COMPETITIVE EXAMINATIONS QUESTIONS

1. (a) With the help of a sketch show all the important parts of a nuclear reactor, describing briefly the functions of each part.
   Under what circumstances would a nuclear power station be recommended for installation ?
   (b) Give a brief comparison, between a nuclear and a conventional thermal power station, in respect of (i) Capital cost, (ii) fuel cost, and (iii) operating and overhead cost, as a percentage of the total cost given by the sum of (i), (ii), and (iii).
2. (a) What are the principal parts of a nuclear reactor ? Explain each part in brief.
   (b) Why are nuclear power stations not so popular and successful in this country ?
3. (a) "The source of future power generation will be only nuclear fuel". Write your comments.
   (b) Explain the working of a reactor in a nuclear power station.
4. (a) Why is shielding of a reactor necessary ? What do you understand by thermal shielding ?
   (b) Explain the working of a reactor in a nuclear power station.
5. (a) Explain the generation of nuclear energy in a nuclear power plant.
   (b) Describe a boiling water reactor with diagram.
6. (a) What are the principal parts of a nuclear reactor ? Explain each part in brief.
   (b) Explain the working of a steam surface condenser.
7. (a) What do you understand by the following terms :
   (i) binding energy, (ii) half life,
   (iii) isotope, and (iv) moderator.
   (b) Discuss the boiling water reactor with the help of a neat sketch and write down its chief characteristics.
8. (a) How are nuclear power plants classified ? Explain how fission reaction takes place and how the chain reaction is controlled.
   (b) Discuss briefly boiling water reactor plant.
9. (a) Describe in brief giving neat sketch, the working of a pressurised water reactor plant.
   (b) Draw a line diagram of a diesel power plant and describe briefly the cooling system and the lubrication system.
10. (a) What is a moderator in nuclear reactor ? Explain the desirable properties of good moderator.
    (b) Draw a neat diagram of CANDU type reactor and explain its working principle and give its advantages over the other types.
11. (a) Draw a neat diagram of nuclear reactor and explain the functions of different components.
    (b) Explain the working principle of a closed cycle gas turbine plant.
12. (a) Draw a neat diagram of nuclear reactor and explain the functions of different components.
    (b) Explain the working principle of a closed cycle gas turbine plant.
13. (a) How are nuclear reactors classified ? Explain with neat sketch the working of a pressurised water reactor.
    (b) What different methods are used to thermal efficiency of the open cycle gas turbine plant ? Explain *any one* of them.
14. (a) Using neat sketches explain the construction and working of an air preheater.
    (b) Explain the layout of *any one* type of nuclear power plant system used in India.
    (c) Clearly bring out the differences in the constructional features of steam turbines of 500 MW rating used in conventional coal fired steam power plant and PWR plant.
15. (a) Explain the following terms with reference to a nuclear reactor :
    (i) Moderator (ii) Coolant
    (iii) Control rods (iv) Reflector.
    (b) Give the layout of a fast breeder reactor power plant and explain its salient features.
    (c) Give a brief account of nuclear waste disposal.

8

Combined Operation of Different Power Plants

8.1. GENERAL ASPECTS

The leading aim of the national economy is to make available maximum amount of generating capacity with the available funds and ensure power generation at the cheapest rate possible. Since a large investment is required in power supply industry, therefore, once generating facilities are created it is desirable to utilise them in optimum manner. It is also of paramount importance that most economic generating scheme should be selected to supply power at lowest cost before huge amount of money is invested. When the generating facilities are established it is a wiser step to think of having integrated operation of neighbouring power systems so that maximum energy generation takes place from power stations like *thermal* and *nuclear* and maximum energy and capacity are utilised from the *hydro-electric* power stations. This is possible only if we have close combined operation of different power systems which if operated individually cannot be utilized to the maximum advantage. This leads to conclusion that if maximum benefit is to be yielded then power systems of different states should be interconnected. It is beyond doubt that the rapid pace of interconnection between the power systems can greatly improve the *continuity, security* and *integrity of power supply* provided it is associated with sound mechanism for monitoring and control.

8.2. ADVANTAGES OF COMBINED OPERATION OF PLANTS

If several power stations (such as hydro, thermal, nuclear etc.) work together to meet the demand of the consumers then the system is known as *'Interconnected system'*. Such a combined system claims the following **advantages** over a single power plant/station :

1. Greater reliability of supply to the consumers.
2. When one of the stations fails to operate the consumers can be fed from the other station, thus avoiding complete shut down.
3. The overall cost of energy per unit of an interconnected system is less.
4. There is a more effective use of transmission line facilities at higher voltage.
5. Less capital investment required.
6. Less expenses on supervision, operation and maintenance.

7. The interconnection of different power plants reduces the amount of generating capacity required to be installed as compared to that which would be required without interconnection.
8. In an interconnected system the spinning reserve required is reduced.

8.3. LOAD DIVISION BETWEEN POWER STATIONS

Under the situation when the load curve has a very high peak value, it is usually supplied for two or more power stations/services by interconnection. In that case, total load as shown on load duration curve may be divided into following two parts :

(*i*) The base load (*ii*) The peak load.

Base load is supplied by one power station and the other power station takes care of the *peak load*. In such cases the *load is economically apportioned to various systems in order to achieve the overall economy.*

In such cases it is not very necessary to interconnect the two systems of the *same type*. For example, if the base load is supplied by the steam power station, then it is not very necessary that the peak load may also be supplied by the steam power station. A hydro-electric power station can very well be adopted for supplying the peak load. Similarly, a hydro-electric station can be used for supplying the base load and in that case the peak load can be supplied by steam power station or a diesel engine station or any other suitable unit. However the selection of the power stations for supplying the base load or peak load is made on the basis of the requirements and ability of the various power stations/services to meet those requirements.

Requirements of a plant supplying the '*Base load*' :

1. Minimum operation cost.
2. Continuous supply of the load.
3. Capital cost of the plant should be minimum.
4. Requirement of plant maintenance should be minimum.
5. Plant should be such that it can be easily located near the load centre.
6. The number of operators required should be minimum.
7. The spare parts etc. should be readily available.

Taking into view the above requirements, let us now consider various types of plants for their suitability to meet the base load.

Hydro-electric stations. (*i*) In these plants the *operating cost is minimum* as practically *no fuel* is required for the purpose of power generation, and as such there is no problem of procurement of the fuel.

(*ii*) *Maintenance cost is lower* than that of other plants.

(*iii*) *Initial cost of the plant is very high and sometimes prohibitive.*

(*iv*) These plants cannot be necessarily located near the load centre as the same can be located at the site suitable for it.

(*v*) In this case there is more or less dependence on availability of water, which in turn depends on the natural phenomenon of rain.

Steam power stations. (*i*) The capital investment in this case as compared to hydro-electric stations is less but with the modern trend of using higher pressures for the purpose, the cost of such stations has increased considerably. But this increased cost has resulted in lower operating costs so much so that even it may compete with that of hydro-electric power stations.

(*ii*) These plants can be easily located near the load centre, as such the cost of transmission lines and the losses occurring can be minimised which results in economical operation.

(*iii*) Maintenance requirement is slightly higher.

Diesel power stations. Due to limited generation capacity of diesel power station it is not much suitable as a base load plant.

Nuclear power station. (*i*) Initial cost is high although operating cost is comparable with that of steam power station.

(*ii*) Due to limited availability of the fuel these plants are not much favoured.

(*iii*) Whenever these plants are constructed they are invariably used as *base load* as otherwise also such plants suit to constant load conditions as economy in operation is such plants can be achieved only, when these are used as base load plants.

Requirements of a plant supplying the *'Peak load'* :

1. Low operating cost.

2. Minimum capital cost.

3. The plant should be capable of being started from cold conditions within minimum time.

4. In case of emergency the plant should have the capacity to withstand the peak load for sometime.

5. It must have quick response to the change in load.

In view of the above requirements let us consider various plants for their suitability to meet the peak load.

Hydro-electric stations. A hydro-electric station *can* be considered for this purpose :

(*i*) It can be easily started from cold conditions as no warming up period is required.

(*ii*) High initial cost is the major disadvantage.

(*iii*) However, in this case, there is no requirement of fuel, so whenever the output of hydro-electric station is to be utilised, it can be used as a *peak station also.*

(*iv*) Particularly in case where the quantity of water available for the purpose of power generation is limited, such stations are used for meeting the peak load in case of a interconnected system.

Nuclear power stations. They do not find their use as peak load plants.

Diesel power stations. (*i*) These plants *can be used for meeting peak load* as they can be easily started from cold conditions and the initial cost in this case is also not high.

(*ii*) In this case the additional advantage is that the number of auxiliaries required is also limited as a result of which the maintenance work required is also less.

(*iii*) These plants have got good overload capacity (minimum being 10 per cent as per Indian Standard Specifications).

(*iv*) Thermal efficiency of diesel engines being high, the operating cost is also less as compared to that of a steam power station of equivalent capacity.

Analysis of Load Sharing between *Base Load* and *Peak Load* Stations :

The suitability of a plant not only depends on the above mentioned factor but also on local conditions for a particular application. However, if the combination of two plants/services is to be used, in that case the next problem is division of load between the plants. It is not desirable to transfer all the loads to one plant and also depending upon the operating characteristics of the various plants the load between the plants should be so decided that overall economy is achieved. This load division can be easily manipulated by viewing the load duration curve of the plants as follows :

Fig. 8.1 shows a load duration curve.

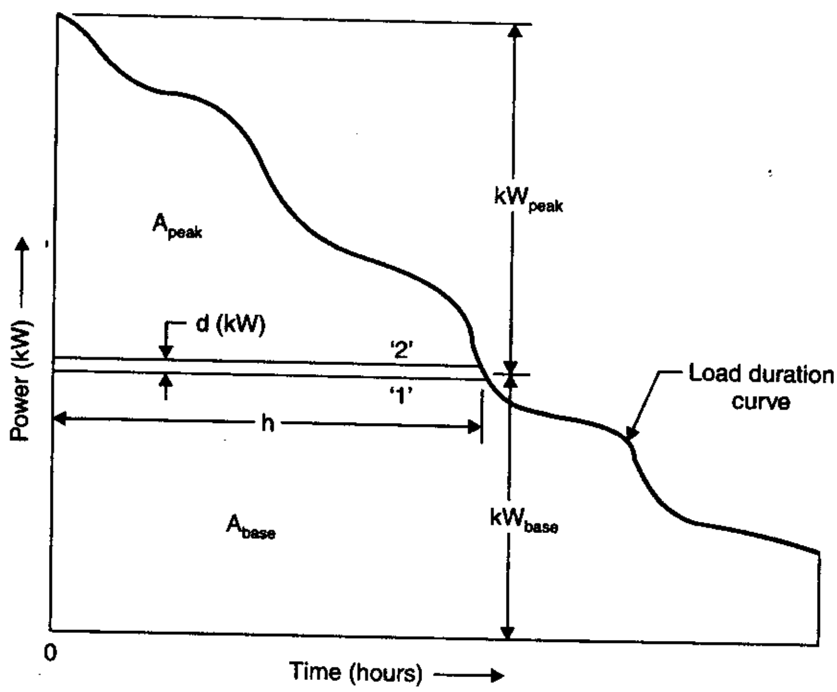


Fig. 8.1. Load duration curve of the plants.

Let A_{peak} = Area of curve for *peak load* plant,

A_{base} = Area of curve for *base load* plant,

kW_{peak} = Load for peak load plant,

kW_{base} = Load for base load plant,

C = Total operating cost of the combination, and

h = Hours per year.

Let the *base load* be supplied by a plant having the annual cost equation as

$$(Rs.)_1 = a_1 + b_1 \text{ kW} + c_1 \text{ kWh} \quad ...(8.1)$$

For the plant supplying the *peak load* let the equation be

$$(Rs.)_2 = a_2 + b_2 \text{ kW} + c_2 \text{ kWh} \quad ...(8.2)$$

Since the base load plant is operated most of the time, therefore, normally a plant having $c_1 < c_2$ is used for meeting the base load.

Let $b_1 > b_2$.

Let the load between the two plants (Fig. 8.1) be divided by arbitrary line drawn on the load duration curve represented by '1'. Under these conditions let kW_{base} be the kW for base load plant and let kW_{peak} be the load for peak load plant.

In this case the total operating cost of the combination is given as :

$$C_1 = a_1 + a_2 + b_1 \text{ kW}_{base} + b_2 \text{ kW}_{peak} + c_1 A_{base} + c_2 A_{peak} \quad ...(8.3)$$

Now, if the base power is extended by the amount of d (kW) to line '2', the total operating cost of the combination will modify as follows :

$$C_2 = a_1 + a_2 + b_1 (\text{kW}_{base} + d \text{ kW}) + b_2 (\text{kW}_{peak} - d \text{ kW}) + (A_{base} + d \text{ kW} \times h) c_1 + (A_{peak} - d \text{ kW} \times h) c_2 \quad ...(8.4)$$

The change in cost,

$$C_2 - C_1 = (b_1 - b_2)\, d\,\text{kW} + (c_1 - c_2)\, d\,\text{kW} \times h \qquad ...(8.5)$$

The optimum condition requirements are that above change must be zero, *i.e.*,

$$h = \frac{b_1 - b_2}{c_2 - c_1} \qquad ...(8.6)$$

Thus it is possible to divide the load between the plants due to which overall economy in operation is effected.

The method described above for distributing the load among the two power plants in an interconnected system can be used for any type of plants as (*i*) Thermal and diesel, (*ii*) Thermal and hydro, (*iii*) Nuclear and hydro and so on.

8.4. HYDRO-ELECTRIC (STORAGE TYPE) PLANT IN COMBINATION WITH STEAM PLANT

Hydro-plants can take up the load quickly and follow the peak variation much better than thermal plants. There is a great reliability in hydro-plants and it is still more in a combined system. In a combined system of hydro and thermal, water storage increases the application of more hydro-power in normal or heavy run-off years, while steam plant can help during the time of drought. *When the run-off is sufficient* (particularly in monsoon) the *hydro-plant is used as base load and thermal plant works as peak load plant. Thermal plant is used as base load plant during the drought period and hydro-plant works as peak load plant.* Fig. 8.2 (*a*), (*b*) shows their uses as base load or as peak load plant.

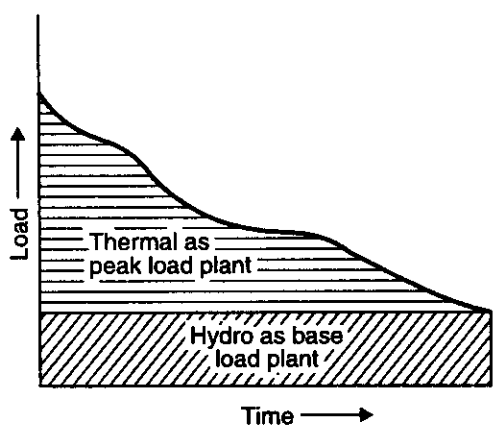


Fig. 8.2 (*a*). Hydro-plant used as base load plant during normal run-off in an inter-connected system.

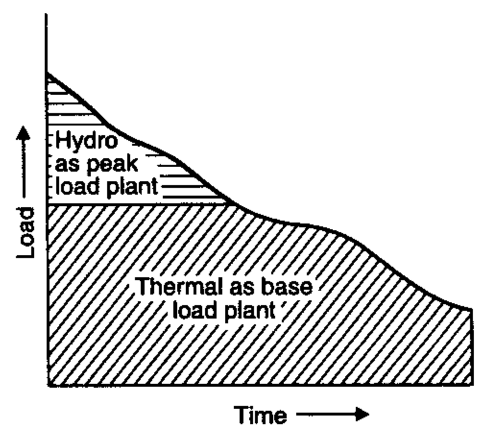


Fig. 8.2 (*b*). Hydro-plant used as peak load during drought period in an interconnected system.

Thermal plants can be used at any portion of the load duration curve but it is more expensive to use peak load station at low load factors.

Following cases will be discussed :

1. Predominant hydro.
2. Predominant thermal.
3. Hydro and thermal equally predominant.

Predominant Hydro :

Some of the hydro-plants, such as run-off river plants, are used as base load plants whereas some others are used as peak load plants. *When the hydro-plants carry the major demand throughout the year then the thermal plants are used in a combined system to improve the hydropower efficiency during the periods when there is low run-off.*

Predominant Thermal :

To develop hydro-plants to operate even at comparatively low annual load factors is always advantageous. This is due to the fact the cost of storage water forms a major portion of the capital investment which is independent of annual load factor and capital cost is less for low than for a high load factor. Thus, *in a predominantly thermal station,* it is *preferable to develop hydro-power at the lowest practical load factor.*

Hydro and Thermal Equally Predominant :

The economic balance between hydro and thermal power in an interconnected system at any time depends upon the *nature of load curve, run-off and its seasonal variation, cost of fuel, availability of condensing water* etc. There is an optimum ratio of hydro-power to total peak demand which gives minimum cost for power supply. This is particularly true for the areas where the cost of hydro-power development is high and fuel cost is low. In areas where fuel is cheap and cost of hydro-power development is not high, the economic power ratio lies between 0.25 to 0.4. In areas where fuel is costly and favourable hydro-power plant sites are abundant the ratio will be higher to the tune of 0.8-0.9.

The combined system of hydro and thermal plants is being adopted all the world over, and is particularly useful to developing countries like India where economy is desirable at every stage of development.

8.5. RUN-OF-RIVER PLANT IN COMBINATION WITH STEAM PLANT

Since during the year the supply of water is not regular in *run-of-river plants,* therefore,these plants cannot meet with variable load requirements. Further as the variation of run-off during the year does not match the variation of power demand during the year, therefore, it becomes necessary to combine such a hydro-plant with steam plant to supply the load according to requirement with maximum reliability. *The run-of-river plant can be used as base load plant during rainy season and thermal plant takes up peak load. During dry season ; the thermal stations can be used as base load plant and run-of-river plant may work as peak load plant.*

8.6. PUMP STORAGE PLANT IN COMBINATION WITH STEAM OR NUCLEAR POWER PLANT

Whenever old and inefficient thermal stations are available they are generally used to take up peak loads. If suitable plants are not available to take load it is desirable to develop pumped storage plant for the purpose. In an interconnected system a pumped storage plant is useful in supplying sudden peak loads of short duration (a few hours in the year). Such a plant (pumped storage) possesses the following advantages when used in interconnected system :

(*i*) Thermal plants are loaded more economically.

(*ii*) The wastage of off-peak energy of thermal plants is reduced.

(*iii*) A pumped storage plant stores the energy using off-peak energy of thermal plant and the same is supplied when demand arises.

A combined system of a pumped storage plant and nuclear power plant is proposed at Ramganga power station in Uttar Pradesh. A parallel development of nuclear power station

(400 MW capacity) near the hydro-site could provide cheap pumping energy to pump storage plant during off peak hours. This arrangement will enable the nuclear station to operate at high capacity factor and thereby make it competitive as compared to the conventional thermal station in that region where the coal prices are relatively high.

8.7. CO-ORDINATION OF HYDRO-ELECTRIC AND GAS TURBINE STATIONS

The working of gas turbine plants at peak load points is most economical under the following conditions :

(*i*) When the amount of energy supplied at peak load is small part of the total energy.

(*ii*) The load factor is less than 15%.

The following points are worth noting :

— The normal capacity of the gas turbine varies from 10 MW to 25 MW.

— The capital cost of a gas turbine plant is quite less (Rs. 1000 to 1200/kW) compared with steam plant (Rs. 1600 to 2000/kW).

— The thermal efficiency of gas turbine plant (25 per cent) is less than that of a steam plant (32 per cent).

— The high working cost of a gas turbine is compensated by *lower fixed charges and lower operating and maintenance charges*.

When used as a peak load plant, the gas turbine plant claims the following advantages over steam plant :

1. A gas turbine plant occupies less space comparatively.
2. Heavy foundations are not required.
3. The construction and installation can be carried out in a smaller period.
4. The cooling water requirement is much less comparatively.
5. Less number of operators are required.
6. The response of gas turbine plant is quick.

8.8. CO-ORDINATION OF DIFFERENT TYPES OF POWER PLANTS

In a particular region if different types of power plants are available it becomes necessary to co-ordinate them and use them with maximum economy. The problem of co-ordination of different types of power plants (*e.g.* hydro, thermal, nuclear, gas turbine and diesel plants) for best possible working and economy is very complicated as the *factors* to be considered for economical co-ordination are large in number ; some of these factors are listed below :

(*i*) Initial capital cost

(*ii*) Fuel cost

(*iii*) Operation and maintenance cost

(*iv*) Availability of fuel

(*v*) The economics of base load and peak load operation

(*vi*) The working characteristics of the plants

(*vii*) The transmission liability

(*viii*) The cost of incremental power.

The best co-ordination, several times, depends on the *nature of load duration curve* and availability of fuels and resources in the country.

Fig. 8.3 shows an annual load curve showing loads allocated to different plants.

The local conditions may change the sequence depending upon the availability of fuels and resources.

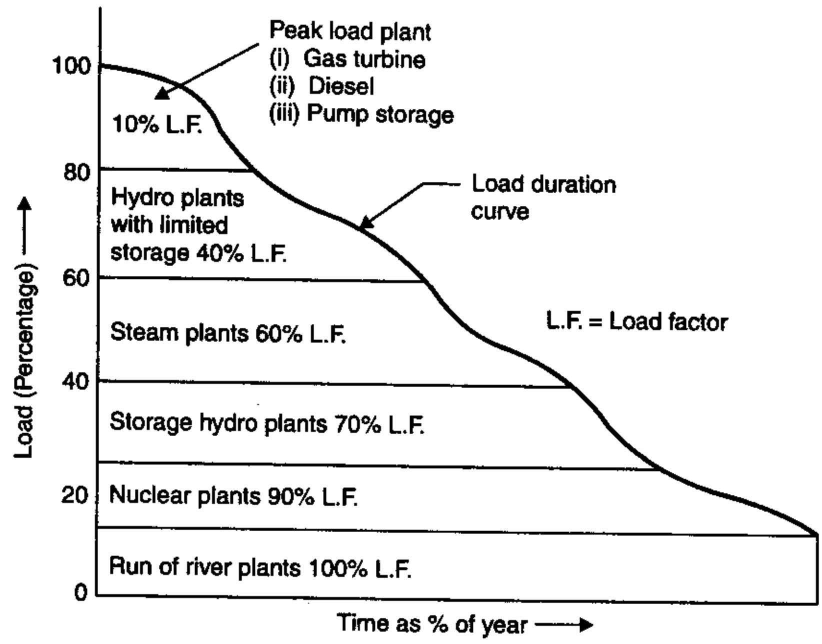


Fig. 8.3. Annual load duration curve showing loads allocated to different plants.

WORKED EXAMPLES

Example 8.1. *The estimated total annual operating costs and capital charges for two proposed power stations are given by the following expressions :*

Annual cost for station A = *Rs. (6,00,000 + 3.0 kW + 0.015 kWh)*

Annual cost for station B = *Rs. (7,50,000 + 5.0 kW + 0.014 kWh)*

where kW represents the capacity of the station and kWh represents the total annual output.

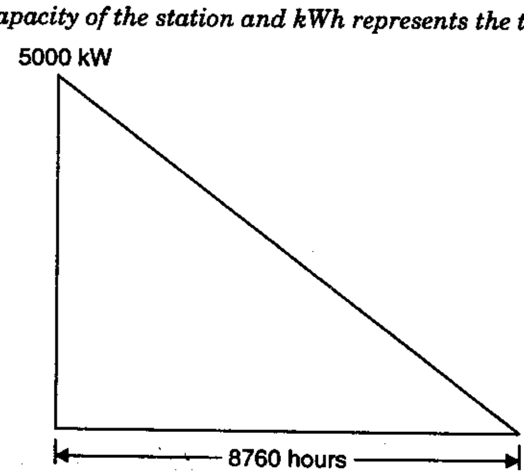


Fig. 8.4

The stations are to be used for supplying a load having a load duration curve as shown in Fig. 8.4. The ordinate of a point on this curve represents a certain load on the station and the abscissa represents the number of hours per year during which the load is equal to or exceeds this amount.

