CHAPTER 11

GENERATING STATIONS

11.1 Introduction

Electrical energy is considered superior to all other forms (Chemical, heat, light or sound) of energy. It is much cheaper than that in other forms and therefore it is economical to use energy in this form for domestic, commercial, industrial and agricultural purposes.

Electrical energy is a very convenient form of energy and it can be easily converted, into other forms of energy. The ever increasing use of electric power for different purposes necessitates to provide bulk electric power economically. This is achieved with the help of suitable power producing units, known as generating stations. A generating station essentially employs a Prime-mover coupled to an alternator. The prime-mover converts energy from some other form into mechanical energy. The alternator convents mechanical energy into electrical energy. The electrical energy produced by the generating station is transmitted and distributed with the help of conductors to various consumers.

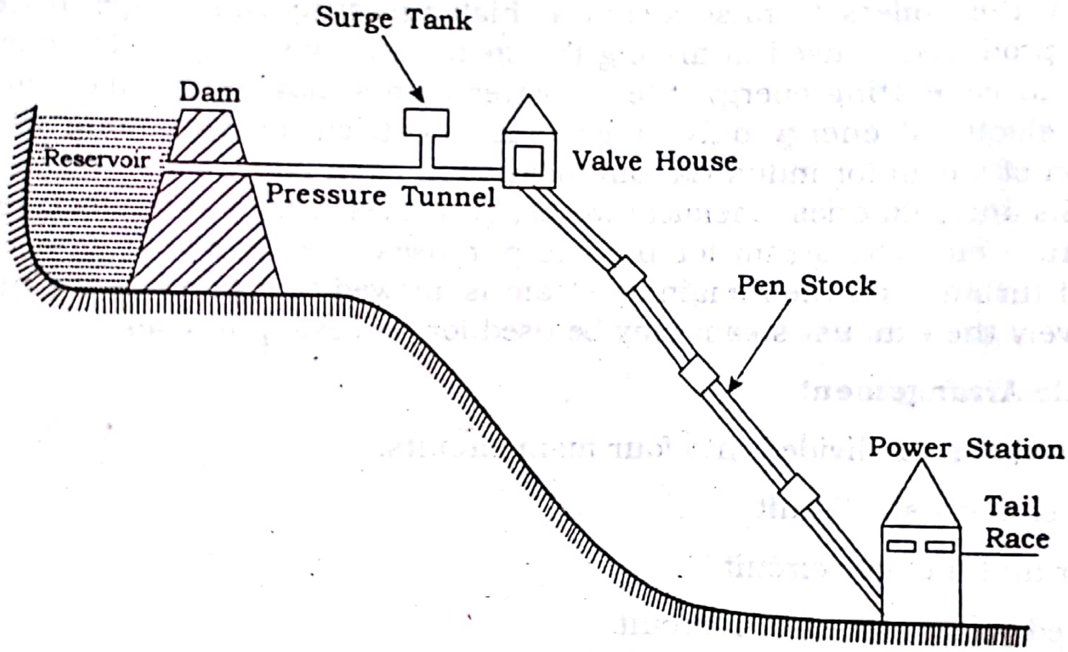
Depending upon the form of energy converted into electrical energy, the generating stations are classified as (i) Hydro-electric power stations (ii) Thermal Stations (iii) Nuclear power stations and (iv) Diesel power stations.

11.2 Hydro-electric Power Station

Hydro-electric power plant is the power plant utilizing the potential energy of water at a high level for the generation of electrical energy. It cannot be located everywhere. Firstly there must be an ample quantity of water at sufficient head and secondly a suitable site must be available. The amount of power that can be developed depends on the quantity of water available, the rate at which it is available, the head etc. In a hydro-electric power station, water head is created by constructing a dam across a river or lake. The pressure head of water or kinetic energy of water is utilized to drive the water turbines coupled to alternators and, therefore, generation of electrical power.

Schematic Arrangement of a Hydro-Electric Plant

The schematic arrangement of a typical hydro-electric plant is shown in figure. An artificial storage reservoir is formed by constructing a dam across a river and a pressure runnel is taken off from the reservoir to the valve house at the start of the penstock. The valve house contains main sluice valves for cutting off water flow to the power station and automatic isolating valves for cutting off water supply in case the penstock bursts. A surge tank is also provided just before the valve house for better regulation of water pressure in the system. From the reservoir the water is carried to valve house through pressure tunnel and from valve house to the water turbine through pipes of large diameter made of steel or reinforced concrete, called the penstock. The water turbine converts hydraulic energy into mechanical energy and the alternator coupled to the water turbine converts mechanical energy into electrical energy. Water after doing useful work is discharged to the tailrace.



