Generation of Electrical Power

THERMAL PLANTS

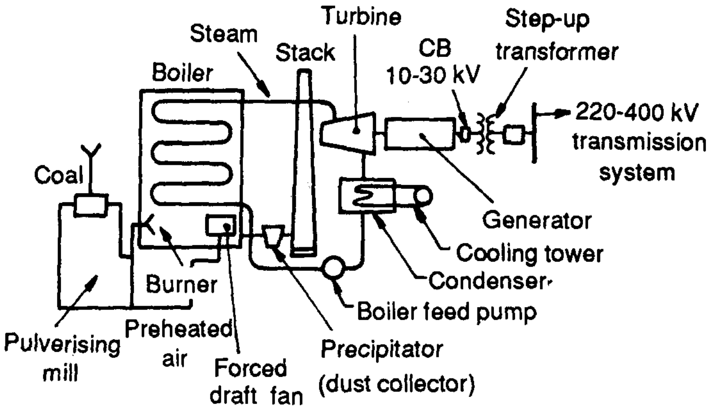
Plant Location

For steam stations, the choice of plant location is governed by the following considerations:

- **Transmission of energy**. A power plant should be located as near the load centre as possible. This reduces th transmission costs and losses in transmission.
- **Cost of real estate and taxes.** Central steam stations need lot of space for installation of equipment and storage of fuel. The cost of land near a load centre may be very high as compared to that at a remote place. In addition to the fixed cost on the capital invested in real estate, the taxes on land should also be taken into account.
- **Transport of fuel**. Central steam stations need lot of coal every day. The site should be such that coal can be transported easily from mines to the plant.
- **Availability of water**. An ample supply of water must be available for condenser cooling water. Thus, sites adjacent to large bodies of water are referable.
- **Disposal of ash**. A central steam station produces huge quantity of ash. A site where ash can be disposed off easily will naturally be advantages.
- **Pollution and noise.** A site near a load centre may be objectionable from the point of view of noise and pollution.
- **Equitable growth of different areas**. It as been seen that availability of power form a nearby sources in an area encourages setting up of heavy industries in that area. As a result of big industries, ancillary industries also come up. This can improve the economy of a backward area considerably. In a welfare state committed to growth of all regions, some power plants should, therefore, be located in backward areas. These areas offer the added advantage of low cost of land and cheap labour.
- **Reliability of supply**. If all the big power stations are located on one side of a state, the reliability of supply in remote areas would be poor. As such generating stations should be located in different areas of the state so that reliability of supply is good at all points.

Layout Of Coal Fired Thermal Power Station

Following figure shows a typical layout of coal fired thermal power station.



HYDRO ELECTRIC PLANTS

Water Power

Hydro-electric projects harness water power for generation of electric energy. When water drops through a height, its energy is able to rotate turbines which are coupled to alternators. The electric power, P is given by

$$P = \frac{735.5}{75} QH \eta \text{ kilowatts}$$

where Q = Discharge (m^3/sec.); H = waterhead (m); η = Overall efficiency of turbine alternator set.

Advantages of Hydro-Electric Plants

Hydro-electric plants offer many distinct advantages over other means of power generation. These advantages can be summarised as under :

- The useful life of a hydro-electric plant is around 50 years as compared o around 25-30 years for a steam station.
- The hydro plants do not require any fuel. Their operating cost are, therefore, low. Since no fuel is required, there are no charges and problems of handling and storage of fuel ad disposal of ash.
- There are no standby losses in hydro plants. They can be run up and synchronized in a few minutes. The load can be adjusted rapidly.
- Hydro plants are more robust as compared to steam plants.
- The maintenance cost of hydro plants is very low as compared to that of steam and nuclear plants.
- Efficiency of hydro plants does not reduce with age. On the other hand efficiency of steam plants decreases with age.
- Generation of electric energy through hydro plants leads to conservation of coal and other fuels.

- The operation of thermal plants is totally dependent on efficient and quick transport of coal. Transport bottle-necks are likely to render thermal plants idle for long periods. Hydro plants are free from such bottle-necks.
- The operating personnel required for hydro plants are smaller in number as compared to those required for other plants.
- Hydro projects are generally multipurpose projects. In addition to electric power generation, they are also useful for irrigation, flood control, navigation etc.
- Hydro plants are free from air pollution due to smoke and exhaust gases.
- Hydro plants are located in remote areas where land costs are low.