Which station should be used to supply the base load, what should be its installed capacity and for how many hours in a year should it be in operation to give the minimum total cost per unit generated ?

Calculate the total cost per unit generated under these conditions.

Solution. Let us consider the cost equations of the two stations. *Since the operating cost of station B is less than that of A, so station B may be selected for supplying the base load.*

Hours (h) for which the base load point is to be operated can be calculated as follows :

$$h = \frac{5-3}{0.015-0.014} = \frac{2}{0.001} = 2000 \text{ hours.}$$

Hence the base load point is to be operated for 2000 hours and the peak load point plant for the remaining period. From the load duration curve, the capacity of the base load plant can be computed as follows.

Refer Fig. 8.5.

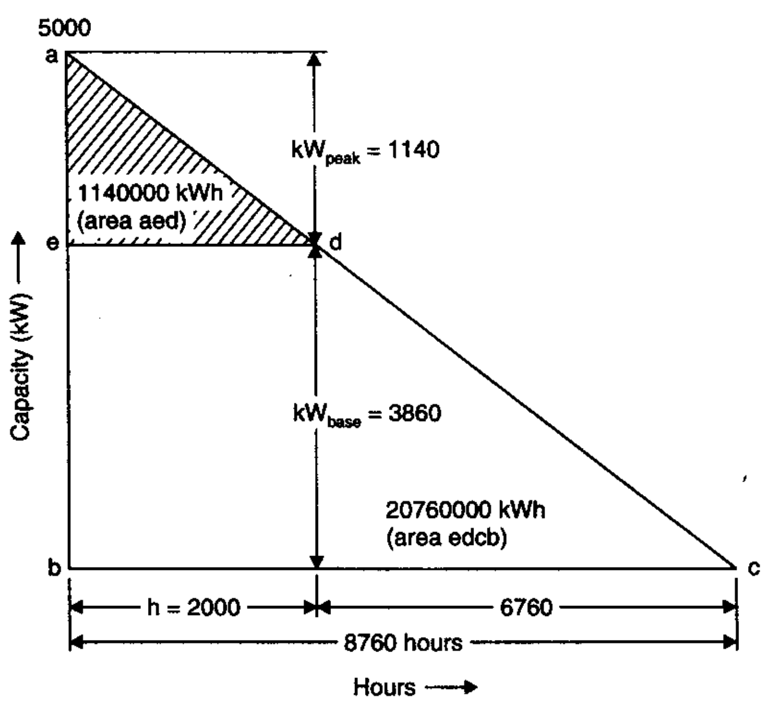


Fig. 8.5

$$\frac{kW_{base}}{6760} = \frac{5000}{8760}$$

$$\therefore \quad kW_{base} = \frac{5000 \times 6760}{8760} \simeq 3860 \text{ kW}$$

$$\therefore \quad kW_{peak} = 5000 - 3860 = 1140 \text{ kW}$$

Cost of generation

Total kWh supplied by peak load plant

$$= \frac{1140 \times 2000}{2} = 1140000 \text{ kWh}$$

Total kWh supplied by base load plant

$$= \frac{5000 \times 8760}{2} - 1140000 = 20760000 \text{ kWh}$$

Cost of generation per annum for *base load plant*

$$= \text{Rs. } (750000 + 5 \times 3860 + 0.014 \times 20760000)$$
$$= \text{Rs. } (750000 + 19300 + 290640)$$
$$= \text{Rs. } 1059940.$$

Cost of generation per annum for *peak load plant*

$$= \text{Rs. } (600000 + 3 \times 1140 + 0.015 \times 1140000)$$
$$= \text{Rs. } (600000 + 3420 + 17100)$$
$$= \text{Rs. } 620520$$

Total cost = 1059940 + 620520 = 1680460

$$\textit{Cost of generation per unit} = \frac{\text{Total cost}}{\text{Total kWh supplied}}$$
$$= \frac{1680460}{\left(\frac{5000 \times 8760}{2}\right)} = \frac{1680460}{21900000}$$
$$= \textbf{Rs. 0.0767 or 7.67 P.} \quad \textbf{(Ans.)}$$

Example 8.2. *In a system the load duration curve is a straight line, the maximum and minimum loads being 120 MW and 24 MW respectively. The costs of the base load and peak load plants, which supply the load, are given below :*

Base load plant : Rs. 240/kW-year + 6 p./kWh

Peak load plant : Rs. 60/kW-year + 12 p./kWh

Determine, for minimum overall cost of the following :

(*i*) *The load shared by peak load plant.*

(*ii*) *The annual load factors for both stations.*

Solution. (*i*) **Load shared by peak load plant :**

Let,
C_{base} = Operating cost of base load plant,
C_{peak} = Operation cost of peak load plant,
P_{base} = Load (peak) on the base load plant, and
P_{peak} = Load (peak) on the peak load plant.

The operating costs of base load and peak load plants may be expressed as follows :

$$C_{base} = A_1 \text{ kW} + B_1 \text{ kWh}$$
$$C_{peak} = A_2 \text{ kW} + B_2 \text{ kWh}$$

From the given data :

$$A_1 = 240, \quad B_1 = 0.06$$
$$A_2 = 60, \quad B_2 = 0.12$$

The time, h hours, for which base load to be operated *for minimum overall cost* is given by :

$$h = \frac{A_1 - A_2}{B_2 - B_1} = \frac{240 - 60}{0.12 - 0.06} = 3000 \text{ hrs.}$$

Now, $P_{base} + P_{peak} = 120$

$\therefore$ $P_{peak} = 120 - P_{base}$

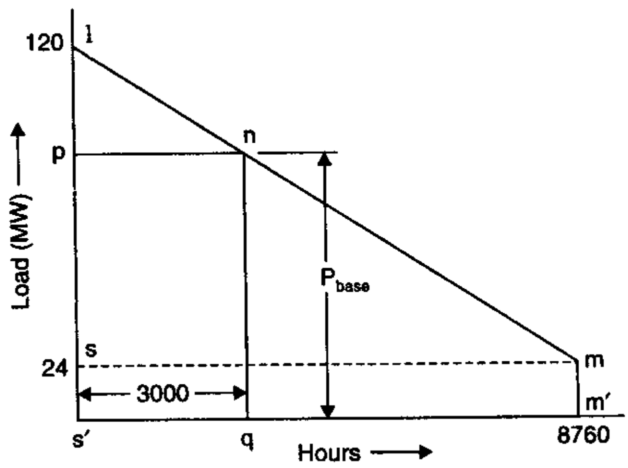


Fig. 8.6

Now, from Δs *lms* and *lnp*, we have

$$\frac{120 - P_{base}}{120 - 24} = \frac{3000}{8760}$$

$$P_{base} = 120 - (120 - 24) \times \frac{3000}{8760} = \mathbf{87\ MW.}\quad \textbf{(Ans.)}$$

$$\therefore \quad P_{peak} = 120 - 87 = \mathbf{33\ MW.}\quad \textbf{(Ans.)}$$

(*ii*) **Annual load factors (L.F.) for both the stations :**

$$\text{L.F. (base load plant)} = \frac{\text{Average load}}{\text{Peak load}} \times \frac{8760}{8760} = \frac{\text{Area '}pnmm's'p\text{'}}{P_{base} \times 8760}$$

$$= \frac{\text{Area '}pnmsp\text{' + area '}smm's's\text{'}}{P_{base} \times 8760}$$

$$= \frac{\frac{1}{2}(3000 + 8760) \times (87 - 24) + 24 \times 8760}{87 \times 8760}$$

$$= \frac{370440 + 210240}{762120} = 0.762 \text{ or } 76.2\%$$

i.e., Load factor for base load plant = **76.2%. (Ans.)**

$$\text{L.F. (peak load plant)} = \frac{\text{Area '}lnpl\text{'}}{P_{peak} \times 8760}$$

$$= \frac{\frac{1}{2} \times 3000 \times 33}{33 \times 8760} = 0.171 \text{ or } 17.1\%$$

i.e., Load factor for peak load plant = **17.1%. (Ans.)**

Example 8.3. *The two power stations X and Y supply to a system whose maximum load is 120 MW and minimum load is 12 MW during the year. The estimated costs of these stations are as follows :*

$$C_X = Rs.\ (120 \times kW + 0.028 \times kWh)$$

$$C_Y = Rs.\ (115 \times kW + 0.032 \times kWh)$$

If the load varies as a straight line, find for minimum cost of generation :

(i) Installed capacity of each station.

(ii) The annual load factor, capacity factor and use factor of each machine.

(iii) The average cost of production per kWh for the entire system.

Assume reserve capacity of Y as 22%.

Solution. Given :

$$C_X = \text{Rs. } (120 \times \text{kW} + 0.028 \times \text{kWh})$$

$$C_Y = \text{Rs. } (115 \times \text{kW} + 0.032 \times \text{kWh})$$

i.e., $A_1 = 120, \quad B_1 = 0.028$

and $A_2 = 115, \quad B_2 = 0.032$

$$h = \frac{A_1 - A_2}{B_2 - B_1} = \frac{120 - 115}{0.032 - 0.028} = 1250 \text{ hours}$$

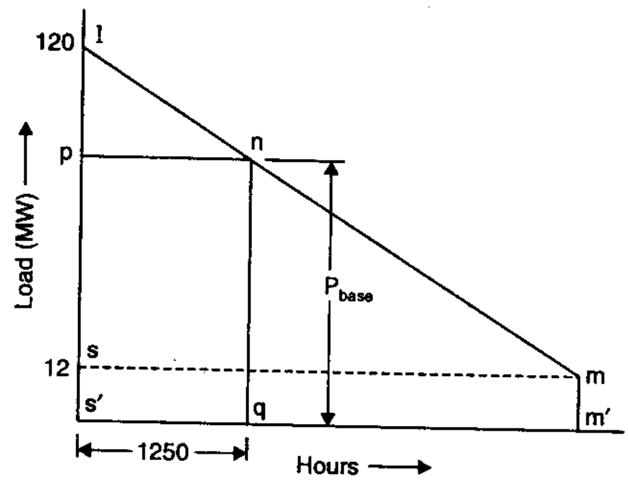


Fig. 8.7

From Δs *lms* and *lnp*, we have

$$\frac{120 - P_{base}}{120 - 12} = \frac{1250}{8760}$$

$\therefore$ $$P_{base} = 120 - (120 - 12) \times \frac{1250}{8760} \simeq 105 \text{ MW}$$

$\therefore$ $$P_{peak} = 120 - 105 = 15 \text{ MW}$$

(*i*) **Installed capacity of each station :**

Installed capacity of base load plant,

$$P_{base} = \mathbf{105\ MW.} \quad \textbf{(Ans.)}$$

Installed capacity of peak load plant = 15 × 1.22 = **18.3 MW. (Ans.)**

(*ii*) **The annual load, capacity and use factors for each station :**

For base load plant :

Load factor (L.F.) $= \dfrac{\text{Actual units generated}}{P_{base} \times 8760}$

$$= \frac{\frac{1}{2}(1250 + 8760) \times (105 - 12) + 112 \times 8760}{105 \times 8760}$$

$$= \frac{465465 + 105120}{919800} = \mathbf{0.62 \text{ or } 62\%.} \quad \textbf{(Ans.)}$$

As there is no reserve capacity of plant X,

$\therefore$ *Capacity factor (C.F.)* = L.F. = **62%. (Ans.)**

Use factor (U.F.) $= \frac{\text{C.F.}}{\text{L.F.}} = \frac{0.62}{0.62} = \mathbf{1.}$ **(Ans.)**

For peak load plant :

$$\text{L.F.} = \frac{\text{Actual units generated}}{P_{peak} \times 8760}$$

$$= \frac{\frac{1}{2} \times 1250 \times 15}{15 \times 8760} = \mathbf{0.071 \text{ or } 7.1\%.} \quad \textbf{(Ans.)}$$

$$\text{C.F.} = \frac{\text{Average load}}{\text{Actual plant capacity}} = \frac{\text{Actual units generated}}{18.3 \times 8760}$$

$$= \frac{\frac{1}{2} \times 1250 \times 15}{18.3 \times 8760} = \mathbf{0.058 \text{ or } 5.8\%.} \quad \textbf{(Ans.)}$$

$$\text{U.F.} = \frac{\text{C.F.}}{\text{L.F.}} = \frac{0.058}{0.071} = \mathbf{0.816 \text{ or } 81.6\%.} \quad \textbf{(Ans.)}$$

(iii) **Average cost of production per kWh for the entire system :**

For plant X (base) :

Total units generated $= \frac{1}{2}(1250 + 8760) \times (105 - 12) + 12 \times 8760$

$= 570585$ MWh $= 570.585 \times 10^6$ kWh

$\therefore$ $C_X = \text{Rs. } (120 \times 105 \times 10^3 + 0.028 \times 570.585 \times 10^6)$

$= \text{Rs. } (12.6 \times 10^6 + 15.97 \times 10^6) = \text{Rs. } 28.57 \times 10^6$

For plant Y (peak) :

Total units generated $= (\frac{1}{2} \times 1250 \times 15) = 9375$ MWh

$= 9.375 \times 10^6$ kWh

$\therefore$ $C_Y = \text{Rs. } (115 \times 15 \times 10^3 + 0.032 \times 9.375 \times 10^6)$

$= \text{Rs. } (1.725 \times 10^6 + 0.3 \times 10^6) = \text{Rs. } 2.025 \times 10^6$

Total units generated from both the plants

$= 570.585 \times 10^6 + 9.375 \times 10^6 \simeq 580 \times 10^6$ kWh

Total generation cost,

$C = C_X + C_Y = 28.57 \times 10^6 + 2.025 \times 10^6 = \text{Rs. } 30.595 \times 10^6$

$\therefore$ *Average cost* $= \frac{\text{Total generation cost}}{\text{Total units generated}} = \frac{30.595 \times 10^6}{580 \times 10^6}$

= **Rs. 0.0527 or 5.3 paise/kWh. (Ans.)**

Example 8.4. *In an industry the maximum and minimum demands are 60 MW and 12 MW respectively and the variation is linear. The hydro-power plant can take the load of 72 MWh per day of the factory at the time of minimum regulated flow and the remaining is supplied by the thermal plant. It is proposed to pump the water from tailrace of the existing plant to reservoir during off-peak* *period of thermal plant and allow the thermal plant to run always of full load condition to economise the supply of power.*

If the overall efficiency of conversion of steam off-peak power to hydel potential power and then hydel power to electric power is 62%, calculate the capacity of steam and hydel plants considering the pumping of water during off-peak period of steam plants.

Solution. Fig. 8.8 shows the load duration curve.

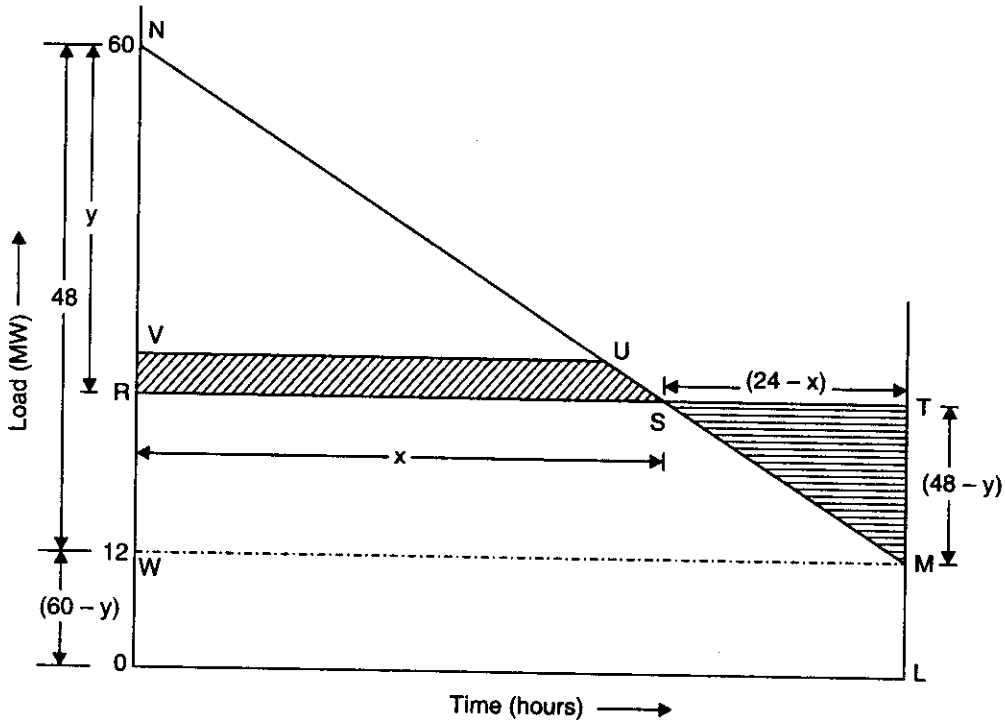


Fig. 8.8

Maximum supply = 60 MW

Let, y = The load taken by existing hydel plant and pump storage plant (in MW).

Then $(60 - y)$ = The power supplied by thermal plant (in MW).

The off-peak power of thermal plant represented by the area *'STMS'* can be used for pumping the water. The power supplied by the existing hydel plant will be given by the area *'NVUN'*.

Hydel potential in electrical form supplied by pump-storage plant must be equal to the area *'RSUVR'*.

∴ Area *'RSUVR'* = 0.62 × area *'STMS'* (data given)

∴ Area *'NSRN'* – area *'NUVN'* = 0.62 × area *'STMS'*.

But area *'NUVN'* represents the energy supplied by the existing hydel plant which is given as 72 MWh.

Let x = Number of hours (out of 24 hours) for which the steam plant operates at full load condition.

Then $(24 - x)$ = Number of hours for which the steam plant works under off-peak conditions.

$$\therefore \quad \frac{1}{2}xy - 72 = \frac{1}{2}(24 - x)(48 - y) \times 0.62$$

or $$xy - 144 = (24 - x)(48 - y) \times 0.62 \quad ...(i)$$

Now from Δs *NRS* and *NWM*, we can write

$$\frac{y}{48} = \frac{x}{24}$$

$$\therefore \quad y = 2x \quad ...(ii)$$

Substituting the value of '*y*' in eqn. (*i*), we get

$$2x^2 - 144 = (24 - x)(48 - 2x) \times 0.62$$

or $$2x^2 - 144 = (1152 - 48x - 48x + 2x^2) \times 0.62$$

or $$2x^2 - 144 = (1152 - 96x + 2x^2) \times 0.62$$

$$2x^2 - 144 = 714.24 - 59.52x + 1.24x^2$$

or $$0.76x^2 + 59.52x - 858.24 = 0$$

$$\therefore \quad x = \frac{-59.52 \pm \sqrt{(59.52)^2 + 4 \times 0.76 \times 858.24}}{2 \times 0.76}$$

$$= \frac{-59.52 \pm \sqrt{3542.63 + 2609}}{1.52} = \frac{-59.52 \pm 78.43}{2}$$

$$= 9.455 \text{ hours}$$

i.e., $$x = 9.455 \text{ hours}$$

$\therefore$ *y (total capacity of hydel-plant)*

$$= 2x = 2 \times 9.455 = \mathbf{18.91\ MW.} \quad \textbf{(Ans.)}$$

$\therefore$ *Steam plant capacity*

$$= 60 - y = 60 - 18.91 = \mathbf{41.1\ MW.} \quad \textbf{(Ans.)}$$

THEORETICAL QUESTIONS

1. State the advantages of operating the power plants combinedly in electric power system.
2. Describe the working of hydro-electric plants having ample storage with steam power plants.
3. How would you make an economic analysis of the combined operation of the hydro and steam power plants ?
4. What are the advantages of pump storage plant as peak load plant in an interconnected system ?
5. State the advantages of gas turbine plant as peak load plant in an interconnected system.
6. Discuss the suitability of steam power plants to supply the load in case of an interconnected system.
7. List the factors which decide the distribution of plants for operation on different portions of the annual load duration curve of a power system.

UNSOLVED EXAMPLES

1. The two power stations I and II supply to a system whose maximum load is 120 MW and minimum load is 12 MW during the year. The estimated costs of these stations are as follows :

$$C_I = \text{Rs. } (125 \times \text{kW} + 0.0275 \times \text{kWh})$$

$$C_{II} = \text{Rs. } (120 \times \text{kW} + 0.03 \times \text{kWh})$$

If the load varies as a straight line, find for minimum cost of generation :

(*i*) Installed capacity of each station.

(*ii*) The annual load, capacity and capacity use factor of each station.

(*iii*) The average cost of production per kWh for entire system.

Assume reserve capacity of II as 20 per cent.

[**Ans.** (*i*) 80 MW, 24 MW (*ii*) 65%, 65%, U.F. = 1 ; 11.5%, 9.5%, U.F. = 82.5% (*iii*) 5.4 paise/kWh]

2. The annual load duration curve of a station varies uniformly from 64000 kW to zero. The load is supplied by two stations whose cost equations are given as :

$$C_1 = \text{Rs. } (84000 + 84 \text{ kW} + 0.0116 \text{ kWh})$$

$$C_2 = \text{Rs. } (50000 + 44 \text{ kW} + 0.02985 \text{ kWh})$$

Find the minimum cost of generation in paise/kWh for the system. [**Ans.** 3 paise/kWh (apprcx.)]

3. An annual load duration curve of a system of loads is a straight line with maximum of 12 MW at the beginning and 2 MW at the end of the year. Annual costs of base and peak load stations are given below :

$$C_1 = 8000 + \text{Rs. } 75/\text{kW} + 3 \text{ paise/kWh (base load)}$$

$$C_2 = 6000 + \text{Rs. } 55/\text{kW} + 4 \text{ paise/kWh (peak load)}$$

Determine the following :

(*i*) The duration of time when peak load station will work in order to obtain the minimum annual cost.

(*ii*) The lowest overall cost per kW (in paise). [**Ans.** (*i*) 2000 hours (*ii*) 4.66 paise/kWh]

4. In a system the load duration curve is a straight line with a maximum demand of 45 MW tapering to zero. The load is to be taken from two sources whose annual cost equations are : C_1 = Rs. $(100 \times 10^3 + 65.7 \times \text{kW} + 0.012 \times \text{kWh})$ and C_2 = Rs. $(60 \times 10^3 + 36.5 \times \text{kW} + 2.122 \times \text{kWh})$. Find the installed capacity and service hours for each station per year to give minimum cost per unit and cost per unit.

[**Ans.** 30 MW and 15 MW, 2920 hours and 58 hours, 2.72 paise/kWh]

9

Economics of Power Generation

9.1. INTRODUCTION

In all fields of industry economics plays an important role. In power plant engineering economics of power system use certain well established techniques for choosing the most suitable system. The power plant design must be made on the basis of most economical condition and not on the most efficient condition as the profit is the main basis in the design of the plant and its effectiveness is measured financially. *The main purpose of design and operation of the plant is to bring the cost of energy produced to minimum.* Among many factors, the efficiency of the plant is one of the factors that determines the energy cost. In majority of cases, unfortunately, the most thermally efficient plant is not economic one.

9.2. TERMS AND DEFINITIONS

1. Connected load. The connected load on any system, or part of a system, *is the combined continuous rating of all the receiving apparatus on consumers' premises, which is connected to the system, or part of the system, under consideration.*

2. Demand. The demand of an installation or system *is the load that is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time.* Demand is expressed in kilowatts (kW), kilovolt-amperes (kVA), amperes (A), or other suitable units.

3. Maximum demand or Peak load. The maximum demand of an installation or system *is the greatest of all the demands that have occurred during a given period.* It is determined by measurement, according to specifications, over a prescribed interval of time.