Schematic arrangement of a Hydro-electric power station.

Advantages of Hydro-Electric Plants

1. No fuel is required by such plants as water is the source of energy. Hence operating costs are low.
2. The plant is highly reliable and it is cheapest in operations and maintenance.
3. It is very neat and clean plant because no smoke or ash is produced.
4. Such plant are robust and have got longer life.
5. Highly skilled engineers are required only at the time of construction but later on only a few experienced persons will be required.
6. Such plants in addition to generation of electric power also serve other purposes such as irrigation and flood control.

Disadvantages

1. It requires large area.
2. Its construction cost is very high and takes long time for errection.
3. Long transmission lines are required as the plants are located in hilly areas which are quite away from the load centre.
4. There is uncertainty about the availability of huge amount of water due to dependence of weather conditions.

11.3. Thermal Stations (Steam power plants)

In steam power plants, the heat of combustion of fuels (Coal, Oil or Gas) is utilized by the boilers to raise steam at high pressure and temperature. The steam so produced is used in driving the steam turbines coupled to generators and thus in generating energy. Steam power plants may be installed either to generate electrical energy only or generate electrical energy along with the generation of steam for industrial purposes such as in paper mills, textile mills, sugar mills and refineries, chemical works, breweries, plastic manufacture, food manufacture etc. The steam for process purposes is extracted from a certain section of turbine and the remaining steam is allowed to expand in the turbine. Alternatively the exhaust steam may be used for process purposes.

Schematic Arrangement

The plant can be divided into four main circuits.