Site Selection For Hydro-Electric Plants

- **Availability of water.** The river run-off data pertaining to many years should be available so that an estimate of the power potential of the project can be made.
- **Water storage.** Because of wide fluctuations in streams flows, storage is needed in most hydro-project to store water during high flow periods and use it during lean flow periods. He storage capacity can be calculated from the hydrograph or from mass curve or by using analytical methods.
- **Head of water.** An increase in effective head reduces the quantity of water to be stored and handled by penstocks, screens and turbines and therefore the capital cost of the plant is reduced.
- **Geological investigation.** Geological investigations are needed to see that the foundation rock for the dam and other structures in firm, stable, impervious and strong enough to withstand water thrust and other stresses. The area should also be free from earthquakes.
- **Water pollution.** Polluted water may cause excessive corrosion and damage to metallic structures. This may render the operation of the plant unreliable and uneconomic. As such it is necessary to see that the water is f good quality and will not cause such troubles.
- **Sedimentation.** The capacity of storage reservoir is reduced due to the gradual deposition of silt. Silt may also cause damage to turbine blades. Silting from forest covered areas is negligible. On the other hand the regions subject to violent storms and not protected by vegetation contribute lot of silt to the run off. In some cases, this factor alone may render an otherwise suitable site unsuitable.
- **Environmental effects.** Hydro projects submerge huge areas and many villages. As such, he environmental effects are also important. The site should ensure safe and pleasing surroundings, avoid health hazards and preserve important cultural and historic aspects of the area.

- **Access to site.** Construction of a hydro project involves transport of huge amount of cement, steel, other building material and heavy machinery. As such, it is generally necessary to set up a new railway line and rail head for this purpose. The site selected should be such that the railway line and roads can be constructed and material and machinery transported.

Classification According to Water Flow Regulation

Hydro plants can be classified, according to the extent of water flow regulation available, into following types :

- Run off river plants without pondage
- Run off river plants with pondage
- Reservoir plants. Most of the hydro-electric plants, everywhere in the world, belong to this category. When water is stored in a big reservoir behind a dam, it is possible to control the flow of water and use it most effectively. Storage increases the firm capacity of the plant. The plant can be used as a base load plant or as a peak load plant depending on the water stored in the reservoir, the rate of inflow and the system load.

Classification According to Load

According to load, hydro plants can be classified as base load plants, peak load plants and pumped storage plant

- **Base load plants.** They feed the base load of the system. Thus they supply almost constant load throughout and operate on a high load factor. Base load plants are usually of large capacity. Run off river plants without pondage and reservoir plants are used as base load plants. For a plant to be used as base load plant, the unit cost of energy generated by the plant should be low.
- **Peak load plants.** They are meant to supply the peak load of the system. Run off river plants with pondage can be used as peak load plants during lean flow periods. Reservoir plants can, of course, be used as peak load plants also. Peak load plants have large seasonal storage. They store water during off-peak periods and are run during peak load periods. Hey operate at a low load factor. A special type of peak load plant is pumped storage plant.
- **Pumped storage plant.** It is a special type of plant meant to supply peak loads.

Classification According to Head

- **Low head plants.** When water head is less than 30 m, the plant is called a low head plant. A dam or barrage across the river creates the necessary head.
- **Medium head plants.** Medium head plants operate at heads between 30 and 100 meters. An open channel brings water from main reservoir to the fore-bay from where penstocks carry water tot he turbines. Francis or Kaplan turbines are used.
- **High head plants.** The plants operating at heads above 100 m are generally classified as high head plants. The civil works for these plants include dam, reservoir, tunnel,

surge tank and penstock. Generally Francis turbines are used for heads below 200 m and Pelton turbines for still higher heads.

TYPES OF LOAD

The main types of load on a system are domestic, industrial, commercial, municipal, traction, agriculture etc. A graph showing the hourly variation in demand during the 24 hours of the day is called a chronological load curve.