4. Demand factor. The demand factor of any system, or part of a system, is *the ratio of maximum demand of the system, a part of the system, to the total connected load of the system, or of the part of the system, under consideration.* Expressing the definition mathematically,

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}} \qquad ...(9.1)$$

5. Load factor. The load factor is *the ratio of the average power to the maximum demand.* In each case, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load factor. The proper interval and period are usually *dependent upon local conditions and upon the purpose for which the load factor is to be used.* Expressing the definition mathematically,

$$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum demand}} . \quad ...(9.2)$$

6. Diversity factor. The diversity factor of any system, or part of a system, *is the ratio of the maximum power demands of the subdivisions of the system, or part of a system, to the maximum demand of the whole system, or part of the system, under consideration, measured at the point of supply.* Expressing the definition mathematically,

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand of entire group}} . \quad ...(9.3)$$

7. Utilization factor. The utilization factor is defined as *the ratio of the maximum generator demand to the generator capacity.*

8. Plant capacity factor. It is defined as the *ratio of actual energy produced in kilowatt hours (kWh) to the maximum possible energy that could have been produced during the same period.* Expressing the definition mathematically,

$$\text{Plant capacity factor} = \frac{E}{C \times t} \quad ...(9.4)$$

where, E = Energy produced (kWh) in a given period,

C = Capacity of the plant in kW, and

t = Total number of hours in the given period.

9. Plant use factor. It is defined as *the ratio of energy produced in a given time to the maximum possible energy that could have been produced during the actual number of hours the plant was in operation.* Expressing the definition mathematically,

$$\text{Plant use factor} = \frac{E}{C \times t'} \quad ...(9.5)$$

where t' = Actual number of hours the plant has been in operation.

10. Types of loads.

(*i*) ***Residential load.*** This type of load includes domestic lights, power needed for domestic appliances such as radios, television, water heaters, refrigerators, electric cookers and small motors for pumping water.

(*ii*) ***Commercial load.*** It includes lighting for shops, advertisements and electrical appliances used in shops and restaurants etc.

(*iii*) ***Industrial load.*** It consists of load demand of various industries.

(*iv*) ***Municipal load.*** It consists of street lighting, power required for water supply and drainage purposes.

(*v*) ***Irrigation load.*** This type of load includes electrical power needed for pumps driven by electric motors to supply water to fields.

(*vi*) ***Traction load.*** It includes trams, cars, trolley, buses and railways.

11. Load curve. A load curve (or load graph) *is a graphic record showing the power demands for every instant during a certain time interval.* Such a record may cover 1 hour, in which case it would be an *hourly load graph* ; 24 hours, in which case it would be a *daily load graph* ; a month in which case it would be a *monthly load graph* ; or a year (8760 hours), in which case it would be a *yearly load graph.* The following points are worth noting :

Refer Fig. 9.1.

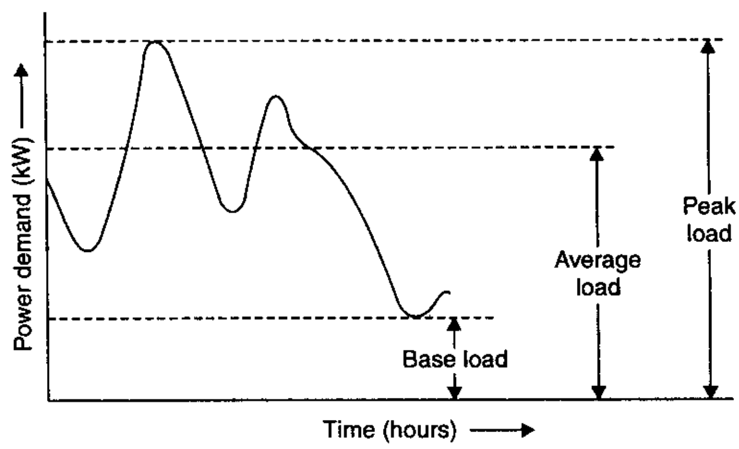


Fig. 9.1. Load curve.

(*i*) *The area under the load curve represents the energy generated in the period considered.*

(*ii*) *The area under the curve divided by the total number of hours gives the average load on the power station.*

(*iii*) *The peak load indicated by the load curve/graph represents the maximum demand of the power station.*

Significance of load curves :

- Load curves give full information about the incoming load and help to decide the installed capacity of the power station and to decide the economical sizes of various generating units.
- These curves also help to estimate the generating cost and to decide the operating schedule of the power station *i.e.*, the sequence in which different units should be run.

12. Load duration curve. A load duration curve represents re-arrangements of all the load elements of chronological load curve in order of descending magnitude. This curve is derived from the chronological load curve.

Fig. 9.2 shows a typical daily load curve for a power station. It may be observed that the maximum load on power station is 35 kW from 8 A.M to 2 P.M. This is plotted in Fig. 9.3. Similarly other loads of the load curve are plotted in *descending order* in the same figure. This is called *load duration curve* (Fig. 9.3).

The following points are worth noting :

(*i*) *The area under the load duration curve and the corresponding chronological load curve is equal and represents total energy delivered by the generating station.*

(*ii*) *Load duration curve gives a clear analysis of generating power economically. Proper selection of base load power plants and peak load power plants becomes easier.*

13. Dump power. This term is used in hydroplants and it shows the *power in excess of the load requirements* and it is made available by *surplus water.*

14. Firm power. It is the power which *should always be available even under emergency conditions.*

15. Prime power. It is the power which may be mechanical, hydraulic or thermal that is *always available for conversion into electric power.*

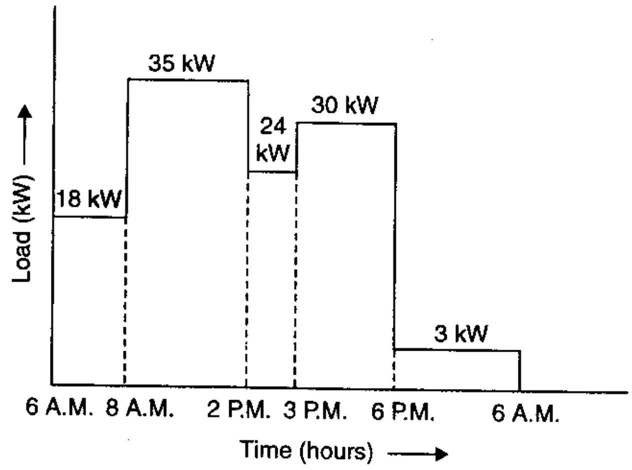


Fig. 9.2. Typical daily load curve.

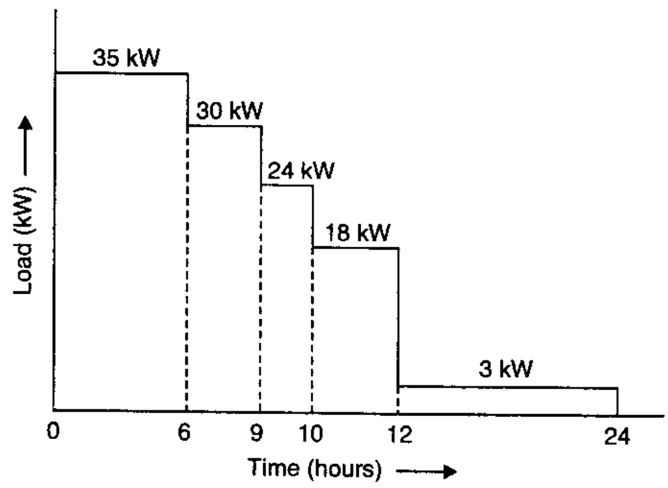


Fig. 9.3. Load duration curve.

16. Cold reserve. It is that *reserve generating capacity which is not in operation but can be made available for service.*

17. Hot reserve. It is that *reserve generating capacity which is in operation but not in service.*

18. Spinning reserve. It is that *reserve generating capacity which is connected to the bus and is ready to take the load.*

9.3. PRINCIPLES OF POWER PLANT DESIGN

The following *factors* should be considered while designing a power plant :

1. Simplicity of design.
2. Low capital cost.
3. Low cost of energy generated.
4. High efficiency.
5. Low maintenance cost.
6. Low operating cost.
7. Reliability of supplying power.
8. Reserve capacity to meet future power demand.

9.4. LOCATION OF POWER PLANT

Some of the considerations on which the location of a power plant depends are :

1. Centre of electrical load. The plant should be located where there are industries and other important consumption places of electricity. There will be considerable advantage in placing the power station *nearer to the centre of the load.*

— There will be *saving in the cost of copper* used for transmitting electricity as the distance of transmission line is reduced.

— The cross-section of the transmission line directly depends upon the maximum current to be carried. In case of alternating current the voltage to be transmitted can be increased thus reducing the current and hence the *cross-section of the transmission line can be reduced.* This will *save the amount of copper.*

— It is desirable now to have a national grid connecting all power stations. This provides for selecting a site which has other advantages such as nearer to fuel supply, condensing water available.

2. Nearness to the fuel source. The cost of transportation of fuel may be quite high if the distance of location of the power plant is considerable. It may be advisable to locate big thermal power plants at the mouth of the coal mines. Lignite coal mines should have centralised thermal power station located in the mines itself as this type of coal cannot be transported. Such type of power stations could be located near oil fields if oil is to be used as a fuel and near gas wells where natural gas is available in abundance. In any case it has been seen that *it is cheaper to transmit electricity than to transport fuel.* Hence the power plant should be located nearer the fuel supply source.

3. Availability of water. The availability of water is of greater importance than all other factors governing station location. Water is required for a thermal power station using turbines for the following two purposes :

(*i*) To supply the make-up water which should be reasonably pure water.

(*ii*) To cool the exhaust steam. This cooling process is done in case of diesel engines too. For *bigger power stations* the quantity of this cooling water is tremendous and requires *some natural source of water* such as *lake, river or even sea.* Cooling towers could be used economically as the same cooling water could be used again and again. Only a part of make up water for cooling will then be required. For *small plants spray pounds* could sometimes be used. *It is economical to limit the rise in cooling-water temperature to a small value (between 6°C and 12°C), and to gain in cycle efficiency at the expense of increased cooling water pumping requirement.*

4. Type of soil available and land cost. While selecting a site for a power plant it is important to know about the character of the soil. If the soil is loose having low bearing power the pile foundations have to be used. Boring should be made at most of the projected site to have an idea of the character of the various strata as well as of the bearing power of the soil. *The best location is that for which costly and special foundation is not required.*

In case of power plants being situated near metropolitan load centres, the land there will be very costly as compared to the land at a distance from the city.

9.5. LAYOUT OF POWER PLANT BUILDING

The following points should be taken care of while deciding about power plant building and its layout :

1. The power plant structure should be simple and rugged with pleasing appearance.
2. Costly materials and ornamental work should be avoided.

3. The power plant interior should be clean, airy and attractive.

4. The exterior of the building should be impressive and attractive.

5. Generally the building should be *single storeyed.*

6. The layout of the power plant should first be made on paper, the necessary equipment well arranged and then design the covering structure. In all layout, allowances must be made for sufficient clearances and for walkways. Good clearance should be allowed around generators, boilers, heaters, condensers etc. Walkway clearances around hot objects and rapidly moving machinery should be wider than those just necessary to allow passage. Also the galleries in the neighbourhood of high tension bus bars should be sufficient as the space will permit.

7. Provision for future extension of the building should be made.

8. The height of the building should be sufficient so that overhead cranes could operate well and the overhauling of the turbines etc. is no problem. Sufficient room should be provided to lift the massive parts of the machines.

9. Each wall should receive a symmetrical treatment in window openings etc.

10. The principal materials used for building the power plant building are brick, stone, hollow tiles, concrete and steel.

11. In case of a *steam power plant*, there are distinct parts of the building *viz.*, *boiler room*, *turbine room* and *electrical bays.* Head room required in the boiler room should be greater than in the others. Ventilation in boiler room presents greater difficulty because of heat liberated from the boiler surfaces. The turbine room is actually the show room of the plant. Mezzanine flooring should be used in the power plant. The chimney height should be sufficient so as to release the flue gases sufficiently high so that the atmosphere is not polluted and the nearby buildings are not affected.

12. The foundation of a power plant is one of the most important considerations. For this the bearing capacity of the sub-soil, selection of a working factor of safety and proportioning the wall footings to economical construction should be well thought of and tested. The pile foundations may have to be used where the soils have low bearing values.

13. In any power plant *machine foundation* plays an important part. The machine foundation should be able to distribute the weight of the machine, bed plate and its own weight over a safe subsoil area. It must also provide sufficient mass *to absorb machine vibrations.*

14. Sufficient room for storage of fuel should be provided indoor as well as outdoor so as to ensure against any prolonged breakdown.

9.6. COST ANALYSIS

The cost of a power system depends upon whether :

(*i*) an entirely new power system has to be set up, or

(*ii*) an existing system has to be replaced, or

(*iii*) an extension has to be provided to the existing system. The cost interalia includes :

1. Capital Cost or Fixed Cost. It includes the following :

(*i*) Initial cost (*ii*) Interest

(*iii*) Depreciation cost (*iv*) Taxes

(*v*) Insurance.

2. Operational Cost. It includes the following :

(*i*) Fuel cost (*ii*) Operating labour cost

(*iii*) Maintenance cost (*iv*) Supplies

(*v*) Supervision (*vi*) Operating taxes.

The above mentioned costs are discussed as follows :

(*a*) **Initial Cost**

Some of the several factors on which cost of a generating station or a power plant depends are :

(*i*) Location of the plant. (*ii*) Time of construction.

(*iii*) Size of units. (*iv*) Number of main generating units.

(*v*) The type of structure to be used.

The *initial cost* of a power station includes the following :

1. Land cost 2. Building cost

3. Equipment cost 4. Installation cost

5. Overhead charges which will include the transportation cost, stores and storekeeping charges, interest during construction etc.

— To *reduce the cost of building*, it is desirable to eliminate the superstructure over the boiler house and as far as possible on turbine house also.

— The *cost on equipment can be reduced* by adopting unit system where one boiler is used for one turbogenerator. Also by simplifying the piping system and elimination of duplicate system such as steam headers and boiler feed headers. The cost can be further reduced by eliminating duplicate or stand-by auxiliaries.

— When the power plant is not situated in the proximity to the load served, the cost of a primary distribution system will be a part of the initial investment.

(*b*) **Interest**

All enterprises need investment of money and this money may be obtained as loan, through bonds and shares or from owners of personal funds. *Interest is the difference between money borrowed and money returned*. It may be charged at a simple rate expressed as % per annum or may be compounded, in which case the interest is reinvested and adds to the principal, thereby earning more interest in subsequent years. Even if the owner invests his own capital the charge of interest is necessary to cover the income that he would have derived from it through an alternative investment or fixed deposit with a bank. *Amortization* in the periodic repayment of the principal as a uniform annual expense.

(*c*) **Depreciation**

Depreciation accounts for the deterioration of the equipment and decrease in its value due to corrosion, weathering and wear and tear with use. It also covers the decrease in value of equipment due to obsolescence. With rapid improvements in design and construction of plants, obsolescence factor is of enormous importance. Availability of better models with lesser overall cost of generation makes it imperative to replace the old equipment earlier than its useful life is spent. The actual life span of the plant has, therefore, to be taken as shorter than what would be normally expected out of it.

The following methods are used to calculate the depreciation cost :

(*i*) Straight line method (*ii*) Percentage method

(*iii*) Sinking fund method (*iv*) Unit method.

(*i*) **Straight line method.** It is the *simplest* and *commonly used method*. The life of the equipment or the enterprise is first assessed as also the residual or salvage value of the same after the estimated life span. This salvage value is *deducted* from the initial capital cost and the balance is *divided by the life as assessed in years*. Thus, the annual value of decrease in cost of equipment is found and is set aside as depreciation annually from the income. *Thus, the rate of depreciation is uniform throughout the life of the equipment*. By the time the equipment has lived out its useful life, an amount equivalent to its net cost is accumulated which can be utilised for replacement of the plant.

(*ii*) **Percentage method.** In this method the deterioration in value of equipment from year to year is taken into account and the amount of depreciation calculated upon actual residual value for each year. It thus, reduces for successive years.

(*iii*) **Sinking fund method.** This method is based on the *conception that the annual uniform deduction from income for depreciation will accumulate to the capital value of the plant at the end of life of the plant or equipment.* In this method, the amount set aside per year consists of annual instalments and the interest earned on all the instalments.

Let, A = Amount set aside at the end of each year for n years,

n = Life of plant in years,

S = Salvage value at the end of plant life,

i = Annual rate of compound interest on the invested capital, and

P = Initial investment to install the plant.

Then, amount set aside at the end of first year = A

Amount at the end of second year

$$= A + \text{interest on } A = A + Ai = A(1 + i)$$

Amount at the end of third year

$$= A(1 + i) + \text{interest on } A(1 + i)$$

$$= A(1 + i) + A(1 + i)i$$

$$= A(1 + i)^2$$

$\therefore$ Amount at the end of nth year = $A(1 + i)^{n-1}$

Total amount accumulated in n years (say x)

= Sum of the amounts accumulated in n years

i.e.,

$$x = A + A(1 + i) + A(1 + i)^2 + ... + A(1 + i)^{n-1}$$

$$= A\,[1 + (1 + i) + (1 + i)^2 + ... + (1 + i)^{n-1}] \quad ...(i)$$

Multiplying the above equation by $(1 + i)$, we get

$$x(1 + i) = A\,[(1 + i) + (1 + i)^2 + (1 + i)^3 + ... + (1 + i)^n] \quad ...(ii)$$

Subtracting equation (*i*) from (*ii*), we get

$$x.i = [(1 + i)^n - 1]\,A$$

$$\therefore \quad x = \left[\frac{(1+i)^n - 1}{i}\right] A$$

where $x = (P - S)$

$$\therefore \quad P - S = \left[\frac{(1+i)^n - 1}{i}\right] A \quad ...(9.6)$$

or

$$A = \left[\frac{i}{(1+i)^n - 1}\right] (P - S) \quad ...(9.7)$$

(*iv*) **Unit method.** In this method *some factor is taken as a standard one and depreciation is measured by that standard.* In place of years an equipment will last, the number of hours that an equipment will last is calculated. This total number of hours is then divided by the capital value of the equipment. This constant is then multiplied by the number of actual working hours each year to get the value of depreciation for that year. In place of number of hours, the number of units of production is taken as the measuring standard.

(*d*) **Operational cost**

The elements that make up the operating expenditure of a power plant include the following costs :

(*i*) Cost of fuels. (*ii*) Labour cost.

(*iii*) Cost of maintenance and repairs. (*iv*) Cost of stores (other than fuel).

(*v*) Supervision. (*vi*) Taxes.

Cost of fuels. In a thermal station fuel is the heaviest item of operating cost. The selection of the fuel and the maximum economy in its use are, therefore, very important considerations in thermal plant design. It is desirable to achieve the highest thermal efficiency for the plant so that fuel charges are reduced. *The cost of fuel includes not only its price at the site of purchase but its transportation and handling costs also.* In the hydroplants the absence of fuel factor in cost is responsible for lowering the operating cost. *Plant heat rate can be improved by the use of better quality of fuel or by employing better thermodynamic conditions in the plant design.*

The cost of fuel varies with the following :

(*i*) Unit price of the fuel.

(*ii*) Amount of energy produced.

(*iii*) Efficiency of the plant.

Labour cost. For plant operation labour cost is another item of operating cost. Maximum labour is needed in a thermal power plant using coal as a fuel. A hydraulic power plant or a diesel power plant of equal capacity require a lesser number of persons. In case of automatic power station the cost of labour is reduced to a great extent. However labour cost cannot be completely eliminated even with fully automatic station as they will still require some manpower for periodic inspection etc.

Cost of maintenance and repairs. In order to avoid plant breakdowns *maintenance* is necessary. *Maintenance* includes *periodic cleaning, greasing, adjustments and overhauling of equipment.* The material used for maintenance is also charged under this head. Sometimes an arbitrary percentage is assumed as maintenance cost. A good plan of maintenance would keep the sets in dependable condition and avoid the necessity of too many stand-by plants.

Repairs are necessitated when the plant breaks down or stops due to faults developing in the mechanism. The repairs may be minor, major or periodic overhauls and are charged to the depreciation fund of the equipment. This item of cost is higher for thermal plants than for hydro-plants due to complex nature of principal equipment and auxiliaries in the former.

Cost of stores (other than fuel). The items of consumable stores other than fuel include such articles as lubricating oil and greases, cotton waste, small tools, chemicals, paints and such other things. The incidence of this cost is also higher in thermal stations than in hydro-electric power stations.

Supervision. In this head the salary of supervising staff is included. A good supervision is reflected in lesser breakdowns and extended plant life. The supervising staff includes the station superintendent, chief engineer, chemist, engineers, supervisors, stores incharges, purchase officer and other establishment. Again, thermal stations, particularly coal fed, have a greater incidence of this cost than the hydro-electric power stations.

Taxes. The taxes under operating head includes the following :

(*i*) Income tax

(*ii*) Sales tax

(*iii*) Social security and employee's security etc.

9.7. SELECTION OF TYPE OF GENERATION

While choosing the type of generation the following points should be taken into consideration :

1. The type of fuel available or availability of suitable sites for water power generation.
2. Fuel transportation cost.
3. Land required.
4. Foundation cost.
5. The availability of cooling water.
6. The type of load to be taken by the power plant.
7. Reliability in operation.
8. Plant life.
9. Cost of transmitting the energy.

9.8. SELECTION OF POWER PLANT EQUIPMENT

Selection of some important power plant equipment is discussed below :

9.8.1. Selection of Boilers

It is now well known fact that only water tube boilers (fire tube boilers not suitable) should be used for all central power stations. While selecting a boiler the following points should be taken care of :

1. Type of fuel to be burnt.
2. Type of load.
3. Cost of fuel.
4. Desirability of heat-reclaiming equipment.
5. Availability of space for boiler installation.

— The design and efficiency of the boiler is considerably influenced by the *type of fuel* used in a boiler. *A high efficiency can be obtained with coal firing as compared to oil or gas firing.* This is due to increased hydrogen loss in gaseous fuels.

— *The location of the plant* will also decide the type of fuel to be used. If the plant is nearer the coal fields, coal will be cheaper. Power plants near to the oil fields and gas wells will naturally use these fuels.

— *Coal firing* will also *influence furnace design and hence the cost of boiler.* In case of low ranking fuel such as lignites etc., pulverised firing is used. Very low fusing temperatures of coal require water cooled walls and in some cases the slag tap furnaces. The yearly minimum operating cost has to be considered which may include production cost and fixed charges. In case of anthracite coal or metallurgical coke etc. the wear on pulverising machinery is relatively much higher than that of bituminous coal.

The cost of boilers vary with the following :

(*i*) Type of boiler used. (*ii*) Operating pressure.
(*iii*) Operating temperature. (*iv*) Type of firing.
(*v*) Efficiency desired.

— *'Heat-reclaiming equipment'* such as *economisers* and *air preheaters* should be provided with boilers. With the addition of economisers and air preheaters the efficiency of the boiler increases from 75% to 90% and above.

— The *'increased pressure' affects the cost of boiler drum, boiler tubes, headers, economisers and other accessories*. Similarly high temperatures increase the cost of superheaters as higher pressure and higher temperatures require special alloy steels. *High pressures require forced circulation also. This also increases the cost but this forced circulation also increases the efficiency of the boiler.*

— The *method of firing* has also an influence on the percentage of total time for which the boiler will be available and should be considered when planning boiler capacity. Stoker firing is in general *slightly less costly than pulverised fuel firing. The pulverised fuel firing increases the efficiency.*

— *Economisers* improve the boiler efficiency by 4 to 10%. The *air preheater* further improves the boiler efficiency from 6 to 8%.

— The exhaust gases should not be cooled *below 150°C*. Below this temperature the condensation of moisture may take place and when mixed with SO_2 this moisture produces a dilute solution of H_2SO_4 which is finitely detrimental to the equipment.

— While selecting the proper economiser size as well as the size of the air preheaters *fixed* as well as *operating* charges should be considered. The fixed charges include the cost of heat recovery equipment, flue work, ducts and also increased fan cost and building cost.

9.8.2. Selection of Prime-movers

For proper selection of prime-mover it is of paramount importance to construct the following curves :

(*i*) A typical daily load curve.

(*ii*) A peak-load curve.

(*iii*) A probable future-load curve.

The prime-movers to be used for generating electricity could be *diesel engines, steam engines, steam turbines, gas turbines, water turbines* etc.