(a) Fuel and Ash Circuit

(b) Air and fuel gas circuit

(c) Feed water and steam circuit

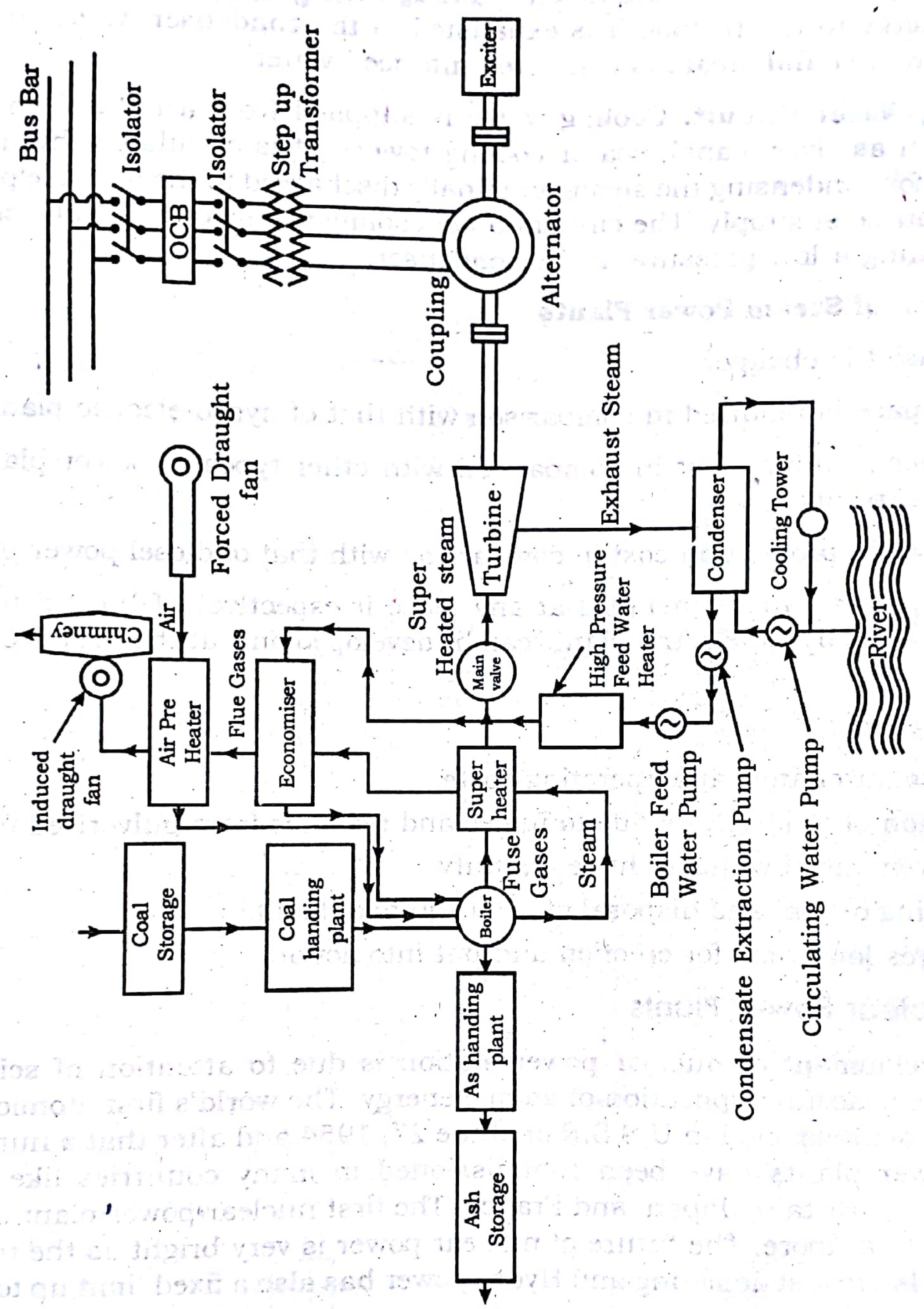
(d) Cooling water circuit

Fuel and Ash Circuit

Fuel from the storage is fed to the boiler through fuel feeding device. Ash produced as a result of combustion of coal collects at the back of the boiler and is removed to ash storage through ash handling equipment.

Air and Fuel Gas Circuit

Air is drawn from the atmosphere by a forced draught fan through the air pre-heater, in which it heated by heat of flue-gases passing to chimney, and then admitted to the furnaces. The flue-gases after passing around boiler tubes and super heater tubes are drawn by the induced draught fan through dust collector economizer and air pre-heater and finally exhausted to the atmosphere through chimney.



Feed Water and Steam Circuit. The condensed water is extracted from the condenser by the condensate pump and is then forced to the I.P. feed water heater, where its temperature is raised by the heat from bled steam. The feed water is now pumped to high-pressure water heater, where it gets heated by the heat from bled steam extracted at suitable point of steam turbine. It is then pumped into boiler through economizer, in which it is further heated by the heat of flue gases. In boiler water is converted into high-pressure steam, which is wet. Wet steam is passed through super heater, where it dried and further superheated, and then supplied to the steam turbine through the main valve. After giving out its heat energy to the turbine it is exhausted to the condenser where its latent heat is extracted and steam is converted into feed water.

Cooling Water Circuit. Cooling water is supplied from a natural source of supply such as river, canal, sea or cooling towers. It is circulated through the condenser for condensing the steam and finally discharged to the suitable position near the source of supply. The circulation of cooling water to the condenser help in maintaining a low pressure in the condenser.

Advantages of Steam Power Plants

1. Fuel used is cheaper
2. Less space is required in comparison with that of hydro-electric plants.
3. Cheaper in initial cost in comparison with other types of power plants of same capacity.
4. Cheaper in production cost in comparison with that of diesel power plants.
5. Such plants can be installed at any place irrespective of the existence of fuels, while hydro-electric plants can be developed only at the source of water power.

Disadvantages:

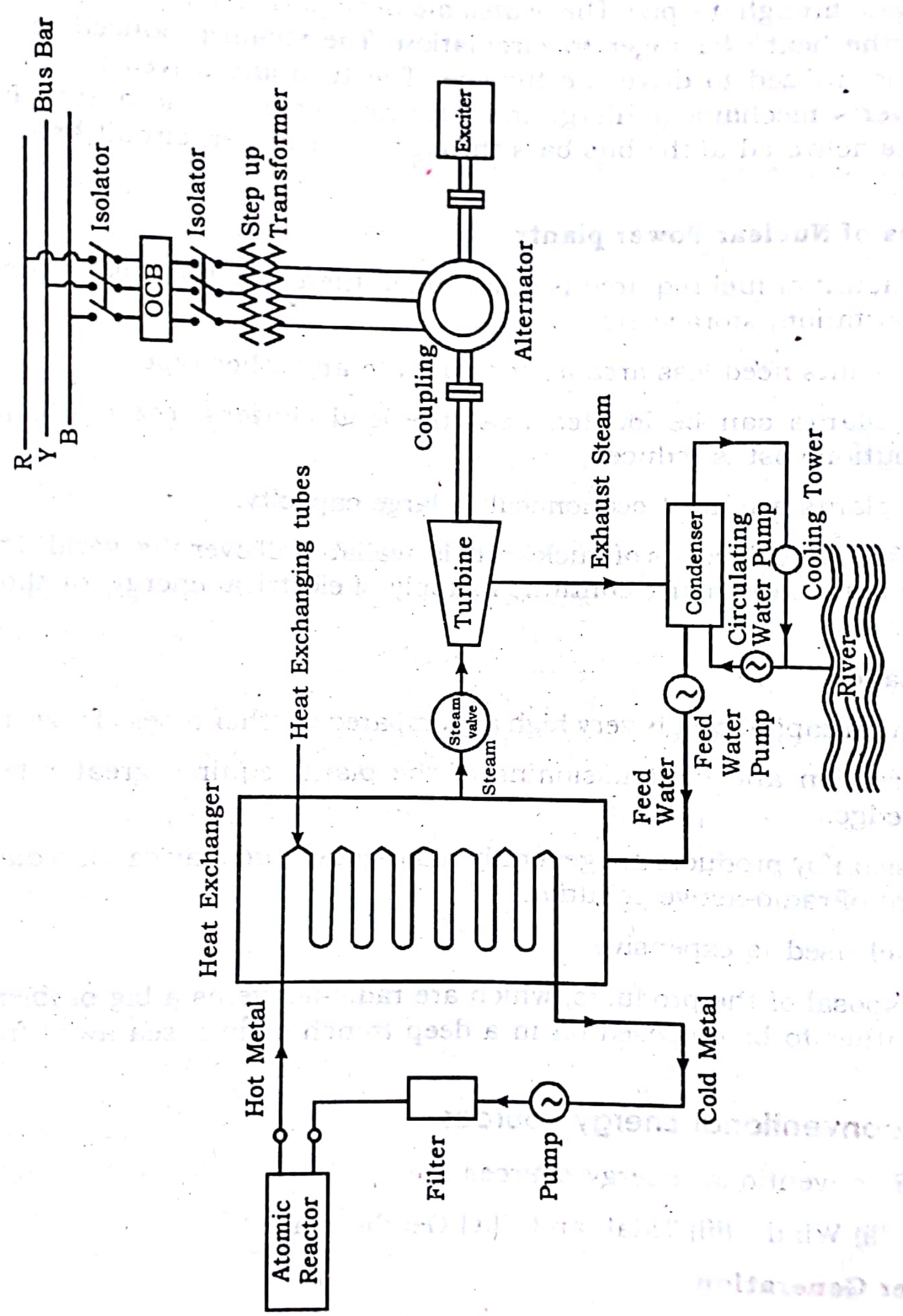
1. High maintenance and operating costs.
2. Pollution of atmosphere due to fumes and residues from pulverized fuels.
3. Requirement of water in huge quantity.
4. Handling of coal and disposal of ash is quite difficult.
5. Requires long time for erection and put into action.

11.4 Nuclear Power Plants

The development of nuclear power station is due to attention of scientists towards the peaceful application of atomic energy. The world's first atomic power plant was commissioned in U.S.S.R on June 27, 1954 and after that a number of atomic power plants have been commissioned in many countries like U.S.A. Canada, Great Britain, Japan and France. The first nuclear power plant in India is located at Tarapore. The future of nuclear power is very bright as the reserves of fossil fuels are fast depleting and Hydro power has also a fixed limit up to which it can be exploited.

In Nuclear power station, nuclear energy is converted into electrical energy. The main atomic fuels used are Uranium and Thorium. These are subjected to nuclear fission in a special apparatus known as reactor. The heat energy thus released is utilized in raising steam at high temperature and pressure. The steam runs the steam turbine which convents steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

Schematic Arrangement of Nuclear Power Plant



A nuclear power plant consists of a nuclear reactor (For heat generation), heat exchanger (For converting water into steam), steam turbine, Alternator, Condenser etc. The reactor and the cooling circuit have to be heavily shielded to eliminate radiation hazards.

