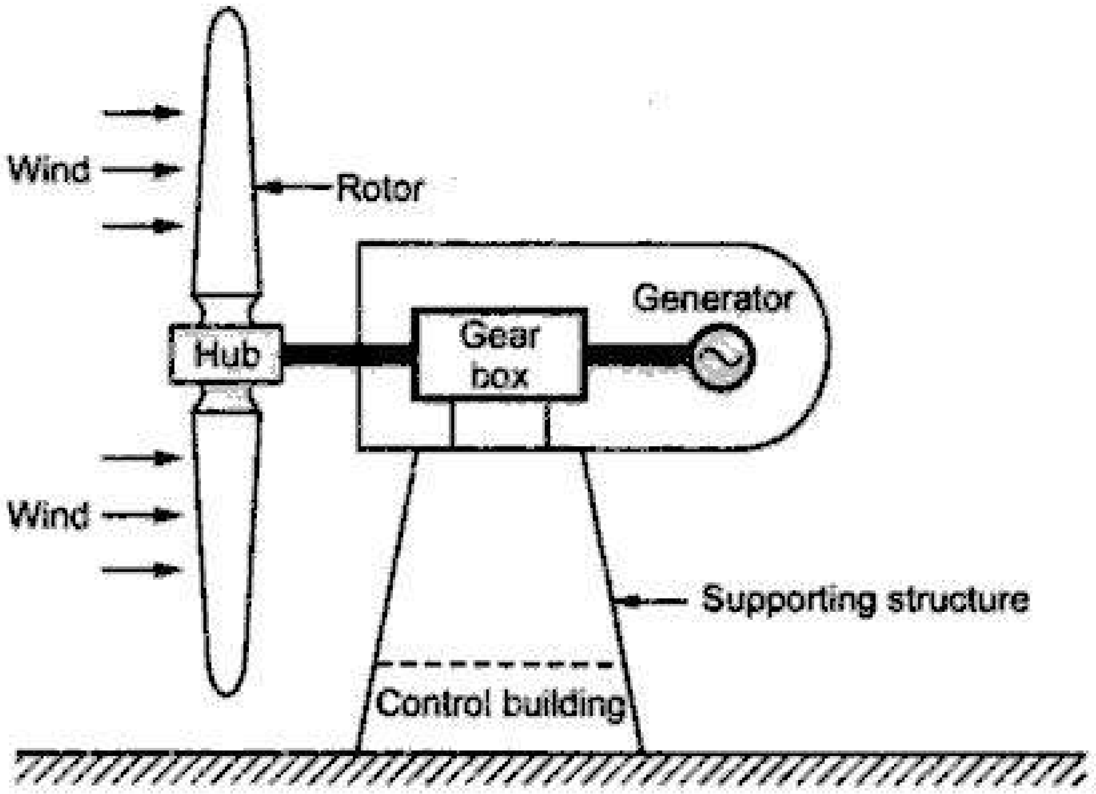

Fig. 1.27 Horizontal axis wind mill

1) Wind rotor

2) Gear box

3) Electrical generator

4) Supporting structure.

1) Wind rotor : These blades (rotors) are attached on the hub which is connected to shaft. These blades have specific design.

2) Gear box : The shaft of the hub acts as input to the gear box. R.P.M. of the shaft is increased in the ratio upto 1 : 100 in the gear box, to produce electricity.

3) Electrical generator : The shaft is further connected to generator shaft. When shaft rotates, the generation shaft in turn rotates producing electrical energy in generator. Thus mechanical energy is converted into electrical energy.

4) Supporting structure : The supporting structure is designed to withstand the wind load. Its type and height is related to the cost and transmission system incorporated. Horizontal axis wind turbines are mounted on towers so as to be above the level of turbulence and other ground related effects.

Conversion of energy

Kinetic energy ⇒ Mechanical energy ⇒ Electrical energy

1.18.1 Advantages

Wind energy offers following advantages.

1) It is available at free of cost.
2) It is available in many off-shore, on-shore, remote areas helpful in supplying electric power to remote areas.
3) It is cost effective and reliable.
4) It supplies energy in rural areas.
5) It doesn't cause pollution during energy generation.
6) It is economically competitive.

1.18.2 Disadvantages

Following are the disadvantages of wind energy.