— While selecting a prime-mover the *initial cost of a unit erected* has to be taken into consideration. The *efficiency of this unit at various loads* is also to be taken into consideration. *As the capacity of the unit increases there is a corresponding reduction in floor space per kW.*

— The selection of the prime-mover depends also on the type of use whether it is used for *industrial purpose* or *for central power stations.*

Prime-movers used for industrial purpose should be *non-condensing so that steam after exhausting could be used for processing.*

In case of *central power stations condensing steam turbines should be used. Diesel engines* have an advantage of higher efficiency and low cost. It also requires less labour and the initial investment is also less. But the cost of coal is less as compared to diesel oil. Also the capacity of diesel engines is limited and hence for *bigger power stations they are unsuitable*. The diesel engines are used as *standby plant* in all the central power stations whether thermal or hydro.

— In places where water is in abundance and a certain head is available hydro power plants/ stations are installed. In rivers where there is a natural fall, the same could be used for driving a *water turbine* in a hydro power plant. The maintenance of hydro power plant is the cheapest.

9.8.3. Selection of Size and Number of Generating Units

There can be no hard and fast rules, but however *looking at the load curve of the station one can guess for the total generating capacity, size and number of the units. Minimum generating capacity of a plant must be more than the predicted maximum demand.* Obviously, the minimum number of generators can be one but this will not be a wise suggestion. As the load on a power station is never constant, owing to variable demands at the different times of the day, the generator will have to run continuously at variable loads, which will be much less than the rated capacity of the generator for most of the times, *without any provision for the maintenance*. So a power station which is expected to be reliable in service, must have at *least two generators, irrespective of the total capacity of the plant.*

The following points are worth noting :

(*i*) The most appropriate way of deciding the size, and number of generating sets in a station is *to select the number of sets in such a way so as to fit in the load curve as closely as possible, so that the plant capacity may be used efficiently*.

(*ii*) Extra spare capacity is not desired as it increases the capital expenditure.

(*iii*) The main aim should be to have units of different capacities which will suitably fit in the load curve so that most of the generators when in use can be operated at nearly full load.

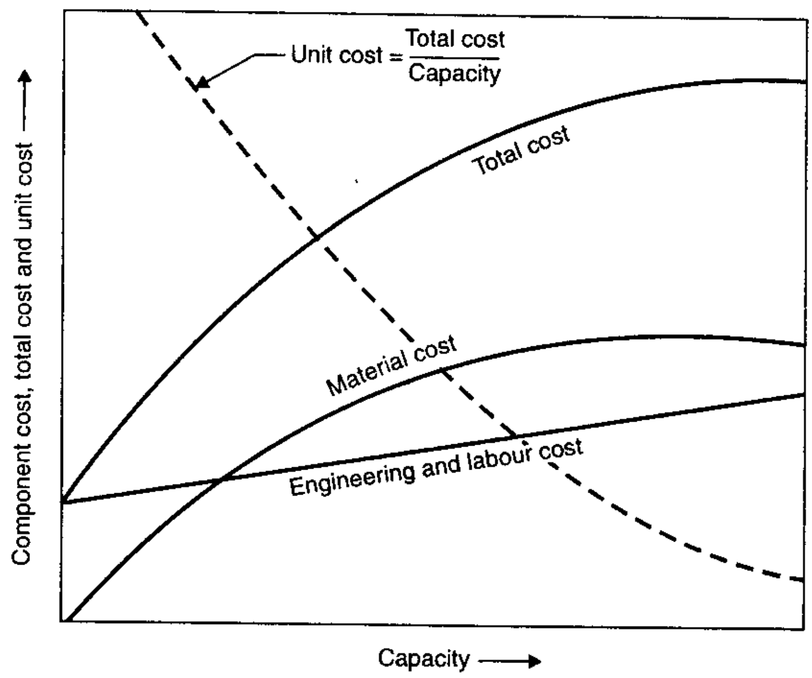


Fig. 9.4. Variation of costs of power plant *versus* its capacity.

The equipment prices are usually compared on the basis of price per unit of capacity, usually termed 'unit price'. *The unit price decreases as the capacity of the machine increases*. This is the main reason for adopting a large size generating unit in power plants. Fig. 9.4 shows the general trend and trend of the major cost components in building a given type of machine. The following points are worth noting :

— The labour and engineering cost curve *increases slightly* with the capacity of the unit.

— The material cost curve *decreases in slope* with an increase in capacity of plant.

— The total cost curve follows the pattern of material cost curve. The total cost curve shows the *positive intercept at zero capacity which represents the cost of just maintaining an organisation of men and plant ready to produce.*

— The dotted curve shows the *reduction in unit price with an increase in capacity* and this is the major argument for installing large units. *The large units are always preferred for the loads with higher load factor (0.8 to 1).*

9.9. ECONOMICS IN PLANT SELECTION

After selection of type of drive (such as steam, gas diesel or water power) which depends on availability of cheap fuels or water resources, further selection of the design and size of the equipment is primarily based upon economic consideration and a *plant that gives the lowest unit cost of production is usually chosen*. In case of all types of equipment the working *efficiency is generally higher with larger sizes of plants and with high load factor operation. Also, the capital cost per unit installation reduces as the plant is increased in size*. However, *a bigger size of plant would require greater investment, and possibilities of lower than optimum load factor usually increase with larger size of the plant*.

Steam power plants. In case of steam power plants the choice of *steam conditions* such as throttle pressure and temperature, is an important factor affecting operating costs and is, therefore, very carefully made. *As throttle pressure and temperature are raised the capital cost increases but the cycle efficiency is increased*. The advantage of higher pressures and temperatures is generally not apparent below capacity of 10,000 kW unless fuel cost is very high.

Heat rates may be improved further through *reheating* and *regeneration*, but again the capital cost of additional equipment has to be *balanced against gain in operating cost*.

The use of heat reclaiming devices, such as air preheaters and economisers, has to be considered from the point of economy in the consumption of fuel.

Internal combustion engine plants. In this case also the selection of I.C. engines also depends on thermodynamic considerations. *The efficiency of the engine improves with compression ratio but high pressures necessitate heavier construction of equipment which increases cost.*

The choice may also have to be made between *four-stroke* and *two-stroke* engines, the *former having higher thermal efficiency* and the *latter lower weight* and *cost*.

The cost of the *supercharger* may be justified if there *is a substantial gain in engine power which may balance the additional supercharge cost*.

Gas turbine power plant. The cost of the gas turbine power plant increases as the simple plant is modified by inclusion of other equipment such as *intercooler, regenerator, reheater*, etc. but the gain in thermal efficiency and thereby a reduction in operating cost may justify this additional expense in first cost.

Hydro-electric power plant. As compared with thermal stations an hydro-electric power plant has little operating cost and if sufficient water is available to cater to peak loads and special conditions for application of these plants justify, *power can be produced at a small cost*.

The *capital cost* per unit installed is *higher if the quantity of water is small*. Also, the unit cost of conveying water to the power house is greater if the quantity of water is small. The cost of storage per unit is also lower if the quantity of water stored is large.

An existing plant capacity may be *increased by storing additional water* through increasing the height of dam or by diverting water from other streams into the head reservoir. However, again it would be an economic study whether this additional cost of civil works would guarantee sufficient returns.

Some hydro-power plants may be made *automatic* or *remote controlled* to reduce the operating cost further, but the cost of automation has to be *balanced against the saving effected in the unit cost of generation*.

Interconnected hydro-steam system. In such a system where *peak loads are taken up by steam units*, the capacity of water turbine may be kept somewhat higher than the water flow capacity at peak loads, and lesser than or equal to maximum flow of river. This would make it possible for the water turbine to generate adequate energy at low cost during sufficient water flow.

Some of the principal characteristics of hydro-electric, steam and diesel power plants are listed below :

S. No.	Characteristics	Hydro-plant	Steam plant	Diesel plant
1.	*Planning and construction*	Difficult and takes long time	Easier than hydro-plant	Easiest
2.	*Civil works cost*	Highest	Lower than hydro-plant	Lowest
3.	*Running and maintenance cost* (as a fraction of total generation cost)	$\frac{1}{10}$	$\frac{1}{7}$	$\frac{1}{6}$
4.	*Overall generation cost*	Lowest	Lower than for diesel plants	Highest
5.	*Reliability*	Good	Good	Excellent

Advantages of interconnection :

Major advantages of interconnecting various power stations are :

1. Increased reliability of supply.
2. Reduction in total installed capacity.
3. Economic operation.
4. Operating savings.
5. Low capital and maintenance costs.
6. Peak loads of combined system can be carried at a *much lower cost* than what is possible with small individual system.

9.10. FACTORS AFFECTING ECONOMICS OF GENERATION AND DISTRIBUTION OF POWER

The economics of power plant operation is greatly influenced by :

(*i*) Load factor (*ii*) Demand factor

(*iii*) Utilisation factor.

Load factor. In a *hydro-electric power station* with water available and a fixed staff for maximum output, the cost per unit generated at 100% *load factor* would be *half* the cost per unit at 50% load factor. In a *steam power station* the difference would not be so pronounced since fuel cost constitutes the major item in operating costs and does not vary in the same proportion as load factor. The cost at 100% load factor in case of this station may, therefore, be about 2/3rd of the cost 50% load factor. For a *diesel station* the cost per unit generated at 100% load factor may be about 3/4th of the same cost at 50% load factor. From the above discussion it follows that :

(*i*) *Hydro-electric power station should be run at its maximum load continuously on all units.*

(*ii*) *Steam power station* should be run in such a way that *all its running units are economically loaded.*

(*iii*) *Diesel power station* should be worked for *fluctuating loads* or *as a stand by.*

Demand factor and utilisation factor. *A highly efficient station, if worked at low utilisation factor, may produce power at high unit cost.*

The time of maximum demand occurring in a system is also important. In an interconnected system, *a study of the curves of all stations is necessary to plan most economical operations.*

The endeavour should be to load the most efficient and cheapest power producing stations to the greatest extent possible. Such stations, called "*base load stations*" carry full load over 24 hours *i.e.,* for three shifts of 8 hours.

— The stations in the *medium range of efficiency* are operated only during the two shifts of 8 hours during 16 hours of average load.

— The older or *less efficient stations* are used *as peak or standby stations* only, and are operated *rarely* or for *short periods of time.*

Presently there is a tendency to use units of large capacities to reduce space costs and to handle larger loads. However, the *maximum economical benefit of large sets occurs only when these are run continuously at near full load. Running of large sets for long periods at lower than maximum continuous rating increases cost of unit generated.*

9.11. HOW TO REDUCE POWER GENERATION COST ?

The cost of power generation can be *reduced by* :

1. Using a plant of simple design that *does not need highly skilled personnel.*
2. Selecting equipment of *longer life and proper capacities.*
3. Carrying out *proper maintenance* of power plant equipment to avoid plant breakdowns.
4. Running the power stations at *high load factors.*
5. Increasing the efficiency of the power plant.
6. Keeping proper supervision, which ensures *less breakdowns* and extended plant life.

9.12. POWER PLANT—USEFUL LIFE

The useful life of a power plant is that *after which repairs become so frequent and extensive that it is found economical to replace the power plant by a new one.* Useful life of some of the power plants is given below :

Plant	*Useful life*
1. Conventional thermal power plant	20–25 years
2. Nuclear power plant	15–20 years
3. Diesel power plant	About 15 years.

The useful life of some of the equipment of a *steam power plant* is given below :

Equipment	*Useful life (years)*
1. Boilers	
(*i*) Fire tube	10–20
(*ii*) Water tube	20
2. Steam turbine	5–20
3. Steam turbo-generators	10–20
4. Condensers	20
5. Pumps	15–20
6. Coal and ash machinery	10–20
7. Feed water heaters	20–30
8. Stacks	10–30
9. Stokers	10–20

10. Transformers	15–20
11. Motors	20
12. Electric meters and instruments	10–15
13. Transmission lines	10–20

9.13. ECONOMICS OF HYDRO-ELECTRIC POWER PLANTS

The cost analysis of an hydro-electric power plant is different from those of the other plants in the respect that the fixed *coal is the major item of the total cost and the operating cost is relatively much smaller* whereas in the steam and other plants, the *operating cost is a large part of the total cost.*

In a hydro-plant the total annual cost can be divided into two following categories :

1. Fixed costs :

(*i*) Interest on capital (*ii*) Amortization of the capital

2. Running costs :

(*i*) Maintenance and repairs. (*ii*) Operating costs including salaries and wages.

(*iii*) Rates and taxes. (*iv*) Stores, oil and other supplies.

(*v*) Management expenses including insurance.

— The *fixed charges* of a hydro-plant are about 60 to 70% of the total cost of power and *these do not depend upon the station output.*

— The *running charges depend upon the station output, but not so much as in the thermal power plants.*

The following items go to form the *total capital outlay* or the *investment on a hydro-plant* :

(*i*) Preliminary surveys and investigations of the topography and geology of the proposed site of the plant.

(*ii*) Purchase of land (needed for adequate storage or pondage) and water rights.

(*iii*) Compensation to oustees.

(*iv*) Cost of preparation of detailed designs and specifications.

(*v*) Cost of testing the materials of construction.

(*vi*) Cost of carrying out experimental work and model tests or designs for hydraulic structures.

(*vii*) The actual cost of construction.

(*viii*) Cost relating the purchase and installation of the equipment.

(*ix*) Interest on capital during construction.

(*x*) Working capital during the period of load development.

(*xi*) Cost in respect of new roads, railway lines, residential houses and even new towns which may have to be constructed.

A typical cost analysis of a hydro-plant is as follows :

S. No.	Components	Cost
1.	Reservoir, dam and water ways	55%
2.	Land	15%
3.	Structures	10%
4.	Power plant and equipment	20%

Besides this there is an another important item called *transmission liability* which refers to the *transmission charges for conveying the electricity from the plant site to the load centre.*

— The total cost of construction of hydro-plant is *invariably higher than that of a thermal plant of equal capacity*. Therefore the annual charges for interest and depreciation are comparatively higher.

— In case of a *hydro-plant*, the *smaller the quantity of water stored higher is the cost per kW.*

9.14. ECONOMICS OF COMBINED HYDRO AND STEAM POWER PLANTS

It has been established that if a region/country is neither rich in fuel reserves nor in hydro resources then a combined operation of hydro and steam power plants give the best results in regard to generation of electricity at *the economical cost.* The following advantages accrue from combined plants :

1. Flexibility of operation.
2. Security of supply.
3. Improved utilisation of hydro-power.
4. Spare plant.

Practically all large power systems in the world have hydro-steam interconnected. *Hydro-plant may function as a capacity plant i.e., to supply system peak with minimum flow conditions*, or it may work as an *energy plant* to replace the costly steam generated electricity by *low cost hydro power.*

In such a system (interconnected) *there should be a daily or seasonal load allocation plan set prehand so that the use of the two power systems is made to the best advantage. A certain amount of forecasting of load and capacity of the system as well as flexibility are necessary for optimum results and experience is a big factor in good co-ordinated action.*

A knowledge of system plant loading schedules for minimum production cost is as important as that of reservoir levels, pond storage and stages of low flow and heavy loads.

9.15. PERFORMANCE AND OPERATING CHARACTERISTICS OF POWER PLANTS

The *performance* of generating power plants is compared by their *average efficiency* over a period of time. The average efficiency of a power plant is the *ratio of useful energy output to the total energy input during the period considered.* This *measure of performance varies with uncontrolled conditions viz.* (*i*) cooling water temperature (*ii*) quality of fuel and (*iii*) shape of load curve. Thus, unless all plant performances are corrected to the same controlled conditions it is not a satisfactory standard of comparison.

The performance of a plant can be precisely represented by the *input-output curve* from the tests conducted on individual power plant. The input-output curve is *graphical representation* between the net energy output (L) and input (I). The input is generally expressed in millions of kcal/h or kJ/h and load output is expressed as megawatts (MW). The input to hydro-plant is measured in cusecs or m^3/s of water.

In general input-output may be represented as follows :

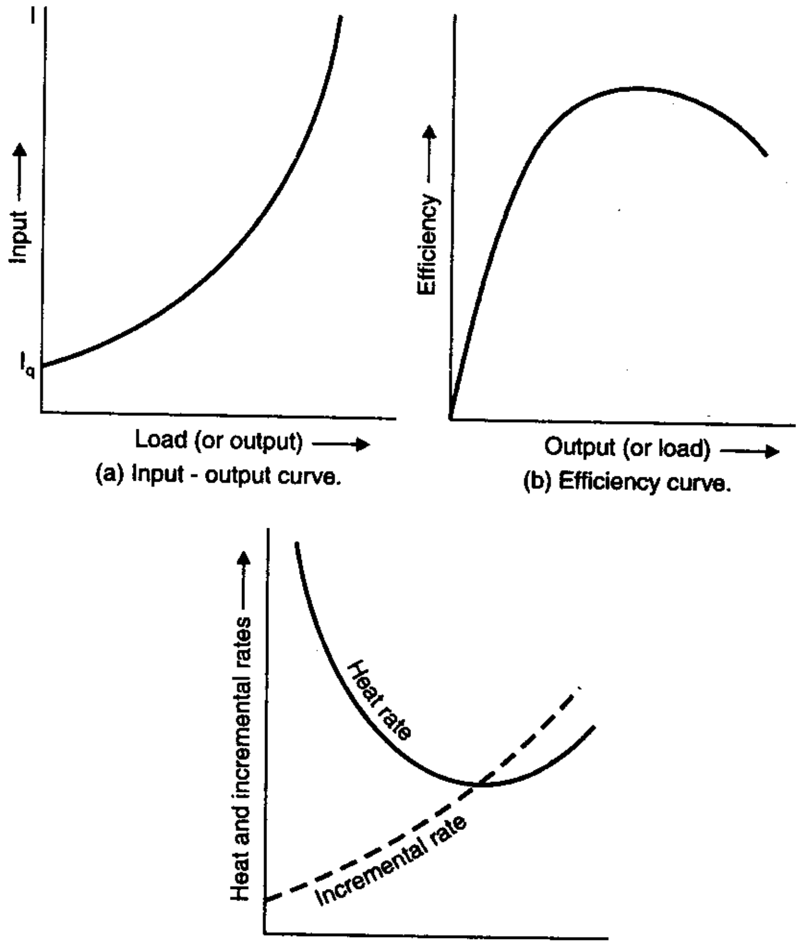
$$I = a + bL + cL^2 + dL^3$$

where I = Input,

L = Output, and

a, b, c and d = Constants

Input-output curve. Fig. 9.5 (a) shows an *input-output curve.* In order to keep the apparatus functioning at zero load, a certain input (I_0) is required *to meet frictional and heat losses.*



(a) Input - output curve.
(b) Efficiency curve.
(c) Heat rate and incremental rate curves.

Fig. 9.5.

Efficiency curve. The efficiency of the power plant is defined *as the ratio of output to input.*

$\therefore$ Efficiency, $$\eta = \frac{L}{I} = \frac{L}{a + bL + cL^2 + dL^3}$$

By using the above formula the efficiency *for any given load* can be calculated.

An *efficiency curve* is shown in Fig. 9.5 (*b*).

Heat rate and incremental rate curves. These curves can be derived from basic input-output curve.

Heat rate (HR) is defined as the *ratio of input to output.*

i.e., $$\text{Heat rate (HR)} = \frac{I}{L} = \frac{a + bL + cL^2 + dL^3}{L} = \frac{a}{L} + b + cL + dL^2$$

Heat rate curve is obtained by plotting values of heat rate against corresponding values of output. Fig. 9.5 (*c*) shows a heat rate curve.

Incremental rate (IR) is defined as the *ratio of additional input (dI) required to increase additional output (dL).*

i.e., Incremental rate $(IR) = \frac{dI}{dL}$.

Incremental rate curve is obtained by plotting values of *IR* against corresponding values of output. Such a curve is shown in Fig. 9.5 (*c*). *This curve expresses additional energy required to produce an added unit of output at the given load.*

9.16. ECONOMIC LOAD SHARING

The primary objective of the design of all generating stations is the *economy*. For a power system to return a profit on the capital invested, proper operation of the plant is essential. As far as the efficiency of boilers, turbines, alternators etc. is concerned, engineers have been successful in increasing the efficiency continuously so that each unit added results in comparatively more efficient operation. Methods have also been devised for economic operation of plants at part loads and under variable load conditions. Attempts have been made to minimise the transmission losses too. Now the *only aspect that remains is the economic distribution of the output of a plant between the generators, or units within the plant.*

Let us consider two generators 1 and 2 which supply in parallel a common load. Generator 1 is more efficient than generator 2 as for the same input, output of generator 1 is more than that of generator 2.

Fig. 9.6 shows the input-output curves of the two generators/units.

In the Fig. 9.6 (*b*) is shown the plot of combined input of generators 1 and 2 *versus* load on generator 1, for a *constant total load.*

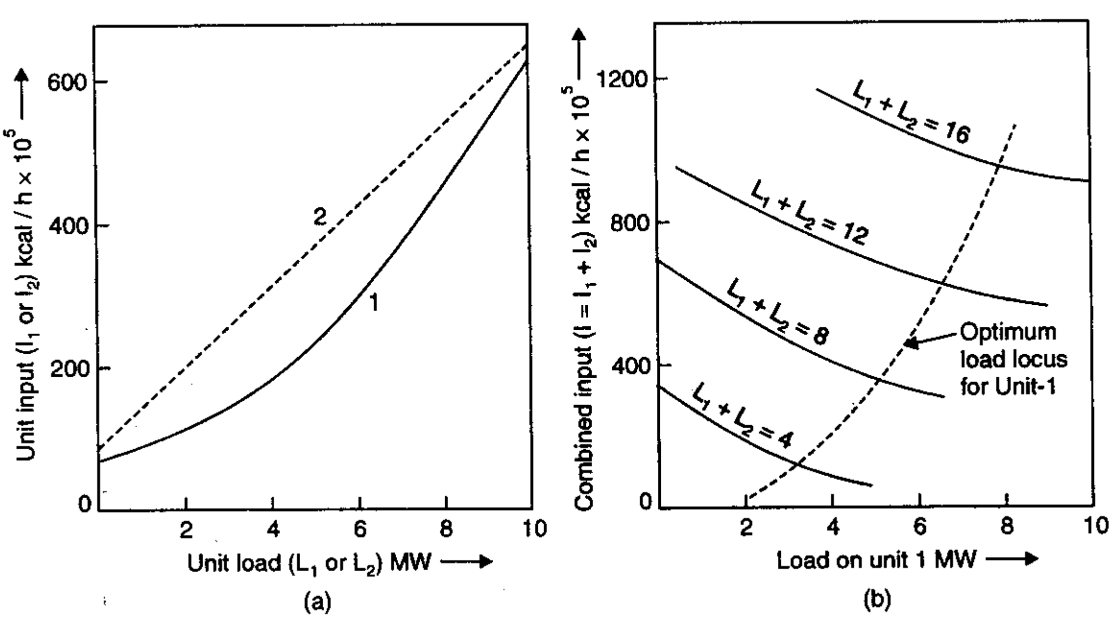


Fig. 9.6.

Although generator 1 requires less input for a given output it is not essential that unit 1 should be loaded first and then generator 2. For economical loading the combined input of units 1 and 2 should be plotted against load on unit 1 for a constant total load. Let a total load of 4 MW be supplied by generators 1 and 2.

$$L = L_1 + L_2$$

where L = combined output

L_1 = output of generator 1

L_2 = output of generator 2

Let the generator 2 supply total load of 4 MW and generator 1 supply zero load. Now corresponding to zero load on generator 1 and 4 MW on generator 2 the values of input to generator 1 (I_1) and input to generator 2 (I_2) can be determined respectively from Fig. 9.6 (*a*) and thus value of $(I_1 + I_2)$ can be plotted against zero load on generator 1. Again let 2 MW be supplied by generator 1 and 2 MW be supplied by generator 2 (so that total load remains 4 MW) then values of I_1 and I_2 can be determined corresponding to 2 MW load on each generator and value of $(I_1 + I_2)$ can be plotted against 2 MW load on generator 1 as shown in Fig. 9.6 (*b*). In this way curve for a total load of 4 MW can be plotted corresponding to different output of generator 1.