The heat energy produced in breaking of atoms of Uranium by fission process in an atomic reactor is extracted by pumping fluid or molten metal like liquid sodium or gas through the pile. The heated metal or gas is then allowed to exchange its heat to the heat exchanger by circulation. The steam produced in the heat exchanger is utilized to drive the turbine. The turnbine drives the alternator, which converts mechanical energy into electrical energy. The output from the alternator is delivered to the bus bars through transformer, circuit breakers and isolators.

Advantages of Nuclear Power plants

1. The amount of fuel required is quite small, therefore, there is no problem of transportation, storage etc.
2. These plants need less area as compared to any other type.
3. These plants can be located near the load centers, therefore, primary distribution cost is reduced.
4. These plants are most economical in large capacity.
5. There are large deposits of nuclear fuels available all over the world. Therefore such plants can ensure continued supply of electrical energy for thousands of years.

Disadvantages

1. The initial capital cost is very high as compared to other types of power plants.
2. The erection and commissioning of the plant requires greater technical knowledge.
3. The fission by products are generally radio-active and may cause a dangerous amount of radio-active pollution.
4. The fuel used is expensive
5. The disposal of the products, which are radio-active, is a big problem. They have either to be disposed off in a deep trench or in a sea away from sea-shore.

11.5 Non conventional Energy Sources

The non conventional energy sources are

(i) Sun (ii) Wind (iii) Tidal and (iv) Geothermal.

Solar Power Generation

The sun is the primary source of energy. Solar energy appears to be the most promising among the non-conventional sources of energy. Sun radiates energy of about 3.5×10^{23} kW into space and only 2×10^{14} reaches the earth. This stupendous solar energy, which is non-exhaustible and completely pollution free, could drive the civilization forever, if it could be properly and economically harnessed. However, it has got some series draw-backs. Energy density per unit area is very low, it is available for only a part of the day, and cloudy and hazy atmospheric conditions largely reduce the energy received.

The generation of electrical energy from solar energy is of special importance for India.

The reasons are:

(i) There is a need for conservation of fossil fuel resources, such as gas, oil, coal etc.

(ii) There is a need for reducing atmospheric and thermal pollution which are having serious detrimental effects on our environments.

(iii) There is a need for supply of electrical energy in remote areas.

Since solar energy is widely spread and so there is a need to make it available in concentrated form for which collectors are used. The surface of these collectors are designed for high absorptive and low emissivity. Collectors are of tow types namely flat plate collectors and focusing collectors.

There are two methods for converting solar energy into electrical energy.

(i) Direct Conversation Method. It is possible to convert solar energy directly into electrical energy by means of silicon wafer photo-voltaic cells, also called the solar cells. The solar cells operate on the principle of photo-voltaic effect, which is a process of generating an e.m.f as a result of the absorption of ionizing radiation. Thus a solar cell is a transducer, which converts the sun's radiant energy directly into electrical energy.

(ii) Conventional boiler method. Large parabolic collectors are employed for collecting solar energy, which is used to heat a fluid. This heat energy is finally transferred to feed water which is converted into steam. This steam is utilized to run a prime-mover coupled to an electric generator, which generates electric power.

Wind Power Generation

Winds are essentially caused by the solar heating of the atmosphere. They carry enormous quantity of energy. Before the development of electric power on large scale, wind power has served many countries as source of power in early days and were called as Wind Mills. Wind power has been used for centuries to sail vessels, pump water, and grind wheat and corn.

Wind power is non-steady and unreliable. There are wide variations in the speed and direction of winds. Also it does not possess the basis requirements of any energy source i.e., readily availability and long lasting supply. It makes necessary to store wind energy in some other forms during periods of high winds for use later on during calm-such as in the forms of chemical energy in rechargeable batteries, potential energy in high reservoirs, mechanical energies in fly wheels etc.

The wind power can be harnessed to drive a wind turbine, to which is coupled to an alternator. The hollow blades of about 25m diameter are arranged on a tower. The air passes from the hollow chimney to the hollow blade ends, and due to centrifugal force the blades rotate. As the air passes into the tower, it drives the wind turbine and thus generates electrical energy. The speed of the wind may be of the order of 40-80 km ph and an out put of 100 kw can be obtained.

Wind mills are of tow types namely horizontal axis wind mills and vertical axis wind mills. Horizontal axis wind mills are also called the wind axis machines. The axis of rotation of such machines is parallel to the direction of wind. Vertical axis wind mills are also called the cross-wind axis machines. Here, the axis of rotation is perpendicular to the direction of the wind.