1) It has low energy density.
2) It is favourable in geographical locations away from cities.
3) The supply is variable, unsteady, irregular, intermittent and sometimes dangerous.
4) Wind turbine design, manufacture and installation have proved to be complex due to widely varying atmospheric conditions in which they have to operate.
5) It has high capital cost per kWh.
6) It requires energy storage batteries which indirectly and substantially contribute to environmental pollution.
7) Wind farms can be located only in vast open areas which are away from load centres.

Examples with Solutions

Example 1.7 : *The supply system has following types of loads*

Type of load	M.D. (kW)	L.F.(%)	Diversity factor	Overall diversity
Domestic	2000	25	1.2	1.35
Commercial	5000	30	1.15	
Idustrial	8000	75	1.25	

What are connected load of each category if the demand factor for domestic, commercial and idustrial loads are 50, 60 and 80 percent respectively. Find i)Maximum demand ii)Daily energy consumption iii) Load factor.

Solution : Sum of individual maximum demands = 2000 + 5000 + 8000 = 15000 kW

Overall diversity factor = 1.35

∴ Maximum demand can be calculated as,

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand}}$$

$$\therefore \quad \text{Maximum demand} = 1.35 \times 15000 = \mathbf{20250\ kW}$$

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

$$\therefore \quad \text{Average load} = \text{Load factor} \times \text{Maximum demand}$$

1.18.2 Disadvantages

Following are the disadvantages of wind energy.

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1.4.4 Advantages of High Voltage Transmission

Summarizing the above discussion, the advantages of high voltage transmission can be stated as,

1. The line losses are inversely proportional to the square of voltage and power factor. So line losses are less.
2. For constant losses, the volume of copper required is inversely proportional to the square of the voltage and power factor. Hence the copper required is much less for high voltage transmission.
3. For constant current density, the line efficiency is very high for high voltage transmission.
4. The percentage line drop is very small for the high voltage transmission.

It may be noted that along with the voltage level, the power factor also plays an important role. Higher power factor also gives less losses, reduced volume of copper and increased line efficience. Hence consumers are always recommanded to maintain high power factor values.

1.4.5 Disadvantages of High Voltage

Though high voltage transmission offers number of advantages, very high voltage transmission is not practically possible. There is a limit to increase the level of transmission voltage. The high voltage transmission has following limitations.

1. Higher the transmission voltage, higher is the insulation required which can cause problems in connection with conductor supports and clearance between the conductors.
2. Higher insulation means high cost.
3. The cost of transformers, switchgear and other equipments is also high for high voltages.
4. Higher the voltage, severe is the corona effect.

Thus a compromise is necessary to select a transmission voltage. The insulation and other cost must be compensated by reduction in cost due to copper saving.

1.4.6 Practical Transmission and Distribution Voltage Levels

Considering the advantages and limitations of high voltage and economical aspects, the following voltage levels are commonly used for the transmission and distribution.

1. For generation : 6.6 kV, 11 kV, 22 kV or 33 kV.
2. For primary transmission : 66 kV, 132 kV, 220 kV upto 400 kV.
3. For secondary transmission : 11 kV, 22 kV or 33 kV.
4. For primary distribution : 6.6 kV or 11 kV.
5. For secondary distribution : 230 V and 400 V.

1.5 Types of Transmission

In general two types of systems are used for the transmission.

1. Overhead system   2. Underground system

1.5.1 Overhead System

In this system, the transmission of electrical power is by using overhead transmission lines over long distances. In such system, the appropriate spacing is provided between the conductors, at the supports as well as at the intermediate points. This spacing provides insulation which avoids an electric discharge to occur between the conductors. The transmission by overhead system is much cheaper than the underground system. The overhead transmission lines are subjected to the faults occurring due to lightening, short circuits, breakage of line etc. but overhead lines can be easily repaired compared to underground system. It is also true that though such faults are rare, if occurred it is very difficult to find exact point of fault as transmission lines are very long. In the overhead system, the insulation must be provided between the conductor and supporting structure. Hence the **maximum stress exists between conductor and earth.**

1.5.2 Underground System

The cables are generally preferred in underground system. All the conductors must be insulated from each other in the underground system. As voltage level is high, insulation required is more. Hence due to insulation difficulties, the voltage level used in underground system is below 66 kV while the voltage level used in overhead transmission lines can be as high as 400 kV. The maintenance cost of the underground system is less compared to overhead system. In crowded areas, overhead system using bare conductors is not practicable where underground system using cables is preferred. The line surges are suppressed by using the cables hence cable must be used for the last part of the connection which can save transformers and generators from the damage due to line surges.

In the underground system, the **maximum stress exists on the insulation between the conductors.**