Similarly curve for total load of 8 MW etc. can be plotted. In these curves *there is at least one point where combined input is minimum for a given total load. Corresponding to this point of minimum, the load generator 1 can be found.* Then the load on generator 2 will be difference of total load and load on generator 1. *This load saving will be the most economical.*

This method is difficult to apply in practice as such because generally stations have got more than two generators / units and in that case the application of above principles becomes a cumbersome process.

Considering any combined constant input in the Fig. 9.6 (*b*), at the point of minimum input

$$\frac{dI}{dI_1} = 0 \qquad \text{...(i)}$$

where, $I = I_1 + I_2$ = input of generator 1 + input of generator 2

= combined input to generators 1 and 2

$L = L_1 + L_2$ = output of generator 1 + output of generator 2

= combined output of generators 1 and 2

Then $$\frac{dI}{dI_1} = \frac{dI_1}{dL_1} + \frac{dI_2}{dL_1} = 0 \qquad \left(\because \frac{dI}{dI_1} = 0\right)$$

As I is constant.

$$\therefore \quad \frac{dI_1}{dL_1} = -\frac{dI_2}{dL_1} \qquad \text{...(ii)}$$

But $$\frac{dI_2}{dL_1} = \frac{dI_2}{dL_2} \times \frac{dL_2}{dL_1} \qquad \text{...(iii)}$$

Also $$L_2 = L - L_1$$

$$\therefore \quad \frac{dL_2}{dL_1} = \frac{dL}{dL_1} - \frac{dL_1}{dL_1}$$

Since L is constant.

$$\therefore \quad \frac{dL}{dL_1} = 0$$

Hence $$\frac{dL_2}{dL_1} = -\frac{dL_1}{dL_1} = -1 \qquad \text{..(iv)}$$

Substituting in (*iii*), we get

$$\frac{dI_2}{dL_1} = -\frac{dI_2}{dL_2} \quad ...(v)$$

∴ From (*ii*) and (*v*),

$$\frac{dI_1}{dL_1} = \frac{dI_2}{dL_2} \quad ...(vi)$$

Thus, *for minimum combined input to carry a given combined output, the slopes of the input-output curve for each unit must be equal.*

If there are n units, supplying a constant load, then the required condition for the minimum input or maximum system efficiency is

$$\frac{dI_1}{dL_1} = \frac{dI_2}{dL_2} = \frac{dI_3}{dL_3} = ... = \frac{dI_n}{dL_n} \quad ...(vii)$$

Condition for maximum efficiency :

Refer Fig. 9.7. *The load at which efficiency will be maximum, the heat rate will be minimum at that load as efficiency is inverse of heat.*

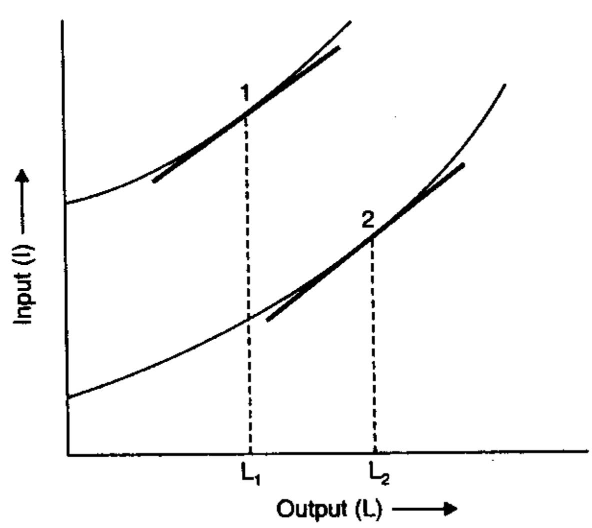


Fig. 9.7.

$$\text{Efficiency} = \frac{L}{I}$$

$$\text{Heat rate } (HR) = \frac{I}{L}$$

∴ For minimum value of heat rate

$$\frac{d}{dL}(HR) = 0 \quad \text{or} \quad \frac{d}{dL}\left(\frac{I}{L}\right)$$

$$\therefore \quad \frac{LdI - IdL}{L^2} = 0 \quad \text{or} \quad LdI = IdL \quad \text{or} \quad \frac{I}{L} = \frac{dI}{dL}$$

This shows that efficiency will be maximum at a load where heat rate is equal to incremental heat rate.

9.17. TARIFF FOR ELECTRICAL ENERGY

9.17.1. Introduction

The cost of generation of electrical energy consists of *fixed cost and running cost*. Since the electricity generated is to be supplied to the consumers, the total cost of generation has to be recovered from the consumers. *Tariffs or energy rates are the different methods of charging the consumers for the consumption of electricity*. It is desirable to charge the consumer according to the maximum demand (kW) and the energy consumed (kWh). *The tariff chosen should recover the fixed cost, operating cost and profit etc. incurred in generating the electrical energy*.

9.17.2. Objectives and Requirements of Tariff

Objectives of tariff :

1. Recovery of cost of capital investment in generating equipment, transmission and distribution system.
2. Recovery of the cost of operation, supplies and maintenance of the equipment.
3. Recovery of the cost of material, equipment, billing and collection cost as well as for miscellaneous services.
4. A net return on the total capital investment must be ensured.

Requirements of tariff :

1. It should be easier to understand.
2. It should provide low rates for high consumption.
3. It should be uniform over large population.
4. It should encourage the consumers having high load factors.
5. It should take into account maximum demand charges and energy charges.
6. It should provide incentive for using power during off-peak hours.
7. It should provide less charges for power connection than lighting.
8. It should have a provision of penalty for low power factors.
9. It should have a provision for higher demand charges for high loads demanded at system peaks.
10. It should apportion equitably the cost of service to the different categories of consumers.

9.17.3. General Tariff Form

A large number of tariffs have been proposed from time to time and are in use. They are all derived from the following general equation :

$$z = a.x + b.y + c$$

where, z = Total amount of bill for the period considered,

x = Maximum demand in kW,

y = Energy consumed in kWh during the period considered,

a = Rate per kW of maximum demand, and

b = Energy rate per kWh.

c = Constant amount charged to the consumer during each billing period. This charge is independent of demand or total energy because a consumer that remains connected to the line incurs expenses even if he does not use energy.

Various types of tariffs :

The various types of tariffs are :

1. Flat demand rate.

2. Straight meter rate.
3. Block meter rate.
4. Hopkinson demand rate (Two-part tariff).
5. Doherty rate (Three-part tariff).
6. Wright demand rate.

1. Flat demand rate :

The flat demand rate is expressed as follows :

$$z = ax \quad ...(9.8)$$

i.e., the bill *depends only on the maximum demand irrespective of the amount of energy consumed*. It is based on the customer's installation of energy consuming devices which is generally denoted by so many kW per month or per year. It is probably one of the early systems of charging energy rates. It was based upon the total number of lamps installed and a fixed number of hours of use per year. Hence the rate could be expressed as a price per lamp or unit of installed capacity.

Now-a-days the use of *this tariff is restricted to signal system, street lighting etc.*, where the number of hours are fixed and energy consumption can be easily predicted. *Its use is very common to supplies to irrigation tubewells*, since the number of hours for which the tubewell feeders are switched on are fixed. The charge is made according to horse power of the motor installed.

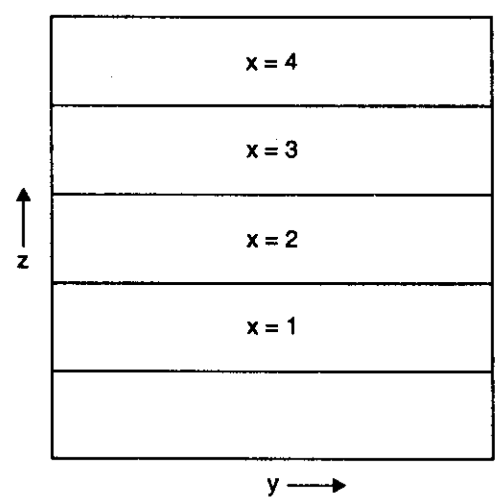


Fig. 9.8. Flat demand rate.

In this form of tariff the unit energy cost decreases progressively with an increased energy usage since the total cost remains constant. The variation in total cost and unit cost are given in Fig. 9.8.

By the use of this form of tariff the cost of metering equipment and meter reading is eliminated.

2. Straight meter rate :

The straight meter rate can be expressed in the form :

$$z = b \cdot y \quad ...(9.9)$$

This is the simplest form of tariff. Here the charge per unit is constant. The charges depend on the energy used. This tariff is *sometimes used for residential and commercial consumer*. The variation of bill according to the variation of energy consumed is shown in Fig. 9.9.

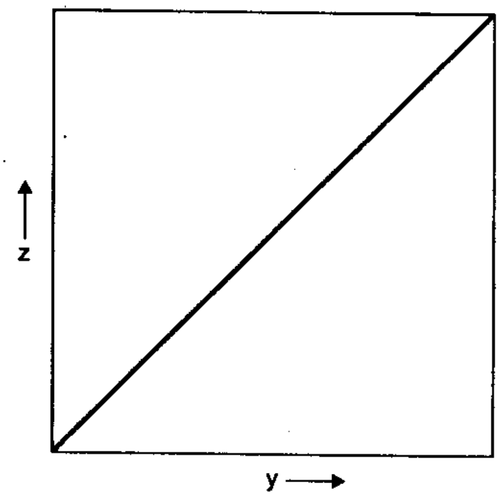


Fig. 9.9. Straight meter rate.

Advantage. *Simplicity.*

Disadvantages. 1. The consumer using no energy will not pay any amount although he has incurred some expenses to the power station.

2. This method does not encourage the use of electricity unless the tariff is very low.

3. Block meter rate :

In order to remove the inconsistency of straight meter rate, the block meter rate charges the consumers on a sliding scale. The term '*block*' indicates that a certain specified price per unit is charged for all or any part of such units. The reduced prices per unit are charged for all or any part of succeeding block of units, each such reduced price per unit applying only to a particular block or portion thereof.

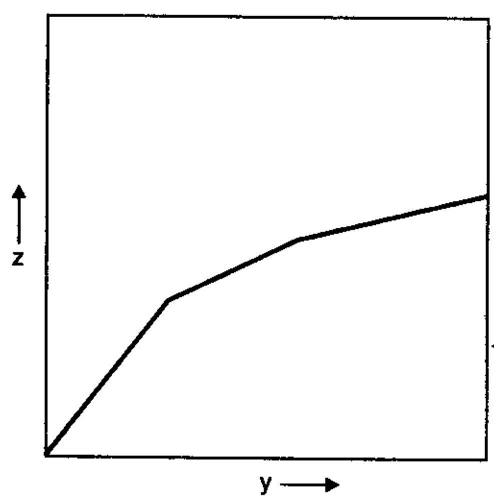


Fig. 6.10. Block meter rate.

The variation of bill according to this method is shown in Fig. 9.10.

The block meter rate accomplishes the same purpose of decreasing unit energy charges with increasing consumption as the step meter rate without its defect. Its *main defect is that it lacks a measure of the customer's demand.*

This tariff is very commonly used for residential and commercial customers. In many states of India, a *reverse form* of this tariff is being used *to restrict the energy consumption.* In this reverse form the unit energy charge increases with increase in energy consumption.

4. Hopkinson demand rate (Two-part tariff) :

This method *charges the consumer according to his maximum demand and energy consumption.* This can be expressed as

$$z = a + by \qquad ...(9.10)$$

This method requires *two meters to record the maximum demand and energy consumption of the consumer.* The variation of z with respect to y taking x as parameter is shown in Fig. 9.11.

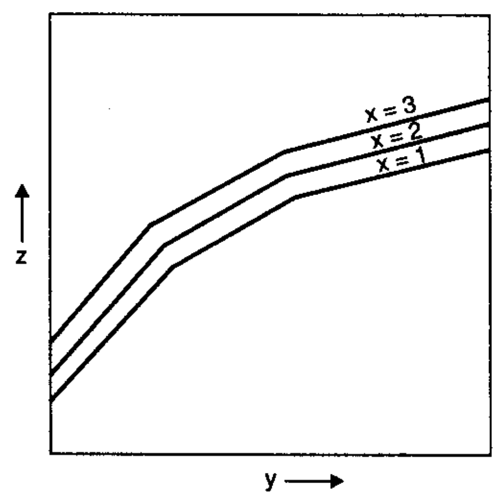


Fig. 9.11. Hopkinson demand rate (Two-part tariff).

This form of tariff is generally used for *industrial customers.*

5. Doherty rate (Three-part tariff) :

Refer Fig. 9.12. When the Hopkinson demand rate is modified by the addition of a customer charge, it becomes a three charge rate or Doherty rate. It was first introduced by Henry L. Doherty

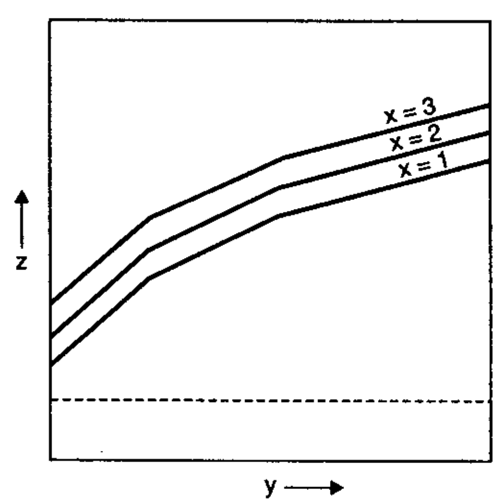


Fig. 9.12. Doherty rate (Three-part tariff).

at the beginning of twentieth century. It consists of a *customer* or *meter charge*, plus *a demand charge* plus *any energy charge*. This is expressed as follows :

$$y = ax + by + c$$

Many people consider that theoretically this is an ideal type of rate. As it requires *two meters, it is better suited for industrial than for residential customers.*

The Doherty rate is sometimes modified by specifying the minimum demand and the minimum energy consumption that must be paid for, if they are less than the minimum values specified. In this manner the customer charge is incorporated with the demand and energy component.

6. Wright demand rate :

This tariff was introduced by Arthur Wright (of England) in 1896. This rate intensifies the inducement by lowering both the demand and energy charge for a reduction in maximum demand or in other words an improvement in load factor. *This rate is usually specified for industrial consumers who have some measure of control over their maximum demands.*

The rate is modified by stating a minimum charge which must be paid if the energy for the billing period falls below the amount by such charge. For allowing fair returns some adjustment in the rate forms are provided. Some of them are :

(*i*) Higher demand charges in summer.

(*ii*) Fuel price adjustment to provide a rate change when fuel prices deviate from the standard.

(*iii*) Wage adjustment.

(*iv*) Tax adjustment.

(*v*) Power factor adjustment.

(*vi*) Discount to be given to the customers for prompt payment of bills.

WORKED EXAMPLES

Example 9.1. *The maximum demand of a power station is 96000 kW and daily load curve is described as follows :*

Time hours	*0—6*	*6—8*	*8—12*	*12—14*	*14—18*	*18—22*	*22—24*
Load (MW)	*48*	*60*	*72*	*60*	*84*	*96*	*48*

(*i*) *Determine the load factor of power station.*

(*ii*) *What is the load factor of standby equipment rated at 30 MW that takes up all load in excess of 72 MW ? Also calculate its use factor.*

Solution. Load curve is shown in Fig. 9.13.

Energy generated = area under the load curve

$= 48 \times 6 + 60 \times 2 + 72 \times 4 + 60 \times 2 + 84 \times 4 + 96 \times 4 + 48 \times 2$

$= 1632$ MWh $= 1632 \times 10^3$ kWh.

(*i*) **Load factor :**

Average load $= \dfrac{1632 \times 10^3}{24} = 68000$ kW

Maximum demand $= 96000$ kW (given)

$\therefore$ Load factor $= \dfrac{\text{Average load}}{\text{Maximum demand}} = \dfrac{68000}{96000} = \mathbf{0.71}$. **(Ans.)**

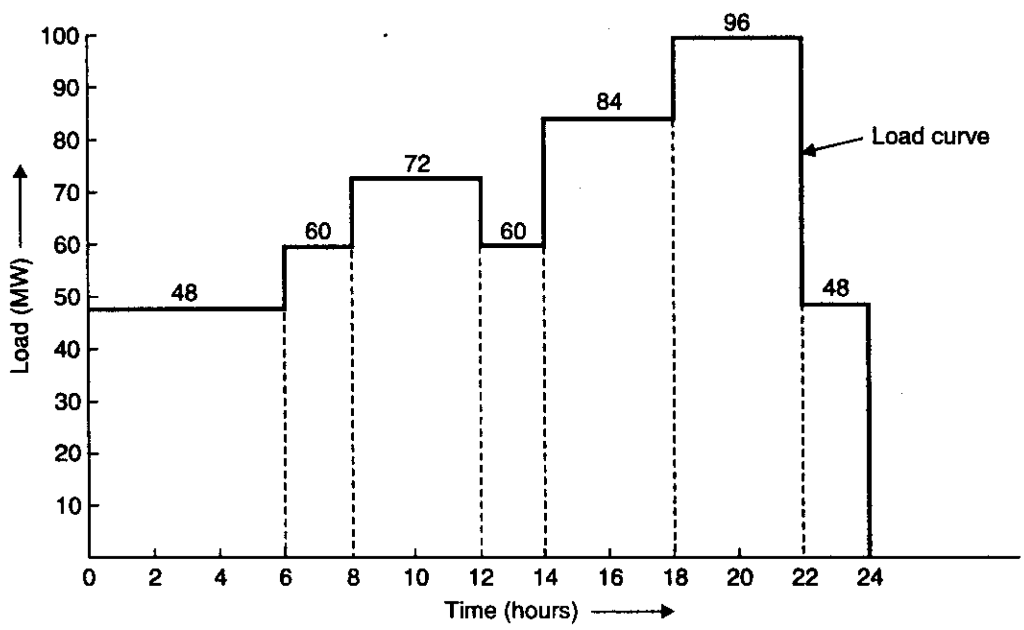


Fig. 9.13.

(*ii*) **Land factor of standby equipment :**

The standby equipment supplies

$84 - 72 = 12$ MW for 4 hours (14 – 18)

$96 - 72 = 24$ MW for 4 hours (18 – 22)

$\therefore$ Energy generated by standby equipment

$= (12 \times 4 + 24 \times 4) \times 10^3 = 144 \times 10^3$ kWh

Time for which standby equipment *remains in operation* (from the load curve)

$= 4 + 4 = 8$ hours

Average $= \dfrac{144 \times 10^3}{8} = 18 \times 10^3$ kW

Load factor $= \dfrac{18 \times 10^3}{24 \times 10^3} =$ **0.75. (Ans.)**

Use factor $= \dfrac{E}{C \times t'}$

where, E = Energy generated,

C = Capacity of the standby equipment, and

t' = Actual number of hours the plant has been in operation.

$\therefore$ **Use factor** $= \dfrac{144 \times 10^3}{30 \times 10^3 \times 8}$

$=$ **0.6. (Ans.)**

☞**Example 9.2.** *An electrical system experiences linear changes in load such that its daily load curve is defined as follows :*

Time	*12 PM*	*2 AM*	*6 AM*	*8 AM*	*12 AM*	*12.30 PM*	*1 PM*	*5 PM*	*6 PM*	*12 PM*
Load (MW)	*24*	*12*	*12*	*60*	*60*	*48*	*60*	*60*	*84*	*24*

(*i*) *Plot the chronological and load duration curve for the system.*

(*ii*) *Find the load factor.*

(*iii*) *What is the utilisation factor of the plant serving this load if its capacity is 120 MW.*

Solution. (*i*) **Chronological load and load duration curves :**

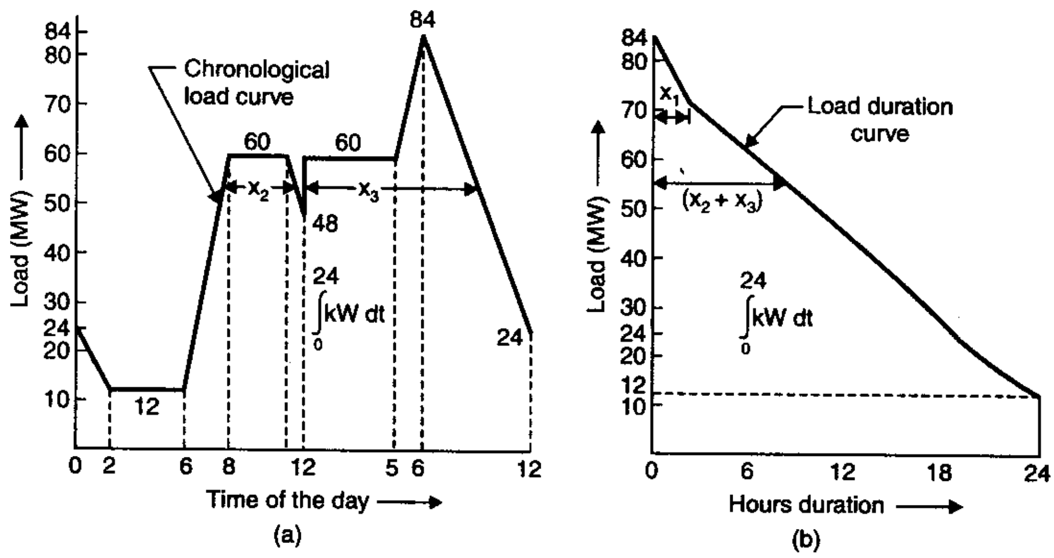


Fig. 9.14. (*a*) Chronological load curve, (*b*) Derived load duration curve.

Chronological load and load duration curves are drawn as shown in the Fig. 9.14 (*a*), (*b*). The procedure for constructing the load duration curve from chronological load curve is as follows :

— The abscissa of the load duration curve is laid off *equal to the number of hours in the chronological curve*, in this case 24 hours.

— The criterion of plotting the load duration curve *makes the abscissa at any load ordinate equal to the length of the abscissa intercepted by that load ordinate on the chronological curve*. Thus :

(*i*) At the maximum demand or peak load, the intercept is one point which will be plotted at 0 hour.

(*ii*) At 70 MW load the intercept is x_1 hours and is plotted as x_1 hour on the load duration curve.

(*iii*) At 55 MW load the intercept is a total of $(x_2 + x_3)$ and is plotted accordingly.

(*iv*) At minimum load of 12 MW the intercept covers the entire period of 24 hours.

Following points may be noted :

1. *Any point on the load duration curve is a measure of number of hours in a given period during which the given load and higher loads have prevailed.*

2. *If the chronological curve indicated a constant demand during the entire day, it would be of rectangular shape and load duration curve would be an exact duplicate.*

(*ii*) **Load factor :**

From the load duration curve, the average load can be estimated.

Average load for the period

$$= \frac{\text{Total energy in load curve for period}}{\text{Total number of hours in period}}$$

$$= \frac{\left(\frac{24+12}{2}\right)\times 2 + 12\times 4 + \left(\frac{12+60}{2}\right)\times 2 + 60\times 4 + \left(\frac{60+48}{2}\right)\times \frac{1}{2} + \left(\frac{48+60}{2}\right)\times \frac{1}{2} + 60\times 4 + \left(\frac{60+84}{2}\right)\times 1 + \left(\frac{84+24}{2}\right)\times 6}{24}$$

$$= \frac{36+48+72+240+27+27+240+72+324}{24}$$

$$= \frac{1086}{24} = 45.2 \text{ MW}$$

$\therefore$ **Load factor** $= \frac{45.2}{84} =$ **0.45 or 54%. (Ans.)**

(*iii*) **Utilisation factor :**

Utilisation factor $= \frac{\text{Maximum load}}{\text{Rated capacity of the plant}}$

$= \frac{84}{120} =$ **0.70 or 70%. (Ans.)**

☞**Example 9.3.** *A power station has to supply load as follows :*

Time (hours) :	*0—6*	*6—12*	*12—14*	*14—18*	*18—24*
Load (MW) :	*45*	*135*	*90*	*150*	*75*

(*i*) *Draw the load curve.*

(*ii*) *Draw load duration curve.*

(*iii*) *Choose suitable generating units to supply the load.*

(*iv*) *Calculate the load factor.*

(*v*) *Calculate the plant capacity factor.*

Solution. (*i*) **Load curve :**

The load curve is shown in Fig. 9.15 (*a*).