Tidal Power Generation

Tidal power represents a permanent source of energy. It can be predicated fairly accurately and is free from all types of pollutions. The rise and fall of tides nearly twice a day are associated with the rotation of earth every 24 hours in relation to both sun and moon.

If tides are available with a large range of several metres, and suitable basin level is provided to store water energy from the tide, the tidal energy stored at height can be utilized to drive a turbine coupled to an electric generator and thus generate electricity. The difference in basin level and sea level provides the head for the turbine.

Geothermal Power Generation

Geo-thermal energy is the energy which lies embedded with in the earth. There are seven types of geothermal resources namely (i) Dry steam fields (ii) West steam fields (iii) Hot water (iv) Geo pressure fields (v) Magma deposits (vi) Hot dry rock (vii) Volcanoes. The first three are called hydro-thermal reservoirs and are the best resources for production of geothermal energy at present.

Dry steam field is the desirable form of geothermal energy. The steam is clean and easy to convert into electrical energy. Steam from the well is collected, filtered to remove abrasive particles and passed through the stream turbines coupled to electric generators.

Geo-thermal energy is in exhaustive, available all the year around, produces minimum pollution, cheaper in production cost and does not involve any combustion of any fuel but have some drawbacks such as poor overall efficiency, requirement of larger areas for its exploitation, possibility of triggering of earthquakes, production of noise during drilling and air pollution.

11.6 Economics of Generation

There are three important types of generating station, namely thermal, hydro-electric and nuclear. While choosing the type of generation we have to consider number of points. Some of these are the kind of fuel available and its cost, availability of suitable sites of a hydro station, nature of load to be supplied etc.

While designing and building a generating station, efforts should be made to achieve overall economy so that the per unit cost of production is as low as possible. There are different factors which influence the production cost such as cost of equipment, depreciation of equipment, interest on capital investment etc.

Important terms

1. Connected load. Connected load is the sum of continuous ratings of all the equipments connected to the system.

For example, If a consumer has connections of ten 40 w lamps and a power plug of 750w, then connected load of the consumer is $10\times40+1\times750=1150$ watts. The sum of the connected loads of all the consumers is the connected load of the power station.

2. Maximum Demand. Maximum demand is the highest demand of load on the power system during a given period.

The nature of load plays an important role in the supply system. Infact the entire system is designed after ascertaining the nature of load and its magnitude. This is decided after a load survey. The system design is not based on the connected load, but on the maximum demand of the system. This is obtained after pooling the individual maximum demands of the consumers. However, this is not as easily ascertained, as the demands of different consumers occur at different times. Actually the loads are classified into different heads i.e., lights fans, domestic power, industrial and commercial. The lighting load comes up mainly during evening hours, say between 6P.M to 10P.M. After 10 P.M. the lighting load reduces to only bout one-tenth value, with very few lights on during that part of the night. The fan load comes up only during the summer months. The industrial load mainly comes up at about 8 A.M. in the morning and may follow the working shift during the day.

The load on the power station varies from time to time. The load variations during the whole day are recorded half hourly or hourly and are plotted against time on a graph. The curve thus obtained is called daily load curve. The maximum ordinate in the load curve gives the maximum demand of the system.

3. Demand Factor. Demand factor is the ratio of maximum demand on the power station to its connected load.

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

The value of demand factor is usually less than one because the maximum demand on the power station generally less than the connected load.

4. Average Load. The average of loads occurring on the power station in a given period is known as average load.

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

$$\text{Monthly average load} = \frac{\text{No. of units generated in a month}}{\text{No. of hours in a month}}$$

$$\text{Yearly average load} = \frac{\text{No. of units generated in a year}}{\text{No. of hours in a year}}$$

5. Load Factor. Load factor is the ratio of average load to the maximum demand during a given period.

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

$$= \frac{\text{Energy generated in a given period}}{\text{Max. demand} \times \text{hours of operation in the given period}}$$

Load factor is an important economic consideration, both for the supply company, as well as the consumer. An increase in load factor decreases the generating cost per unit. Load factor is always less than one because average load is smaller than the maximum demand.

6. Diversity factor. Diversity factor is the ratio of sum of consumer's maximum demand to the maximum demand on the power station.

$$\text{Diversity factor} = \frac{\text{Sum of consumer's maximum demand}}{\text{Maximum demand on the station}}$$

The diversity of a load broadly represents the nature of the load and its chances of being used simultaneously by the consumers. If a consumer has 16 light points in his house, but on the average, uses only 8 at a time, the diversity of light load in his premises, would be called as 2, indicating that only about half the connected load will actually come up at a time. Maximum demand is decreased by increasing the diversity. The greater the diversity factor, the lesser is the cost of generation.