IMPORTANT FACTORS

Load Factor

Load factor for a system or a plant is the ratio of the average load to the peak load, for a certain period of time.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Peak load}}$$

Load factor can be defined as the ratio of the energy consumed in a certain time (say 24 hours or a year) to the energy which would be consumed if the load is maintained at the maximum value throughout that time.

$$\text{Load factor} = \frac{\text{Energy consumed during a time of } t \text{ hours}}{\text{Peak load x } t}$$

The peak load is generally taken as that prevailing for a half hour period and the average load may be that pertaining to a day, a month or a year, thus giving daily, monthly or yearly load factor.

The load factor depicts the variation of load during a certain period but it does not give any indication of the shape of the load duration curve.

Plant Factor

The plan capacity factor (also known as plant factor) is the ratio of the average annual load to the power plant capacity.

$$\text{Plant factor} = \frac{\text{Average annual load}}{\text{Rated plant capacity}}$$

It can also be defined as the ratio of the energy produced by the plant in a year to the maximum energy that the plant could have produced. If the plant is always run at its rated capacity, the capacity factor is 100 %.

The capacity factor depicts he extent of the use of the generating station. It is different from load factor because of the reason that the rated capacity of each plant is always greater than the expected maximum load. The power plants have always some reserve capacity o take into account the future expansion increase in load and maintenance.

$$\text{Plant factor} = \frac{\text{Maximum load}}{\text{Plant capacity}} \text{ x Load Factor}$$

It is evident that if the rated plant capacity equals he maximum load, the capacity factor and load factor become identical.

Utilisation Factor

It is defined as the ratio of the maximum demand to the rated capacity of plant.

$$\text{Utilisation factor} = \frac{\text{Maximum load}}{\text{Rated Plant Capacity}}$$

Diversity factor

The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor i.e.,

Diversity factor = Sum of individual max. demands/Max. demand on power station

A power station supplies load to various types of consumers whose maximum demands generally do not occur at the same time. Therefore, the maximum demand on the power station is always less than the sum of individual maximum demands of the consumers. Obviously, diversity† factor will always be greater than 1. The greater the diversity factor, the lesser‡ is the cost of generation of power.

Plant use factor

It is ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation i.e.

Plant use factor = Station output in kWh/ Plant capacity × Hours of use

Suppose a plant having installed capacity of 20 MW produces annual output of $7{\cdot}35 \times 10^6$ kWh and remains in operation for 2190 hours in a year.

Then $$\text{Plant use factor} = \frac{7.35x10^6}{(20x10^3)x2190} = 0.167 = 16.7\%$$

Example

The plant of previous example has an installed capacity of 125 MW. Find the plant factor and the utilisation factor.

Solution

$$\text{Plant factor} = \frac{100}{125} \text{ x } 0.5917 = 0.473 \quad \text{(or capacity factor)}$$

$$\text{Utilisation factor} = \frac{100}{125} = 0.8$$

Example

The maximum demand of a power plant is 40 MW. The capacity factor is 0.5 and the utilisation factor is 0.8. Find

a) *load factor*

b) *plant capacity*

c) *reserve capacity*

d) *annual energy production.*

Solution

(a) Load factor = $\frac{\text{Capacity factor}}{\text{Utilisatio n factor}} = \frac{0.5}{0.8} = 0.625$

(b) Plant capacity = $\frac{\text{Max. demand}}{\text{Utilisaton factor}} = \frac{40}{0.8} = 50 \text{ MW}$

(c) Reserve capacity = 0 - 40 = 10 MW

(d) Annual energy production = 40 x 0.625 x 8760 = 219000 MWh

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

Demand factor = max demand/connected load = 20/43 = 0.465

Average demand = (units generated/annum)/hours in year

= 61.5 x 10^6/8760 = 7020 kW

Load Factor = average demand/max demand = 7020/(20 x 10^3)

= 0.351 or 35.1%

COST OF ELECTRICAL ENERGY

The generation cost per kWh of energy depends on the cost covering the purchase, installation and erection of equipment, cost of fuel, labour, repair etc. The generation cost can be divided into fixed cost i.e. the cost which depends on the extent of plant investment and financial rates and remains a fixed one irrespective of the amount of energy generated and operating cost which includes the expenditure for fuel, labour, supervision etc. The operating costs of a plant are generally variable in magnitude and depend on the amount of energy produced.