(*ii*) **Load duration curve :**

The load duration curve is shown in Fig. 9.15 (*b*).

(*iii*) **Selection of generating units :**

Load duration curve will indicate the operation schedule of different generating units.

1. One generating unit (unit 1) of 45 MW will run for **24 hours**
2. Second generating unit (unit 2) of 45 MW will run for **18 hours**
3. Third generating unit (unit 3) of 45 MW will run for **10 hours**
4. Fourth generating unit (unit 4) of 15 MW will run for **4 hours**

One additional unit (unit 5) should be kept as standby. Its capacity should be equal to the capacity of biggest set, *i.e.*, 45 MW.

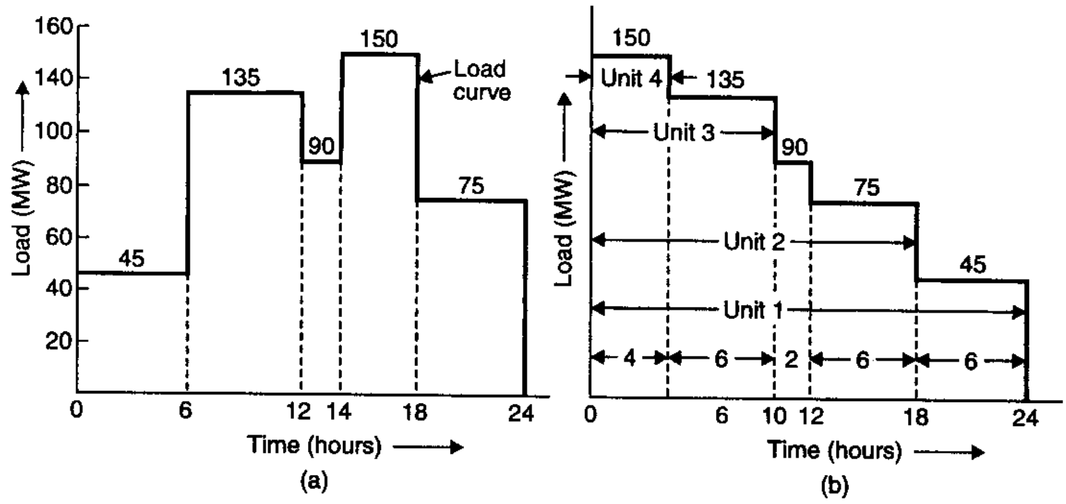


Fig. 9.15. (*a*) Load curve, (*b*) Load duration curve.

(*iv*) **Load factor :**

Energy generated $= 45 \times 6 + 135 \times 6 + 90 \times 2 + 150 \times 4 + 75 \times 6$

$= 270 + 810 + 180 + 600 + 450 = 2310$ MWh

Average load $= \dfrac{2310 \times 10^3}{24}$ kW $= 96250$ kW

Maximum demand $= 150 \times 10^3 = 150000$ kW

$\therefore$ **Load factor** $= \dfrac{\text{Average load}}{\text{Maximum demand}}$

$= \dfrac{96250}{150000} = $ **0.64. (Ans.)**

(*v*) **Plant capacity factor :**

Plant capacity factor $= \dfrac{E}{C \times t}$

where, E = Energy generated (kWh),

C = Capacity of the plant (kW),

$= 45 \times 4 + 1 \times 15 = 195$ MW $= 195 \times 10^3$ kW, and

t = Number of hours in the given period = 24 hours.

$\therefore$ *Plant capacity factor* $= \dfrac{2310 \times 10^3}{195 \times 10^3 \times 24} = $ **0.49. (Ans.)**

Example 9.4. *A generating station has a maximum demand of 5000 kW, and the daily load on the station is as follows :*

Load (MW)	*1000*	*1750*	*4000*	*1500*
Time	*11 PM to 8 AM*	*6 AM to 8 AM*	*8 AM to 12.00 Noon*	*12 PM to 1 PM*
Load (MW)	*3750*	*4250*	*5000*	*2250*
Time (hours)	*1 PM to 5 PM*	*5 PM to 7 PM*	*7 PM to 9 PM*	*9 PM to 11 PM*

(*i*) *Draw the load curve.*

(*ii*) *Draw the load duration curve.*

(*iii*) *Select the size and number of generator units.*

(*iv*) *What reserve plant would be necessary ?*

(*v*) *Load factor.*

(*vi*) *Plant capacity factor.*

Solution. (*i*) **Load curve** is shown in the Fig. 9.16 (*a*).

(*ii*) **Load duration curve** is shown in Fig. 9.16 (*b*).

(*iii*) **Size and number of generator units :**

From the load duration curve it is evident that generating sets of capacity 1000 kW, 1500 kW and 2500 kW will fulfill the requirement.

(*iv*) **Reserve capacity :**

Also, reserve capacity = largest size of the unit in the station = **2500 kW. (Ans.)**

(*v*) **Load factor :**

Area under the load curve gives the energy generated during 24 hours

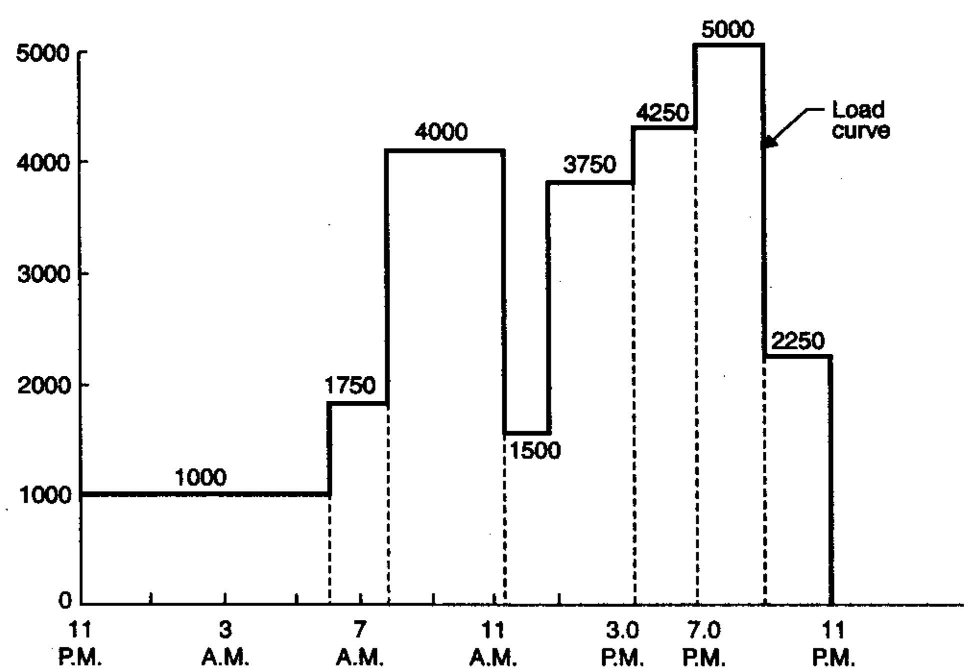
$= 1000 \times 7 + 1750 \times 2 + 4000 \times 4 + 1500 \times 1 + 3750 \times 4 + 4250 \times 2 + 5000 \times 2 + 2250 \times 2$

$= 7000 + 3500 + 16000 + 1500 + 15000 + 8500 + 10000 + 4500$

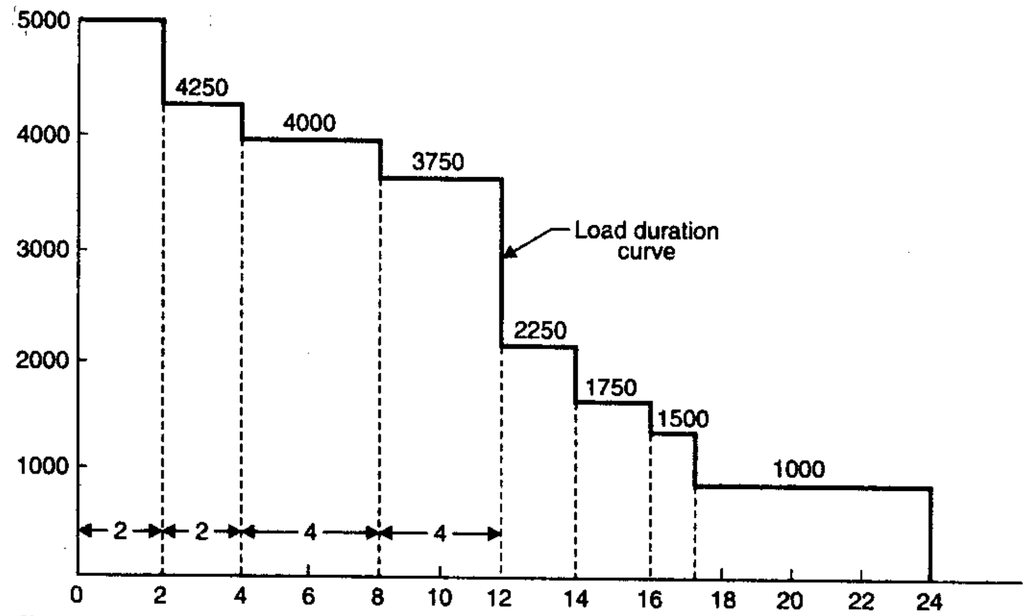
= 66000 kWh

or Average load $= \dfrac{66000}{24} = 2750$ kW

$\therefore$ *Load factor* $= \dfrac{\text{Average load}}{\text{Maximum demand}} = \dfrac{2750}{5000} = \mathbf{0.5}$. **(Ans.)**



(a)



(b)

Fig. 9.16. (*a*) Load curve, (*b*) Load duration curve.

(*vi*) **Plant capacity factor :**

$$\text{Plant capacity factor} = \frac{E}{C \times t} = \frac{66000}{(2500 + 1500 + 1000 + 2500) \times 24} = \mathbf{0.367.} \quad \textbf{(Ans.)}$$

Example 9.5. *A 60 MW power station has an annual peak load of 50 MW. The power station supplies loads having maximum demands of 20 MW, 17 MW, 10 MW and 9 MW. The annual load factor is 0.45. Find :*

(*i*) *Average load.* (*ii*) *Energy supplied per year.*
(*iii*) *Diversity factor.* (*iv*) *Demand factor.*

Solution. Capacity of power station = 60 MW

Maximum demand on power station = 50 MW

(*i*) **Average load :**

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

i.e.,
$$0.45 = \frac{\text{Average load}}{50}$$

$\therefore$ *Average load* $= 50 \times 0.45 = \mathbf{22.5\ MW.}$ **(Ans.)**

(*ii*) **Energy supplied per year :**

Energy supplied per year

$= \text{Average load} \times \text{number of hours in one year}$

$= (22.5 \times 10^3) \times 365 \times 24 = \mathbf{197.1 \times 10^6\ kWh.}$ **(Ans.)**

(*iii*) **Diversity factor :**

$$\text{Diversity factor} = \frac{\text{Sum of individuals maximum demands}}{\text{Simultaneous maximum demand}}$$

$$= \frac{20 + 17 + 10 + 9}{50} = \frac{56}{50} = 1.12$$

Hence diversity factor = **1.12. (Ans.)**

(*iv*) **Demand factor :**

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}} = \frac{50}{20 + 17 + 10 + 9} = \frac{50}{56} = 0.89$$

Hence demand factor = **0.89. (Ans.)**

Example 9.6. *The yearly duration curve of a certain plant can be considered as a straight line from 300 MW to 80 MW. Power is supplied with one generating unit of 200 MW capacity and two units of 100 MW capacity each. Determine :*

(*i*) *Installed capacity.* (*ii*) *Load factor.*
(*iii*) *Plant factor.* (*iv*) *Maximum demand.*
(*v*) *Utilization factor.*

Solution. The load duration curve is shown in the Fig. 9.17.

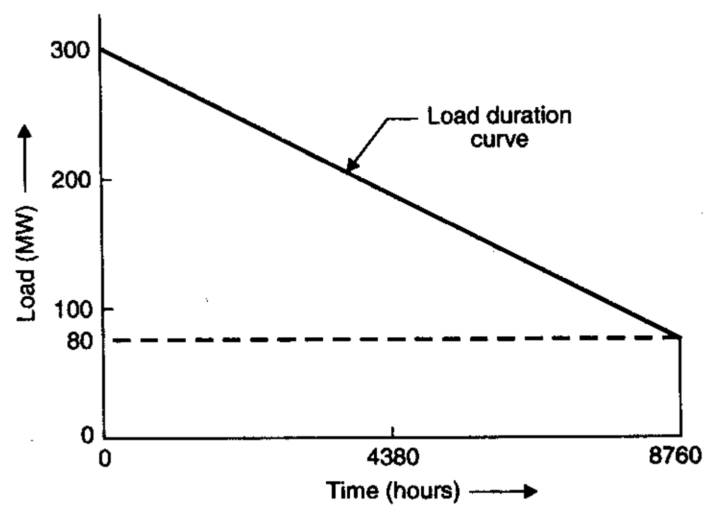


Fig. 9.17. Load duration curve.

(*i*) **Installed capacity :**

Installed capacity = 200 + 2 × 100 = **400 MW. (Ans.)**

(*ii*) **Load factor :**

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

$$\text{Average load} = \frac{\text{Total energy in load curve for the period}}{\text{Total number of hours in the period}}$$

$$= \frac{80 \times 8760 + \frac{1}{2} \times (300 - 80) \times 8760}{8760}$$

$$= \frac{8760}{8760}\left[80 + \frac{1}{2}(300 - 80)\right] = 190 \text{ MW}$$

$\therefore$ *Load factor* $= \frac{190}{300}$ = **0.633. (Ans.)**

(*iii*) **Plant factor :**

Plant factor $= \dfrac{\text{Average load}}{\text{Capacity of the plant}} = \dfrac{190}{400}$

$= \mathbf{0.475.}$ **(Ans.)**

(*iv*) **Maximum demand = 300 MW. (Ans.)**

(*v*) **Utilization factor :**

Utilization factor $= \dfrac{\text{Maximum load}}{\text{Rated capacity of the plant}}$

$= \dfrac{300}{400} = \mathbf{0.75.}$ **(Ans.)**

☞**Example 9.7.** *A generating station has a maximum demand of 30 MW, a load factor of 0.6, a plant capacity of 0.48, and a plant use factor of 0.82. Find :*

(*i*) *The daily energy produced.*

(*ii*) *The reserve capacity of the plant.*

(*iii*) *The maximum energy that could be produced if the plant were running all the time.*

(*iv*) *The maximum energy that could be produced daily, if the plant when running according to operating schedule were fully loaded.*

Solution. Maximum demand of the power station = 30 MW

Load factor = 0.6

Plant capacity = 0.48

Plant use factor = 0.82

(*i*) **The daily energy produced :**

Load factor $= \dfrac{\text{Average demand}}{\text{Maximum demand}}$

$0.6 = \dfrac{\text{Average demand}}{30}$

∴ Average demand $= 30 \times 0.6 = 18$ MW or 18000 kW

Daily energy product = Average demand × number of hours

$= 18000 \times 24 = \mathbf{4.32 \times 10^5}$ **kWh. (Ans.)**

(*ii*) **Reserve capacity of the plant :**

Plant capacity factor $= \dfrac{\text{Average demand}}{\text{Installed capacity}}$

$0.48 = \dfrac{18000}{\text{installed capacity}}$

∴ Installed capacity $= \dfrac{18000}{0.48} = 37500$ kW

∴ *Reserve capacity of the plant*

= Installed capacity – maximum demand

$= 37500 - 30000 = \mathbf{7500}$ **kW. (Ans.)**

(*iii*) **Maximum daily energy produced when running all the time**

$= \mathbf{4.32 \times 10^5}$ **kWh. (Ans.)**

(*iv*) **Maximum energy that could be produced daily :**

Maximum energy that could be produced, operating as per operating schedule

$$= \frac{\text{Actual energy produced}}{\text{Plant use factor}}$$

$$= \frac{4.32 \times 10^5}{0.82} = \mathbf{5.268 \times 10^5\ kWh.} \quad \textbf{(Ans.)}$$

Example 9.8. *A power station has the following loads :*

1. Residential lighting load :

Maximum demand	*= 1200 kW*
Load factor	*= 0.21*
Diversity between consumers	*= 1.32*

2. Commercial load :

Maximum demand	*= 2400 kW*
Load factor	*= 0.32*
Diversity between consumers	*= 1.2*

3. Industrial load :

Maximum demand	*= 6000 kW*
Load factor	*= 0.82*
Diversity between consumers	*= 1.22*

Overall diversity factor may be taken as 1.42.

Determine the following :

(i) Maximum demand on system.

(ii) Daily energy consumption (total).

(iii) Overall load factor.

(iv) Connected load (total) assuming that demand factor for each load is unity.

Solution. (*i*) **Maximum demand on system :**

$$\text{Group diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Actual maximum demand of the group}}$$

$$\therefore \quad 1.42 = \frac{1200 + 2400 + 6000}{\text{Maximum demand on system}}$$

i.e., Maximum demand on system $= \dfrac{1200 + 2400 + 6000}{1.42}$

$= \mathbf{6760.5\ kW.}$ **(Ans.)**

(*ii*) **Daily energy consumption :**

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

or Average demand = Maximum demand × load factor

$= 1200 \times 0.21 + 2400 \times 0.32 + 6000 \times 0.82$

$= 5940$ kW

$\therefore$ *Daily energy consumption* $= 5940 \times 24 = \mathbf{142560\ kWh.}$ **(Ans.)**

(*iii*) **Overall load factor :**

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

$$= \frac{5940}{6760.5} = \mathbf{0.878.} \quad \textbf{(Ans.)}$$

(*iv*) **Connected load :**

Maximum demand $= 1200 \times 1.32 + 2400 \times 1.2 + 6000 \times 1.22 = 11784$ kW

Connected load $= \dfrac{\text{Maximum demand}}{\text{Demand factor}} = \dfrac{11784}{1}$

$=$ **11784 kW. (Ans.)**

Example 9.9. *The following data relates to a steam power plant :*

Maximum demand	= *30000 kW*
Load factor	= *0.42*
Coal consumption	= *1.1 kg/kWh*
Boiler efficiency	= *84%*
Turbine efficiency	= *88%*
Price of coal	= *Rs. 70 per tonne.*

Determine the following :

(*i*) *Thermal efficiency of the plant.*

(*ii*) *Coal bill of the plant for one year.*

Solution. (*i*) **Thermal efficiency of the plant :**

Thermal efficiency of the plant

= Boiler efficiency × turbine efficiency

$= 0.84 \times 0.88 =$ **0.7392 or 73.92%. (Ans.)**

(*ii*) **Coal bill :**

Average demand on station = Maximum demand × load factor

$= 30000 \times 0.42 = 12600$ kW

∴ Energy generated per year $= 12600 \times (365 \times 24)$ kWh

∴ Coal consumption $= 12600 \times (365 \times 24) \times 1.1$ kg per year

∴ *Coal bill* $= \dfrac{12600 \times (365 \times 24) \times 1.1 \times 70}{1000}$

$=$ **Rs. 8498952. (Ans.)**

☞**Example 9.10.** *A power station is to supply for regions of load whose peak loads are 10 MW, 5 MW, 8 MW and 7 MW. The diversity factor of the load at the station is 1.5 and the average annual load factor is 0.6. Calculate :*

(*i*) *Maximum demand on the station.*

(*ii*) *Annual energy supplied from the station.*

Suggest the installed capacity and the number of units taking all aspects into account.

Solution. (*i*) **Maximum demand :**

Maximum demand on power station $= \dfrac{\text{Sum of individual maximum demands}}{\text{Diversity factor}}$

$= \dfrac{10 + 5 + 8 + 7}{1.5}$

$=$ **20 MW or 20000 kW. (Ans.)**

(*ii*) **Annual energy supplied :**

Average load = Maximum demand × load factor

$= 20000 \times 0.6 = 12000$ kW

Annual energy supplied from the station

= Average load × (365 × 24)

= 12000 × (365 × 24) = **105.12 × 10^6 kWh. (Ans.)**

Installed capacity and number of units :

Considering 50% increase in maximum demand on the power station in next five years, the *installed capacity* should be **30000 kW or 30 MW. (Ans.)**

Select, four similar units each of 7.5 MW capacity because minimum number of spare parts will be required to be stored, at the same time *three units can supply present maximum demand and fourth unit can be taken out for routine maintenance or during breakdown without any disruption in supply.*

Example 9.11. *The peak load on a 50 MW power station is 39 MW. It supplies power through four transformers whose connected loads are 17, 12, 9 and 10 MW. The maximum demands on these transformers are 15, 10, 8 and 9 MW respectively. If the annual load factor is 50% and the plant is operating for 65% of the period in a yèar, find out the following :*

(i) Average load on the station *(ii) Energy supplied per year*

(iii) Demand factor *(iv) Diversity factor*

(v) Power station use factor.

Solution. Power station rated capacity = 50 MW or 50000 kW

Maximum demand on the power station = 39 MW or 39000 kW

Sum of connected load = 17 + 12 + 9 + 10 = 48 MW or 48000 kW

Sum of maximum demands on the transformers = 15 + 10 + 8 + 9 = 42 MW or 42000 kW

Annual load factor = 50% or 0.5

Plant operating period = 0.65 × (365 × 24) = 5964 hours.

(*i*) **Average load on the station :**

Average load on the station = Maximum demand × load factor

= 39000 × 0.5 = **19500 kW. (Ans.)**

(*ii*) **Energy supplied per year :**

Energy supplied per year = Average load × (365 × 24)

= 19500 × 8760

= **170.82 × 10^6 kWh. (Ans.)**

(*iii*) **Demand factor :**

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Sum of connected load}}$$

$$= \frac{39000}{48000} = \mathbf{0.8125.\ (Ans.)}$$

(*iv*) **Diversity factor :**

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

$$= \frac{42000}{39000} = \mathbf{1.077.\ (Ans.)}$$

(*v*) **Power station use factor :**

$$\text{Use factor} = \frac{\text{Energy generated per year}}{\text{Rated capacity} \times \text{number of operating hours}}$$

$$= \frac{170.82 \times 10^6}{50000 \times 5694} = \mathbf{0.6\ or\ 60\%.\ (Ans.)}$$

Example 9.12. *A base load power station and standby power station share a common load as follows :*

Base load station annual output	$= 180 \times 10^6$ *kWh*
Base load station capacity	= *42 MW*
Maximum demand on base load station	= *36 MW*
Standby station capacity	= *22 MW*
Standby station annual output	$= 17 \times 10^6$ *kWh*
Maximum demand (peak load) on stand by station	= *18 MW*

Determine the following for both power stations :

(i) Load factor. *(ii) Capacity (or plant) factor.*

Solution. Base load station :

Average load $= \dfrac{180 \times 10^6}{365 \times 24} = 20548$ kW

(*i*) **Load factor** $= \dfrac{\text{Average load}}{\text{Maximum demand}} = \dfrac{20548}{36 \times 10^3} = \mathbf{0.57.}$ **(Ans.)**

(*ii*) **Capacity factor** $= \dfrac{\text{Energy generated}}{\text{Capacity of plant} \times (24 \times 365)}$

$$= \frac{180 \times 10^6}{42 \times 1000 \times 24 \times 365} = \mathbf{0.489.} \quad \textbf{(Ans.)}$$

Standby power station :

Annual average load $= \dfrac{17 \times 10^6}{365 \times 24} = 1940.6$ kW

(*i*) **Load factor** $= \dfrac{\text{Average load}}{\text{Maximum demand}} = \dfrac{1940.6}{18 \times 1000} = \mathbf{0.1078.}$ **(Ans.)**

(*ii*) **Capacity factor** $= \dfrac{\text{Energy generated}}{\text{Capacity} \times (24 \times 365)}$

$$= \frac{17 \times 10^6}{22 \times 1000 \times 24 \times 365} = \mathbf{0.088.} \quad \textbf{(Ans.)}$$

☞**Example 9.13.** *A base load station having a capacity of 18 MW a standby station having a capacity of 20 MW share a common load. Find (i) annual load factor, (ii) use factor and (iii) capacity factor of the two power stations from the following data :*

Annual standby station output	$= 7.35 \times 10^6$ *kWh*
Annual base load station output	$= 101.35 \times 10^6$ *kWh*
Peak load on the standby station	= *12 MW*
Hours of use of standby station during the year	= *2190 hours.*

Solution. Standby station :

Capacity of standby station	= 20 MW or 20000 kW
Maximum demand on standby station	= 12 MW or 12000 kW
Annual standby station output	$= 7.35 \times 10^6$ kWh
Hours of use of standby station during the year	= 2190 hours

Annual average load of standby station $= \dfrac{\text{Output in kWh}}{365 \times 24} = \dfrac{7.35 \times 10^6}{365 \times 24} = 839$ kW (*i*) **Annual load factor :**

$$\textit{Annual load factor} = \frac{\text{Annual average load}}{\text{Maximum demand}} = \frac{839}{12000} = \mathbf{0.07 \quad or \quad 7\%. \quad (Ans.)}$$

(*ii*) **Use factor :**

$$\textit{Use factor} = \frac{\text{Total kWh generated}}{\text{Rated capacity of station} \times \text{number of operating hours}}$$

$$= \frac{7.35 \times 10^6}{20000 \times 2190} = \mathbf{0.1678 \quad or \quad 16.78\%. \quad (Ans.)}$$

(*iii*) **Capacity factor :**

$$\textit{Capacity factor} = \frac{\text{Average load}}{\text{Rated capacity}} = \frac{839}{20000}$$

$$= \mathbf{0.0419 \quad or \quad 4.19\%. \quad (Ans.)}$$

Base load station :

Capacity of base load station = 18 MW or 18000 kW

Assume maximum demand on base load station equal to its rated capacity *i.e.*, 18 MW.