7. Plant Capacity Factor. It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period.

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

The plant capacity factor is an indication of the reserve capacity of the plant. A power station is so designed that it has some reserve capacity for meeting the increased load demand in future.

$$\text{Reserve capacity} = \text{Plant capacity} - \text{Max. demand}$$

8. Plant Use Factor. It is the ratio of actual energy produced to the product of plant capacity and the number of hours for which the plant was in operation.

$$\text{Plant use factor} = \frac{\text{Actual energy produced}}{\text{Plant capacity} \times \text{time (hours) the plant was in operation}}$$

Example 1

The maximum demand on a power station is 200MW. If the annual load factor is 60%. Calculate the total energy generated in year?

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

$$\text{Units generated/annum} = \text{Average load in KW} \times \text{hours in a year}$$

$$= \text{Maximum demand in KW} \times \text{load factor} \times \text{hours in a year}$$

$$= 200 \times 10^3 \times 0.6 \times 8760$$

$$= \mathbf{10512 \times 10^5 KWH}$$

Example 2

A generating station has a connected load of 35 MW and a maximum demand of 15MW. The units generated being 45×10^6 per annum. Calculate (i) the demand factor and (ii) load factor?

(i) $$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}} = \frac{15}{35} = 0.4286$$

(ii) $$\text{Average load} = \frac{\text{Units generated / annum}}{\text{Hours in a year}}$$

$$= \frac{45 \times 10^6}{8760} = 5137 \text{ KW}$$

$$\text{load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{5137}{15 \times 10^3} = \mathbf{0.3424}$$

Example 3

A power station supplies the following loads to various consumers:

Industrial consumer - 1250KW

Commercial - 600KW

Domestic power - 70KW

Domestic light - 300KW

If the maximum demand on the station is 2000KW and the number of KWh generated per years is 40×10^5, determine (i) the diversity factor and (ii) annual load factor?

(i) Diversity factor $= \dfrac{\text{Sum of individual max. demands}}{\text{Max. demand on the station}}$

$$= \frac{1250 + 600 + 70 + 300}{2000} = 1.135$$

(ii) Average load $= \dfrac{\text{KWh generated per annum}}{\text{Hours in a year}}$

$$= \frac{40 \times 10^5}{8760} = \mathbf{456.62\ KW}$$

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

$$= \frac{456.62}{2000} = 0.2283 = \mathbf{22.83\%}$$

Example 4

A generating station has a maximum demand of 48000 KW calculate the cost per unit generated from the following data:

Capital cost	=	Rs. 95×10^6
Annual load factors	=	40%
Annual cost of fuel and oil	=	Rs. 9×10^6
Taxes, wages and salaries etc.	=	Rs. 7.5×10^6
Interest and depreciation	=	12%

Solution:

Cost per unit $= \dfrac{\text{Total annual cost}}{\text{Units generated per annum}}$

$$= \frac{\text{Annual fixed charges + annual running charges}}{\text{Units generated / annum}}$$

Annual fixed charges include annual interest and depreciation on capital investment of building and equipment, taxes, salaries of management and clerical staff etc. Annual running charges include annual cost of fuel, lubricating oil, maintenance, repairs and salaries of operating staff etc.

Units generated/annum $= \text{Max.demand} \times \text{L.F} \times \text{hour's in a year}$

$= 48000 \times 0.4 \times 8760 = 16.819 \times 10^7 \text{KWh}$

Annual fixed charges

Annual interest and depreciation = 12% of the capital lost

$= 0.12 \times 95 \times 10^6$

$= \text{Rs. } 11.4 \times 10^6$

Annual running charges

Total annual running charges = Annual cost of fuel and oil + taxes, wages and salaries

$= \text{Rs. } 9 \times 10^6 + \text{Rs. } 7.5 \times 10^6$

$= \text{Rs. } 16.5 \times 10^6$

Total annual charges $= \text{Rs. } 11.4 \times 10^6 + \text{Rs. } 16.5 \times 10^6$

$= \text{Rs. } 27.9 \times 10^6$

$$\text{Cost per unit} = \frac{27.9 \times 10^6}{16.819 \times 10^7}$$

$= \text{Rs. } 0.1658$

= **16.58 paise**