CAPITAL COST OF PLANTS

In addition to the costs mentioned above, the capital cost of a hydro-electric plant includes the costs of dam, earth work, excavation, railhead, highways and other civil works and compensation to property owners whose lands would be submerged in the reservoir.

ANNUAL FIXED COST

Components

The annual fixed cost of a plant consists of interest, taxes, insurance, depreciation, managerial and general maintenance costs and rate of return.

(a) **Interest, taxes and insurance**. The capital for setting up the plant may be provided by the Government or the private owner) or acquired through a loan from a financial institution or institution or acquired by the sale of stock or bonds or both. The annual interest and dividend have to be included in the total cost of service. The utility may have to pay various taxes to town, state and federal authorities. However, only the taxes which are a function of the capital investment should be included in the fixed costs and h other taxes should b included in the operating costs.

Every well managed utility has to incur expenditure on insurance against accidents to equipment and personnel. The list of risks and insurance is usually very long e.g. fire, flood, hail, earthquake, explosion, public liability, workmen compensation etc. The insurance may be obtained from insurance companies.

(b) **Depreciation.** Every equipment deteriorate or depreciates due to wear and tear, corrosion, weathering etc. In addition, the equipment may become inadequate due to increase in demand or become obsolete and may need replacement by a modern one.

It is necessary for the financial stability and safety that the capital of an enterprise must remain intact. When a plant becomes useless, funds must be available to replace it.

(c) **Managerial and general maintenance costs**. A part of total wage bill of a power plant is constant irrespective of the amount of energy generated. Similarly a certain amount of supervision and maintenance is needed even when it is not producing any energy. These costs are proportional to the size of the plant and the equipment and should be included in fixed costs.

(d) **Rate of return.** An undertaking can be successful only if it earns profit. It is a private limited company and has floated shares or bonds, it must pay a good dividend so that the value of the shares may be high and the undertaking may be successful. Therefore, a certain rate of return on investment should be taken into account in calculating the annual fixed costs.

FIXED CHARGE RATE

The annual costs are calculated by multiplying the costs are calculated by multiplying he capital cost by a decided fixed charge rate. The value of the fixed charge rate is fixed on the basis of the above mentioned components of annual fixed costs.

The total annual fixed cost of an installation having a number of units is, evidently, the sum of individual annual fixed costs of different units.

OPERATING COST OR PRODUCTION COST

Components

(a) **Fuel.** This is the largest item of expense in thermal, diesel and gas turbine stations. The fuel may be in the form of coal, oil, natural gas, wood scrap etc. The cost of fuel depends on the type of fuel, calorific value, availability and freight rates. The annual fuel cost of a station depends on he amount of energy produced, the efficiency of the plant and the unit price of fuel.

(b) **Operating labour.** The operation of a plant needs staff and labour. In a steam plant labour is needed for unloading and storing of fuel, disposal of refuse, operation of boiler, prime mover etc.

(c) **Maintenance cost.** Every plant needs preventive maintenance (inspection, cleaning, repair, overhauling etc.) to keep it in good condition.

(d) **Supplies.** This item includes the cost of water for make up, cooling purposes and general use, lubricating oil and other consumable materials.

AMOUNT PLAN COST

The total annual station cost for he entire generating station having n generating units is the sum of individual plant costs of different units.

GENERATION COST

It is usually necessary to estimate the generation cost (i.e. cost of unit energy generated) for a generating unit. This information is needed when different generating units are to be compared. For this purpose it is necessary to calculate the expected energy output of the generating unit for one year.

EFFECT OF LOAD FACTOR ON UNIT ENERGY COST

The unit cost of energy generated by a power plant depends quite substantially on the load factor. The fixed costs remain constant irrespective of the load factor. Thus at low load factors the fixed costs are shared by a smaller number of units of energy resulting in a relatively higher unit energy cost. At high load factors, the same fixed costs are shared by a large number of units of energy thereby reducing the unit energy cost. At 100 % load factor, the installed capacity is used to the maximum extent, maximum energy is generated and the unit energy cost is minimum. As load factor decreases, the unit energy cost increases, the effect becoming more pronounced as load factor becomes too low.