Annual base load station output $= 101.35 \times 10^6$ kWh

$$\text{Annual average load of base load station} = \frac{\text{Output in kWh}}{365 \times 24}$$

$$= \frac{101.35 \times 10^6}{365 \times 24} = 11570 \text{ kW}$$

(*i*) **Annual load factor :**

$$\textit{Annual load factor} = \frac{\text{Annual average load}}{\text{Maximum demand}}$$

$$= \frac{11570}{18000} = \mathbf{0.643 \quad or \quad 64.3\%. \quad (Ans.)}$$

(*ii*) **Use factor :**

$$\textit{Use factor} = \frac{\text{Total kWh generated}}{\text{Rated capacity} \times \text{number of operating hours}}$$

$$= \frac{101.35 \times 10^6}{18000 \times (365 \times 24)} = \mathbf{0.643 \quad or \quad 64.3\%. \quad (Ans.)}$$

(*iii*) **Capacity factor :**

$$\textit{Capacity factor} = \frac{\text{Average load}}{\text{Rated capacity}} = \frac{11570}{18000}$$

$$= \mathbf{0.643 \quad or \quad 64.3\%. \quad (Ans.)}$$

COST ANALYSIS

Example 9.14. *Determine the annual cost of a feed water softner from the following data :*

Cost = *Rs. 96000*

Salvage value = *5%*

Life = *10 years*

Annual repair and maintenance cost = *Rs. 3000*

Annual cost of chemicals	*= Rs. 6000*
Labour cost per month	*= Rs. 360*
Interest on sinking fund	*= 5%.*

Solution. Capital cost, P = Rs. 96000.

Salvage value, $S = \frac{5}{100} \times 96000$ = Rs. 4800

Rate of interest on sinking fund, i = 5% or 0.05

Life, n = 10 years

∴ Annual sinking fund payment

$$= (P - S)\left[\frac{i}{(1+i)^n - 1}\right]$$

$$= (9600 - 4800)\left[\frac{0.05}{(1+0.05)^{10} - 1}\right] = \text{Rs. } 7250.8$$

Total cost per year :

Annual sinking fund	= Rs. 7250.8
Annual repair and maintenance cost	= Rs. 3000
Annual cost of chemicals	= Rs. 6000
Annual labour cost	= (360 × 12) = Rs. 4320
∴ *Total cost per year*	= 7250.8 + 3000 + 6000 + 4320
	= **Rs. 20570.8. (Ans.)**

Example 9.15. *The output of a generating station is 500 × 10⁶ kWh per year and average load factor is 0.7. If the annual fixed charges are Rs. 50 per kW of installed plant and annual running charges are 5 per kWh, what is the cost per kWh of energy at the bus bar.*

Solution. Output energy per annum = 500×10^6 kWh

Average load $= \frac{\text{Annual average load}}{365 \times 24} = \frac{500 \times 10^6}{365 \times 24} = 57077$ kW

Maximum demand $= \frac{\text{Average load}}{\text{Load factor}} = \frac{57077}{0.7}$

= 81538 kW

Assuming installed capacity equal to maximum demand,

Fixed charges = 50 × 81538 = Rs. 4076900

Running charges = Rs. $\frac{5}{100} \times 500 \times 10^6$ = Rs. 25000000

Total annual charges = Rs. 25000000 + Rs. 4076900

= Rs. 29076900

Cost of energy at bus-bar $= \frac{\text{Total annual charges}}{\text{Output energy per annum}}$

$= \frac{29076900}{500 \times 10^6}$

= **Rs. 0.058 or 5.8 p/kWh. (Ans.)**

Example 9.16. *From the following data calculate the cost of generation per unit delivered from the power plant :*

Installed capacity of the power plant	*= 200 MW*
Annual load factor	*= 0.4*
Capital cost of power plant	*= Rs. 280 lacs*
Annual cost of fuel, oil, salaries, taxation	*= Rs. 60 lacs.*
Interest and depreciation	*= 13%.*

Solution. Installed capacity of the power plant = 200 MW or 200×10^3 kW

Assuming maximum demand equal to installed capacity,

Maximum demand $= 200 \times 10^3$ kW

Annual load factor = 0.4

Total units generated per annum = Maximum demand × load factor × (365 × 24)

$= 200 \times 10^3 \times 0.4 \times (365 \times 24) = 700.8 \times 10^6$ kWh

Capital cost of the power plant = Rs. 280×10^5

Annual interest and depreciation = Rs. $280 \times 10^6 \times \frac{13}{100}$ = Rs. 3.64×10^6

Annual cost of fuel, oil, salaries, taxation etc. = Rs. 60×10^5 or 6×10^6

Total annual cost = Rs. 3.64×10^6 + Rs. 6×10^6 = Rs. 9.64×10^6

$$\textit{Generating cost} = \frac{\text{Total annual cost}}{\text{Total units generated per annum}} = \frac{9.64 \times 10^6}{700.8 \times 10^6}$$

= **Rs. 0.0137 or 1.37 p/kWh. (Ans.)**

☞**Example 9.17.** *The following data relate to a 10 MW power station :*

Cost of plant	*= Rs. 1200 per kW*
Interest, insurances and taxes	*= 5% per annum*
Depreciation	*= 5%*
Cost of primary distribution	*= Rs. 500000*
Interest, insurances, taxes and depreciation	*= 5%*
Cost of coal including transportation	*= Rs. 4.4 per kN*
Operating cost	*= Rs. 500000*
Plant maintenance cost :	
(i) Fixed	*= Rs. 20000 per annum*
(ii) Variable	*= Rs. 30000 per annum*
Installed plant capacity	*= 10000 kW*
Maximum demand	*= 9000 kW*
Annual load factor	*= 0.6*
Consumption of coal	*= 255000 kN*

Determine the following :

(i) Cost of power generation per kW per year.

(ii) Cost per kWh generated.

(iii) Total cost of generation per kWh.

Transmission or primary distribution chargeable to generation.

Solution. Installed capacity of plant = 10 MW or 10000 kW

Total cost of plant = Rs. 10000 × 1200 = Rs. 12 × 10^6

Annual interest, insurances and taxes = Rs. 0.05 × 12 × 10^6 = Rs. 0.06 × 10^6
= Rs. 600000

Annual depreciation = Rs. 0.05 × 12 × 10^6 = Rs. 0.6 × 10^6
= Rs. 600000

Annual interest, insurance, taxes and depreciation on primary distribution
= Rs. 0.05 × 500000 = Rs. 25000

Annual plant maintenance cost (fixed) = Rs. 20000

Total fixed cost = Rs. (600000 + 600000 + 25000 + 20000)
= Rs. 1245000

Annual operating cost = Rs. 500000

Annual plant maintenance cost (variable) = Rs. 30000

Annual cost of coal = Rs. 4.4 × 255000 = Rs. 1122000

Total annual running cost = Rs. (500000 + 300000 + 1122000)
= Rs. 1652000

Maximum demand = 9000 kW

Annual load factor = 0.6

Average load = 9000 × 0.6 = 5400 kW

Annual energy generated = 5400 × 365 × 24 = 47.3 × 10^6 kWh

(*i*) **Cost of power generation per kW per year :**

Annual cost per kW of maximum demand $= \dfrac{\text{Fixed cost per annum}}{\text{Maximum demand}}$

$= \dfrac{1245000}{9000}$ = **Rs. 138.33. (Ans.)**

(*ii*) **Cost per kWh generated :**

Annual cost/kWh $= \dfrac{\text{Annual running cost}}{\text{Annual energy generated}}$

$= \dfrac{1652000}{47.3 \times 10^6}$ = **Rs. 0.035 or 3.5 p. (Ans.)**

(*iii*) **Total cost per kWh :**

Total cost per kWh $= \dfrac{\text{Total annual cost}}{\text{Annual energy generated}}$

$= \dfrac{1245000 + 1652000}{47.3 \times 10^6}$

= **Rs. 0.06 or 6 p. (Ans.)**

Example 9.18. *Annual 200 MW steam power station is estimated to cost Rs. 350 millions. Other costs are as follows :*

Insurance and taxes = *Rs. 5 lacs per annum*

Fuel and lubricants = *Rs. 70 lacs per annum*

Transport and storage = *Rs. 10 lacs per annum*

Salaries and wages = *Rs. 12 lacs per annum*

Miscellaneous = *Rs. 2 lacs per annum*

Reckoning interest and depreciation at 15% per annum of capital cost, determine :

The cost of energy generated per unit if the power station works at an average load factor of 0.6. What would it be, if the load factor be increased to 75% with a consequent increase in fuel costs by 10%, other costs remaining the same ?

Solution. Capacity of steam power station = 200 MW or 200000 kW

Cost of power station = Rs. 350 millions = Rs. 350×10^6

Annual cost of insurance and taxes = Rs. 5 lacs = Rs. 0.5×10^6

Annual cost of fuel and lubricants = Rs 70 lacs = Rs. 7×10^6

Annual cost of transport and storage = Rs. 10 lacs = Rs. 1×10^6

Annual cost of salaries and wages = Rs. 12 lacs = Rs 1.2×10^6

Annual miscellaneous cost = Rs. 2 lacs = Rs. 0.2×10^6

Annual interest and depreciation = Rs. $350 \times 10^6 \times \frac{15}{100}$ = Rs. 52.5×10^6

Total annual cost = Rs. $(0.5 + 7 + 1 + 1.2 + 0.2 + 52.5) \times 10^6$ = Rs. 62.4×10^6

Total energy generated per annum

= Maximum demand × average load factor × (365 × 24)

= $200000 \times 0.6 \times (365 \times 24) = 1051.2 \times 10^6$ kWh

Cost of generation $= \dfrac{\text{Total annual cost}}{\text{Total units generated}}$

$= \dfrac{62.4 \times 10^6}{1051.2 \times 10^6}$ = **Rs. 0.0594 per kWh or 5.94 p. per kWh.** **(Ans.)**

If the load factor is improved to 75% :

Total energy generated per annum

= $200000 \times 0.75 \times (365 \times 24) = 1314 \times 10^6$ kWh

Annual operating cost = Rs. $(0.5 + 7 \times 1.1 \times 10^6 + 1 + 1.2 + 0.2 + 52.5) \times 10^6$

= Rs. 63.1×10^6

Cost of generation $= \dfrac{\text{Total annual cost}}{\text{Total units generated}}$

$= \dfrac{63.1 \times 10^6}{1314 \times 10^6}$ = **Rs. 0.048 per kWh or 4.8 p. per kWh.** **(Ans.)**

Example 9.19. *A steam station has two 110 MW units. Following cost data are given :*

Particulars	***Units A***	***Units B***
Capital cost	*Rs. 2400 per kW*	*Rs. 3000 per kW*
Fixed charge rate	*10%*	*10%*
Capital factor	*0.55*	*0.60*
Fuel consumption	*1 kg/kWh*	*0.9 kg/kWh*
Fuel cost	*Rs. 96 per 1000 kg*	*Rs. 96 per 1000 kg*
Annual cost of operation, labour, maintenance and supplies	*20% of annual fuel cost*	*15% of annual fuel cost*
Utilisation factor	*1*	*1*

Calculate the following :

(i) Annual plant cost and generation cost of unit A.

(ii) Annual plant cost and generation cost of unit B.

(iii) Overall generation cost of the station.

Solution. (*i*) **Annual plant cost and generation cost of unit A :**

Annual fixed cost of unit A

$$= \frac{10}{100} \times 2400 \times (100 \times 1000)$$

$$= \text{Rs. } 26.4 \times 10^6$$

Annual energy output = Maximum demand × capacity factor × no. of hours

$$= (100 \times 1000) \times 0.55 \times (356 \times 24)$$

$$= 52.998 \times 10^7 \text{ kWh}$$

Annual fuel consumption $= 1 \times 52.998 \times 10^7$

$$= 52.998 \times 10^7 \text{ kg}$$

Fuel cost $= \frac{96}{1000} \times 52.998 \times 10^7 = \text{Rs. } 50.87 \times 10^7$

Annual cost of operating labour, maintenance and supplies

= 20% of annual cost

$$= \frac{20}{100} \times 50.87 \times 10^6 = \text{Rs. } 10.174 \times 10^6$$

The annual operating cost of unit A

= Annual fuel cost + annual cost of operation, labour and maintenance

$$= \text{Rs. } (50.87 \times 10^6 + 10.174 \times 10^6) = \text{Rs. } 61.044 \times 10^6$$

Annual plant cost of unit A

= Annual fixed cost + annual operating cost

$= \text{Rs. } (26.4 \times 10^6 + 61.044 \times 10^6) =$ **Rs.** $\mathbf{87.444 \times 10^6}$. **(Ans.)**

Generation cost of unit A

$$= \frac{\text{Annual plant cost}}{\text{Annual energy output}}$$

$= \frac{87.444 \times 10^6}{52.998 \times 10^7} =$ **Rs. 0.165 or 165.5 p/kWh. (Ans.)**

(*ii*) **Annual plant cost and generation cost of unit B :**

Annual fixed cost of unit B

$$= \text{Rs. } \frac{10}{100} \times 3000 \times 110 \times 1000 = \text{Rs. } 33 \times 10^6$$

Expected annual energy output

$$= (110 \times 1000) \times (365 \times 24) \times 0.6 = 57.816 \times 10^7 \text{ kWh}$$

Annual fuel consumption

$$= 0.9 \times 57.816 \times 10^7 = 52.0344 \times 10^7 \text{ kg}$$

Fuel cost $= \frac{96}{100} \times 52.0344 \times 10^7 = \text{Rs. } 49.95 \times 10^6$

Annual cost of maintenance, repair etc.

$$= \text{Rs. } \frac{15}{100} \times 49.95 \times 10^6 = \text{Rs. } 7.4925 \times 10^6$$

Annual operating cost

= Fuel cost + maintenance cost

= Rs. $(49.95 \times 10^6 + 7.4925 \times 10^6)$ = Rs. 57.4425×10^6

Annual plant cost of unit B

= Fixed cost + operating cost

= Rs. $33 \times 10^6 + 57.4425 \times 10^6$

= **Rs. 90.4425×10^6 (Ans.)**

Generation cost of unit B

$$= \frac{\text{Annual plant cost}}{\text{Annual energy output}}$$

$$= \frac{90.4425 \times 10^6}{57.816 \times 10^7}$$

= **Rs. 0.1564 or 15.64 p/kWh. (Ans.)**

(*iii*) **Overall generation cost of the station**

$$= \frac{\text{Sum of annual plant cost of both units}}{\text{Sum of energy supplied}}$$

$$= \frac{87.444 \times 10^6 + 90.4425 \times 10^6}{52.998 \times 10^7 + 57.816 \times 10^7}$$

= **Rs. 0.16 or 16 p/kWh. (Ans.)**

☞**Example 9.20.** *The annual costs of operating a 15000 kW thermal power station are as follows :*

Cost of plant	*= Rs. 1080 per kW*
Interest, insurance, taxes on plant	*= 5 per cent*
Depreciation	*= 5 per cent*
Cost of primary distribution system	*= Rs. 600000*
Interest, insurance, taxes and depreciation on primary distribution system	*= 5 per cent*
Cost of secondary distribution system	*= Rs. 1080000*
Interest, taxes, insurance and depreciation on secondary distribution system	*= 5 per cent*
Maintenance of secondary distribution system	*= Rs. 216000*
Plant maintenance cost	
(i) Fixed cost	*= Rs. 36000*
(ii) Variable cost	*= Rs. 48000*
Operating costs	*= Rs. 720000*
Cost of coal	*= Rs. 7.2 per kN*
Consumption of coal	*= 300000 kN*
Dividend to stock holders	*= Rs. 1200000*
Energy loss in transmission	*= 10 per cent*
Maximum demand	*= 14000 kW*
Diversity factor	*= 1.5*
Load factor	*= 0.7*

Determine : (i) Charge per kW per year

(ii) Rate per kWh.

Solution. Maximum demand = 14000 kW

Load factor $= 0.7 = \dfrac{\text{Average load}}{\text{Maximum demand}}$

∴ Average load = 0.7 × 14000 = 9800 kW

∴ Energy generated per year = 9800 × (365 × 24)

$= 85.8 \times 10^6$ kWh

Cost of plant = Capacity of plant × cost per kW

$= 15000 \times 1080 = \text{Rs. } 16.2 \times 10^6$

Interest, insurances, taxes on plant

$$= \frac{5}{100} \times 16.2 \times 10^6 = \text{Rs. } 810000$$

Plant depreciation $= \dfrac{5}{100} \times 16.2 \times 10^6 = \text{Rs. } 810000$

Cost of primary distribution system = Rs. 600000

Interest, insurance, taxes, depreciation on primary distribution system

$$= \frac{5}{100} \times 600000 = \text{Rs. } 30000$$

Cost of secondary distribution system = Rs. 1080000

$$= \frac{5}{100} \times 1080000 = \text{Rs. } 54000$$

Cost of coal = 7.2 × 300000 = Rs. 2160000.

(*i*) **Charge per kW per year :**

Fixed costs

Interest, taxes and insurance on plant	= Rs. 810000
Plant depreciation	= Rs. 810000
Interest, taxes, insurance and depreciation on :	
Primary distribution system	= Rs. 30000
Secondary distribution system	= Rs. 54000
Fixed part of plant maintenance	= Rs. 36000
Dividend of stock-holder	= Rs. 1200000
∴ Total fixed cost	= Rs. 2940000

Sum of maximum demand of consumers

= Maximum demand × diversity factor

= 14000 × 1.5 = 21000 kW

Charge per kW per year $= \dfrac{2940000}{21000}$

= **Rs. 140 per kW. (Ans.)**

(*ii*) **Rate per kWh :**

Variable costs

Cost of coal = Rs. 2160000

Plant maintenance = Rs. 48000

Operating costs = Rs. 720000
Maintenance of secondary distribution system = Rs. 216000
Total variable cost = Rs. 3144000
Energy loss in transmission = 10 percent

∴ Net energy transmitted

$= 0.9 \times 85.8 \times 10^6 = 77.22 \times 10^6$ kWh

∴ **Rate per kWh** $= \dfrac{3144000}{77.22 \times 10^6}$ = **Rs. 0.0407 or 4.07 p/kWh. (Ans.)**

Example 9.21. *It is proposed to supply a load with a maximum demand of 100 MW and a load factor of 0.4. Choice is to be made from nuclear, hydro and steam power plants. Calculate the overall cost per kWh in each scheme.*

Cost	*Nuclear power plant*	*Hydro-power plant*	*Steam power plant*
Capital per kW installed	*Rs. 6000*	*Rs. 4320*	*Rs. 2160*
Interest	*10%*	*10%*	*12%*
Depriciation	*10%*	*8%*	*12%*
Operating cost per kWh	*12 paise*	*6 paise*	*18 paise*
Transmission and distribution cost/kWh	*0.24 paise*	*0.96 paise*	*0.24 paise*

Solution. (*i*) **Nuclear power plant :**

Capital cost $= 6000 \times (100 \times 10^3) = \text{Rs. } 60 \times 10^7$

Interest $= \dfrac{10}{100} \times 60 \times 10^7 = \text{Rs. } 6 \times 10^7$

Depreciation $= \text{Rs. } 6 \times 10^7$

Annual fixed cost (interest + depreciation) $= \text{Rs. } 12 \times 10^7$

Energy generated per year

$= \text{Average load} \times (365 \times 24)$

$= \text{Load factor} \times \text{maximum demand} \times (365 \times 24)$

$= 0.4 \times (100 \times 10^3) \times (365 \times 24)$

$= 350.4 \times 10^6$ kWh

Running cost per kWh = Operating cost per kWh
+ transmission and distribution cost per kWh

$= 12 + 0.24 = 12.24$ p

∴ **Overall cost per kWh** = Running cost/kWh + fixed cost/kWh

$= 12.24 + \dfrac{12 \times 10^7}{350.4 \times 10^6} \times 100 =$ **46.48 p. (Ans.)**

(*ii*) **Hydro-electric power plant :**

Capital cost $= 4320 \times 100 \times 10^3 = \text{Rs. } 43.2 \times 10^7$

Interest $= \dfrac{10}{100} \times 43.2 \times 10^7 = \text{Rs. } 43.2 \times 10^6$

Depreciation $= \dfrac{8}{100} \times 43.2 \times 10^7 = 34.56 \times 10^6$

Annual fixed cost = Interest + depreciation

= Rs. $(43.2 + 34.56) \times 10^6$ = Rs. 77.76×10^6

Running cost per kWh = (Operation cost + transmission cost)

= (6 + 0.96) p = 6.96 p

Overall cost per kWh = Running cost/kWh + annual fixed cost/kWh

$$= 6.96 + \frac{77.76 \times 10^6}{350.4 \times 10^6} \times 100$$

= 6.96 + 22.2 = **29.16 p.** **(Ans.)**

(*iii*) **Steam power plant :**

Capital cost = Rs. $2160 \times 100 \times 10^3$ = Rs. 21.6×10^7

Interest $= \text{Rs. } \frac{12}{100} \times 21.6 \times 10^7 = \text{Rs. } 25.92 \times 10^6$

Depreciation $= \text{Rs. } \frac{12}{100} \times 21.6 \times 10^7 = \text{Rs. } 25.92 \times 10^6$

Annual fixed cost = Interest + depreciation

= Rs. $2 \times 25.92 \times 10^6$ = Rs. 51.84×10^6

Running cost/kWh = 18 + 0.24 = 18.24 p

∴ **Overall cost/kWh** = Running cost/kWh + fixed cost/kWh

$$= 18.24 + \frac{51.84 \times 10^6}{350.4 \times 10^6} \times 100$$

= 18.24 + 14.79 = **33.03 p.** **(Ans.)**

From the above calculations it is concluded that overall cost/kWh is *minimum in case of hydropower plant.*

☞**Example 9.22.** *A power plant of 180 MW installed capacity has the following data :*

Capital cost	*= Rs. 2160 / kW installed*
Interest and depreciation	*= 12 per cent*
Annual load factor	*= 0.6*
Annual capacity factor	*= 0.5*
Annual running charges	*= Rs. 36* $\times 10^6$
Energy consumed by power auxiliaries	*= 6 per cent*

Calculate : (i) Reserve capacity

(ii) Generation capacity.