Example

Determine the generation cost per unit of energy from the following plant data:

Installed capacity = 120 MW

Capacity cost of plant = Rs.10000 per kW

Interest and depreciation = 15 %

Fuel consumption = 0.64 kg/kWh

Fuel cost = Rs.500 per 1000 kg

Salaries, wages, repairs and other operating costs per annum

= Rs.10,000,000

Peak load = 100 MW

Load factor = 60 %

Solution

Average load = 100 x 0.6 = 60 MW

Energy generated = 60 x 1000 x 8760 = 5256 x 10^5 kW-hr

Total Investment = 120 x 10^3 x 10000 = Rs.1200 x 10^6

Interest and depreciation = Rs.1200 x 10^6 x $\frac{15}{100}$ = Rs.180 x 10^6 per year

Fuel consumption = 0.64 x 5256 x 10^5 kg/year = 363.84 x 10^4 kg per year

Fuel cost = Rs.363.84 x 10^4 x $\frac{500}{1000}$ per year = Rs.18.192 x 10^6 per year

Salaries, wages etc. = Rs. 10 x 10^6 per year

Annual plant cost = Rs. 35819.2 x 10^4 per year

Generation cost = Rs. $\frac{35819.2x10^4}{5256x10^5}$ = Rs.068 per unit.

FIXED AND OPERATING COST OF STEAM PLANTS

The capital cost of a steam plant includes the cost of land, design specifications, installation, power house building, equipment, installation, testing, commissioning, etc. The annual fixed costs include the interest on the capital cost, depreciation, taxes, insurance and fixed managerial and general maintenance cost.

The operating cost of steam plant includes the cost (including coal and ash handling), oil, water, stores, repair, maintenance, salaries and wages of operating staff etc. The effect of cost of coal on the total cost of steam power is quite considerable. A change in fuel cost by 25 % may cause around 10% change in the total cost per kWh of steam energy.

FIXED AND OPERATING COST OF HYDRO PLANTS

The capital cost of a hydro plant includes the cost of preliminary survey, detailed survey, dam, earthwork, highways, bridges, excavation, railhead, other civil engineering works, compensation to land owners whose lands would be submerged in the reservoir, power house substructure and superstructure, design, specifications, equipment, installation, testing, commissioning etc. The capital cost is very much affected by topographical and geological conditions. The annual fixed costs include the interest on the capital cost, depreciation, taxes, insurance and fixed managerial and general maintenance.

The operation costs o hydro plants include salaries and wages of operating and maintenance staff and supplies. Because of the absence of fuel cost, the operating cost of a hydro plant is very small.

TARIFFS

Flat Rate Tariff

The flat demand rate can be expressed in the form, A = cx i.e. the bill depends only on the maximum demand irrespective of the amount of energy consumed.

This is the earliest form of tariff and the bill in those days was based on the total number of lamps installed in the premises. Now-a-days the use of this tariff is restricted to sign lighting, signal system, street lighting etc. where the number of hours are fixed and energy consumption can be easily predicted. Its use is very common for supplies to irrigation tube wells since the number of hours for which the tube well feeders are switched on are fixed. The charge is made according to the horse power of the motor installed. The cost of metering equipment and meter reading is eliminated by the use of this form of tariff.

The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

Disadvantages

- Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.
- 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.

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.

Two Part Tariff

This tariff, also known as two part tariff, can be expressed in the form

$$A = cx + dy$$

Thus the total bill includes a demand charge based on the maximum demand plus a charge based on energy consumed. The factors *e* and *d* may be constant or may vary as per sliding scale. This tariff is used for industrial customers. This tariff introduces the problem of measuring the maximum power demand of the customers. This maximum demand can either be taken as a certain fraction of the connected load or measured by a maximum demand meter. It is usual to specify a minimum demand that must be paid for.

Advantages

- It is easily understood by the consumers.
- It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages

- The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.
- There is always error in assessing the maximum demand of the consumer.

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 :

- **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.
- **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.
- **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 reactive power and hence shall have to pay more charges.