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

and Capacity factor $= \frac{\text{Average load}}{\text{Rated capacity}}$

$$\therefore \quad \frac{\text{Load factor}}{\text{Capacity factor}} = \frac{\text{Rated capacity}}{\text{Maximum demand}}$$

$$\frac{0.6}{0.5} = \frac{180}{\text{Maximum demand}}$$

$$\therefore \quad \text{Maximum demand} = \frac{0.5 \times 180}{0.6} = 150 \text{ MW.}$$

(*i*) **Reserved capacity :**

Reserved capacity = Installed/rated capacity – maximum demand

= 180 – 150 = **30 MW. (Ans.)**

(*ii*) **Generation cost :**

Average load = Load factor × maximum demand

= 0.6 × 150 = 90 MW

Energy generated per annum

$= 90 \times 10^3 \times (365 \times 24) = 788.4 \times 10^6$ kWh

Energy consumed by auxiliaries

$= \frac{6}{100} \times 788.4 \times 10^6 = 47.3 \times 10^6$ kWh

Net energy available $= 788.4 \times 10^6 - 47.3 \times 10^6 = 741.1 \times 10^6$ kWh

Fixed cost of generation = Interest + depreciation

$= \text{Rs. } \frac{12}{100} \times 2160 \times 180 \times 10^3 = \text{Rs. } 46.65 \times 10^6$

Total annual cost = Running cost + fixed cost

$= 36 \times 10^6 + 46.65 \times 10^6 = \text{Rs. } 82.65 \times 10^6$

∴ *Generation cost* $= \frac{82.65 \times 10^6}{741.1 \times 10^6} \times 100 =$ **11.1 p. (Ans.)**

Example 9.23. *A power station has the installed capacity of 180 MW. Calculate the cost of generation, other data pertaining to power station are given below :*

Capital cost	*= Rs. 300 × 10⁶*
Rate of interest and depreciation	*= 18 per cent*
Annual cost of fuel oil, salaries and taxation	*= Rs. 36 × 10⁶*
Load factor	*= 0.4*

Also calculate the saving in cost per kWh if the annual load factor is raised to 0.5.

Solution. Assuming maximum demand equal to the capacity of the power plant,

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

$$0.4 = \frac{\text{Average load}}{180}$$

∴ Average load = 0.4 × 180 = 72 MW

Energy generated per annum $= 72 \times 10^3 \times (365 \times 24) = 630.72 \times 10^6$ kWh

Fixed cost = Interest and depreciation on capital cost

$= \frac{18}{100} \times 300 \times 10^6 = \text{Rs. } 54 \times 10^6$

Running (operating cost) = Cost of fuel oil, salaries and taxation

$= \text{Rs. } 36 \times 10^6$

Total annual cost = Fixed cost + operating cost

$= \text{Rs. } (54 + 36) \times 10^6$

$= \text{Rs. } 90 \times 10^6$

∴ *Cost per kWh* $= \frac{90 \times 10^6}{630.72 \times 10^6} \times 100 =$ **14.27 p. per kWh. (Ans.)**

When the load factor is raised to 0.5 :

Average load = Load factor × maximum demand

= 0.5 × 180 = 90 MW

Energy produced per annum = $90 \times 10^3 \times 365 \times 24$

= 788.4×10^6 kWh

Total annual cost will not change.

∴ Cost per kWh $= \dfrac{90 \times 10^6}{788.4 \times 10^6} \times 100$

= 11.41 p. per kWh

∴ *Saving in cost per kWh* = 14.27 – 11.41

= **2.86 p. (Ans.)**

Example 9.24. *A 60 MW generating station has the following data :*

Capital cost	*= Rs. 18 × 10^6*
Annual taxation	*= Rs. 0.48 × 10^6*
Annual salaries and wages	*= Rs. 1.44 × 10^6*
Cost of coal	*= Rs. 72 per tonne*
Calorific value (C.V.) of coal	*= 23000 kJ/kg*
Rate of interest and depreciation	*= 12 per cent*
Plant heat rate	*= 138000 kJ/kWh at 100% capacity*

Calculate the generating cost/kWh at 100% capacity factor.

Solution. Maximum demand = 60 MW (= peak load)

Fixed cost = Interest and depreciation on capital cost

$= \text{Rs. } \dfrac{12}{100} \times 18 \times 10^6 = \text{Rs. } 2.16 \times 10^6$

Running cost = Annual salaries, wages and taxation

= Rs. $(1.44 + 0.48) 10^6$

= Rs. 1.92×10^6

At 100% capacity factor :

Rated/installed capacity = 60 MW

Capacity factor $= \dfrac{\text{Average load}}{\text{Rated capacity}} = 1$

or Average load = Rated capacity = 60 MW

Average energy produced per annum

= $60 \times 10^3 \times (365 \times 24)$ kWh

= 525.6×10^6 kWh

Total plant heat rate = $138000 \times 525.6 \times 10^6$ kJ

Weight of coal required per annum $= \dfrac{138000 \times 525.6 \times 10^6}{23000 \times 1000}$ tonnes

= 3.15×10^6 tonnes

Cost of fuel = Rs. $72 \times 3.15 \times 10^6$

= Rs. 226.8×10^6

Total annual cost = Rs. $(2.16 + 1.92 + 226.8) \times 10^6$

= Rs. 230.88×10^6

Generation cost $= \dfrac{230.88 \times 10^6}{525.6 \times 10^6} \times 100$

$= \mathbf{43.93\ p.}$ **(Ans.)**

ECONOMIC LOAD SHARING

Example 9.25. *An input-output curve of a 10 MW station is expressed as follows :*

$$I = 4 \times 10^6 (10 + 8L + 0.4L^2)$$

where I is in kJ/hour and L is in megawatts.

(i) Without plotting any curve find the load at which the maximum efficiency occurs.

(ii) Find the increase in input required to increase station output from 3 to 5 MW by means of the input-output curve and also by incremental rate curve.

Solution. (*i*) **Load at which maximum efficiency occurs :**

$$I = 4 \times 10^6 (10 + 8L + 0.4L^2)$$

or $$\frac{I}{L} = 4 \times 10^6 \left(\frac{10}{L} + 8 + 0.4L\right)$$

Efficiency $$= \frac{\text{Output}}{\text{Input}} = \frac{L}{I}$$

$\therefore$ Efficiency, $$\eta = \frac{1}{4 \times 10^6 \left(\frac{10}{L} + 8 + 0.4L\right)} \quad ...(i)$$

Now the *efficiency will be maximum* when $\left(\frac{10}{L} + 8 + 0.4L\right)$ is *minimum*

i.e., $$\frac{d}{dL}\left(\frac{10}{L} + 8 + 0.4L\right) = 0$$

$\therefore$ $$-\frac{10}{L^2} + 0.4 = 0 \quad \text{or} \quad L^2 = \frac{10}{0.4} = 25 \quad \text{or} \quad L = 5 \text{ MW}$$

Hence the load at which the maximum efficiency occurs = **5 MW. (Ans.)**

(*ii*) **Increase in input :**

(*a*) ***By input output curve :***

When load, L = 3 MW

Input, $I_3 = 4 \times 10^6 (10 + 8 \times 3 + 0.4 \times 3^2)$

$= 150.4 \times 10^6$ kJ/h

When load, L = 5 MW

Input, $I_5 = 4 \times 10^6 (10 + 8 \times 5 + 0.4 \times 5^2)$

$= 240 \times 10^6$ kJ/h

Increase in input required $= I_5 - I_3$

$= (240 - 150.4) \times 10^6$

$= \mathbf{89.6 \times 10^6\ kJ/h.}$ **(Ans.)**

(*b*) ***By incremental rate curve :***

When load varies from 3 to 5 MW, the incremental rate may be considered to be straight line and the average height of area under the curve between 3 MW and 5 MW would be

$$= \frac{3 + 5}{2} = 4 \text{ MW}$$

$$I = 4 \times 10^6 (10 + 8L + 0.4L^2)$$

Increment rate, $IR = \frac{dI}{dL} = 4 \times 10^6 (8 + 0.8L)$

$\therefore$ $IR = 4 \times 10^6 (8 + 0.8 \times 4)$ when load = 4 MW

$= 4 \times 10^6 (8 + 3.2) = 4 \times 10^6 \times 11.2$

Hence total increase in input $= 4 \times 10^6 \times 11.2 (5 - 3) =$ **89.6 × 10⁶ kJ/h. (Ans.)**

This shows that increase in input required to increase the required output in both cases (*a*) and (*b*) is same. This *indicates that the incremental rate curve can be taken as straight line for small increase in output.*

Example 9.26. *The input-output curve of a 50 MW power station is given by :*

$$I = 4 \times 10^6 (8 + 8L + 0.4L^2) \text{ kJ/hour}$$

where I is the input in kJ/hour and L is load in MW.

(i) Determine the heat input per day to the power station if it works for 20 hours at full load and remaining period at no load.

(ii) Also find the saving per kWh of energy produced if the plant works at full load for all 24 hours generating the same amount of energy.

Solution. (*i*) **Heat input per day :**

Total energy generated by the plant during 24 hours

$= 20 \times 50 + 4 \times 0 = 1000$ MWh

Input to the plant when the plant is running at full load

$I_{50} = 4 \times 10^6 (8 + 8 \times 50 + 0.4 \times 50^2) \times 20$

$= 4 \times 1408 \times 20$ kJ during 20 hours when the plant was running at *full load.*

Input at no load, $I_0 = 4 \times 10^6 \times 8 \times 4$

$= 128 \times 10^6$ kJ during 4 hours when the plant was running at *no load.*

Total input to the plant during 24 hours

$= I_{50} + I_0 = 4 \times 10^6 \times 1408 \times 20 + 128 \times 10^6$

$= 10^6 (5632 \times 20 + 128) =$ **112768 × 10⁶ kJ/day. (Ans.)**

(*ii*) **Saving per kWh :**

Average heat supplied per kWh generated

$$= \frac{112768 \times 10^6}{1000 \times 10^3} = 112768 \text{ kJ/kWh}$$

If the same energy is generated within 24 hours, the average load is given by :

Average load $= \frac{1000}{24} = 41.67$ MW

Heat supplied during 24 hours in this case

$I_{50} = 4 \times 10^6 (8 + 8 \times 50 + 0.4 \times 41.67^2) \times 24$

$= 4 \times 10^6 (8 + 400 + 694.5) \times 24$

$= 4 \times 10^6 \times 1102.5 \times 24$ kJ/day $= 105840 \times 10^6$ kJ/day

Net saving per day

$= 112768 \times 10^6 - 105840 \times 10^6 = 6928 \times 10^6$ kJ/day

$\therefore$ *Saving per kWh* $= \frac{6928 \times 10^6}{1000 \times 10^3} =$ **6928 kJ/kWh. (Ans.)**

Example 9.27. *The incremental fuel costs for two generating units 1 and 2 of a power plant are given by the following equations :*

$$\frac{dF_1}{dP_1} = 0.07\,P_1 + 24$$

$$\frac{dF_2}{dP_2} = 0.075\,P_2 + 22$$

where F is fuel cost in rupees per hour and P is power output in MW. Determine :

(i) The economic loading of the two units when the total load supplied by the power plants is 180 MW.

(ii) The loss in fuel cost per hour if the load is equally shared by both units.

Solution. (*i*) **Economic loading of two units :**

$$P_1 + P_2 = 180 \qquad \text{...(Given)} \qquad \text{...}(i)$$

The condition required for economic loading is given by :

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2}$$

$$\therefore \qquad 0.07\,P_1 + 24 = 0.075\,P_2 + 22 \qquad \text{...}(ii)$$

Substituting the value of P_2 (= $180 - P_1$) from (*i*) in (*ii*), we get

$$0.07\,P_1 + 24 = 0.075\,(180 - P_1) + 22$$

or $$0.07\,P_1 + 24 = 13.5 - 0.075\,P_1 + 22$$

or $$0.145\,P_1 = 11.5$$

or $$P_1 = \frac{11.5}{0.145} = \textbf{79.3 MW.} \quad \textbf{(Ans.)}$$

and $$P_2 = 180 - 79.3 = \textbf{100.7 MW.} \quad \textbf{(Ans.)}$$

(*ii*) **Loss in fuel cost :**

If the load is equally shared by both the units $\left(\text{supplying } \frac{180}{2} = 90 \text{ MW each}\right)$, then the increase in cost of fuel for *unit 1* is

$$= \int_{79.3}^{90} (0.07\,P_1 + 24)\,dP_1 = \left[\frac{0.07\,P_1^2}{2} + 24P_1\right]_{79.3}^{90}$$

$$= 0.035\,(90^2 - 79.3^2) + 24\,(90 - 79.3)$$

$$= 63.4 + 256.8 = \text{Rs. } 320.2/\text{hour}$$

Increase in cost of fuel for *unit 2*

$$= \int_{100.7}^{90} (0.075\,P_2 + 22)\,dP_2 = \left[\frac{0.075P_2^2}{2} + 22P_2\right]_{100.7}^{90}$$

$$= \frac{0.075}{2}\,(90^2 - 100.7^2) + 22\,(90 - 100.7)$$

$$= -\,76.5 - 235.4 = \text{Rs. } -\,311.9/\text{hour}$$

This indicates that the cost of fuel for unit 2 **decreases.**

Net increase in cost (or loss in fuel cost) due to departure from economic distribution of load

$$= 320.2 - 311.9 = \textbf{Rs. 8.3/hour.} \quad \textbf{(Ans.)}$$

Example 9.28. *Two steam turbines each of 30 MW capacity take a load 45 MW. The steam consumption rates in kg per hour for both turbines are given by the following equations :*

$$S_1 = 2400 + 12L_1 - 0.00012\,L_1^2$$
$$S_2 = 1200 + 8.4L_2 - 0.00006\,L_2^2$$

L represents the load in kW and S represents the steam consumption per hour. Find the most economical loading when the load taken by both units is 45 MW.

Solution. $L_1 + L_2 = 45 \text{ MW} = 45000 \text{ kW}$ ...(*i*)

For the most economical loading, the required condition is

$$\frac{dS_1}{dL_1} = \frac{dS_2}{dL_2}$$

$$\therefore \quad 12 - 2 \times 0.00012\,L_1 = 8.4 - 2 \times 0.00006\,L_2$$

$$12 - 0.00024\,L_1 = 8.4 - 0.00012\,L_2 \qquad ...(ii)$$

Substituting the value of L_2 (= $45000 - L_1$) from (*i*) in (*ii*), we get

$$12 - 0.00024\,L_1 = 8.4 - 0.00012\,(45000 - L_1)$$
$$12 - 0.00024\,L_1 = 8.4 - 5.4 + 0.00012\,L_1$$
$$0.00036\,L_1 = 9$$

$$\therefore \quad L_1 = \frac{9}{0.00036} = \mathbf{25000\ kW \quad or \quad 25\ MW.\ (Ans.)}$$

and $$L_2 = 45000 - 25000 = \mathbf{20000\ kW \quad or \quad 20\ MW.\ (Ans.)}$$

TARIFF

Example 9.29. *Two electrical units used for same purpose are compared for their economical working :*

(i) Cost of Unit-1 is Rs. 6000 and it takes 120 kW.

(ii) Cost of Unit-2 is Rs. 16800 and it takes 72 kW.

Each of them has a useful life of 40000 hours.

Which unit will prove economical if the energy is charged at Rs. 96 per kW of maximum demand per year and 6 p. per kWh ?

Assume both units run at full load.

Solution. (*i*) **Unit-1 :**

Capital cost per hour $= \frac{6000}{40000}$ = Re. 0.15

Maximum demand = 120 kW

Charge for maximum demand per hour

$$= \frac{120 \times 96}{(365 \times 24)} = \text{Rs. } 1.315$$

Energy charge per hour = Maximum demand × one hour × charge per kWh

$$= 120 \times 1 \times \frac{6}{100} = \text{Rs. } 7.2$$

∴ Total charges per hour for operation of Unit-1

$$= 0.15 + 1.135 + 7.2 = \text{Rs. } 8.485$$

(*ii*) **Unit-2 :**

Capital cost per hour $= \frac{16800}{40000}$ = Re. 0.42.

Charge for maximum demand per hour

$$= \frac{72 \times 96}{365 \times 24} = \text{Re. } 0.789$$

Energy charge per hour $= 72 \times 1 \times \frac{6}{100} = \text{Rs. } 4.32$

Total charges per hour for the operation of Unit-2

$$= 0.42 + 0.789 + 4.32 = \text{Rs. } 5.529$$

The charges of operation for the Unit-2 per hour are less than the charges of operation for the Unit-1, therefore *Unit-2 is more economical* in this case. **(Ans.)**

Example 9.30. *The monthly electricity consumption of a residence can be approximated as under :*

Light load	*: 6 tube lights 40 watts each working for 4 hours daily*
Fan load	*: 6 fans 100 watts each working for 6 hours daily*
Refrigerator load	*: 2 kWh daily*
Miscellaneous load	*: 2 kW for 2 hours daily*

Find the monthly bill at the following tariff :

First 20 units	*Rs. 0.50/kWh*
Next 30 units	*Rs. 0.40/kWh*
Remaining units	*Rs. 0.30/kWh*
Constant charge	*Rs. 2.50 per month*

Discount for prompt payment = 5 per cent.

Solution. Total energy consumption in 30 days

$$= (6 \times 40 \times 4 \times 30 + 6 \times 100 \times 6 \times 30) \times \frac{1}{1000} + 2 \times 30 + 2 \times 2 \times 30$$

$$= (28800 + 108000) \times \frac{1}{1000} + 60 + 120 = 316.8 \text{ kWh per month}$$

The monthly bill $= \text{Rs. } [(20 \times 0.5 + 30 \times 0.4 + 266.8 \times 0.3) + 2.5]$

$$= \text{Rs. } [(10 + 12 + 80.04) + 2.5] = \text{Rs. } 104.54$$

$$\left[\because \begin{array}{l} \text{Remaining units per month} \\ = 316.8 - 20 - 30 = 266.8 \end{array}\right]$$

Net monthly bill if the payment is made promptly

$$= 104.54 \times 0.9 = \textbf{Rs. 94.08.} \quad \textbf{(Ans.)}$$

Example 9.31. *An industrial undertaking has a connected load of 220 kW. The maximum demand is 180 kW. On an average each machine works for 60% time. Find the yearly expenditure on electricity if the tariff is :*

Rs. 1200 + Rs. 120 per kW of maximum demand per year + Re. 0.15 per kWh.

Solution. Energy consumption in one year

$$= 180 \times 0.6 \times (365 \times 24) = 946080 \text{ kWh}$$

Total electricity bill $= \text{Rs. } (1200 + 120 \times 180 + 0.15 \times 946080) =$ **Rs. 164712. (Ans.)**

☞**Example 9.32.** *A Hopkinson demand rate is quoted as follows :*

Demand rates :

First 1 kW of maximum demand	*= Rs. 6/kW/month*
Next 4 kW of maximum demand	*= Rs. 5/kW/month*
Excess 5 kW of maximum demand	*= Rs. 4/kW/month*

Energy rates :

First 50 kWh	= *7 paise / kWh*
Next 50 kWh	= *5 paise / kWh*
Next 200 kWh	= *4 paise / kWh*
Next 400 kWh	= *3 paise / kWh*
Excess over 700 kWh	= *2 paise / kWh.*

Determine : (i) The monthly bill for a total consumption of 2000 kWh and a maximum demand of 15 kW. Also find out the unit energy cost.

(ii) Lowest possible bill for a month and a corresponding unit energy cost.

Solution. (*i*) **Monthly bill and energy cost :**

Demand charges per month $= \text{Rs. } (1 \times 6 + 4 \times 5 + 10 \times 4) = \text{Rs. } 66$

Energy charge $= \text{Rs. } [50 \times 7 + 50 \times 5 + 200 \times 4 + 400 \times 3 + 1300 \times 2] \times \frac{1}{100}$

$= \text{Rs. } (350 + 250 + 800 + 1200 + 2600) \times \frac{1}{100} = \text{Rs. } 52$

∴ *Monthly bill* $= 66 + 52 =$ **Rs. 118. (Ans.)**

Average unit energy cost $= \frac{118}{2000} \times 100 =$ **5.9 paise/kWh. (Ans.)**

(*ii*) **Lowest possible bill :**

The lowest possible bill will occur when average load

= Maximum load or at 100% load factor

∴ Maximum load $= \text{Average load} = \frac{2000}{30 \times 24} = 2.77 \text{ kW}$

∴ Demand charges $= \text{Rs. } (6 + 1.77 \times 5) = \text{Rs. } 14.85$

Energy charges will be same = Rs. 52

∴ *Minimum monthly bill* $= 14.85 + 52 =$ **Rs. 66.85. (Ans.)**

Unity energy cost for this condition

$= \frac{66.85}{2000} \times 100 =$ **3.34 paise/kWh. (Ans.)**

TARIFF AND COST ANALYSIS

☞**Example 9.33.** *A new factory requires a maximum demand of 700 kW and load factor of 25%. The following two suppliers are available :*

(i) Public supply tariff is Rs. 48 per kW of maximum demand plus 2.4 p. per kWh.

Capital cost	= *Rs. 84000*
Interest and depreciation	= *10 per cent*

(ii) Private oil engine generating station :

Capital cost	= *Rs. 300000*
Fuel consumption	= *3 N / kWh*
Cost of fuel	= *Rs. 8.4 per kN*
Wages	= *0.48 p / kWh*
Maintenance cost	= *0.36 p / kWh*
Interest and depreciation	= *15 per cent.*

Find which supply will be more economical ?

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

$\therefore$ Average load = Load factor × maximum demand = 0.25 × 700 = 175 kW

Energy consumed per year = 175 × (365 × 24) = 1.533 × 10^6 kWh.

(*i*) **Public supply :**

Maximum demand charges per year

= 48 × 700 = Rs. 33600

Energy charge per year $= \dfrac{2.4}{100} \times 1.533 \times 10^6$ = Rs. 36792

Interest and depreciation $= \dfrac{10}{100} \times 84000$ = Rs. 8400

Total cost = Rs. (33600 + 36792 + 8400) = Rs. 78792

$\therefore$ *Energy cost per kWh* $= \dfrac{78792}{1.533 \times 10^6} \times 100 =$ **5.14 p.**

(*ii*) **Private oil engine generating station :**

Fuel consumption $= \dfrac{3 \times 1.533 \times 10^6}{1000} = 4599$ kN

Cost of fuel = 4599 × 8.4 = Rs. 38631

Cost of wages and maintenance $= \left(\dfrac{0.48 + 0.36}{100}\right) \times 1.533 \times 10^6$ = Rs. 12877

Interest and depreciation $= \dfrac{15}{100} \times 300000$ = Rs. 45000

Total cost = Rs. (38631 + 12877 + 45000) = Rs. 96508

Energy cost per kWh $= \dfrac{96508}{1.533 \times 10^6} \times 100 =$ **6.29 p.**

As the energy cost per kWh for oil engine is less than the public supply, the oil engine generation is more preferable. **(Ans.)**

☞**Example 9.34.** *A load having a maximum demand of 100 MW and a load factor of 0.4 may be supplied by one of the following schemes :*

(i) A steam station capable of supplying the whole load.

(ii) A steam station in conjunction with pump storage plant which is capable of supplying 130 × 10^6 kWh energy per year with a maximum output of 40 MW.

Find out the cost of energy per unit in each of the two cases mentioned above.

Use the following data :

Capital cost of steam station = Rs. 2000/kW of installed capacity

Capital cost of pump storage plant = Rs. 1300/kW of installed capacity

Operating cost of steam plant = 6 p./kWh

Operating cost of pump storage plant = 0.5 p./kWh

Interest and depreciation together on the capital invested should be taken as 12 per cent. Assume that no space capacity is required.

Solution. (*i*) **Steam station :**

Capital cost = 100 × 10^3 × 2000 = Rs. 200 × 10^6

Interest and depreciation $= \dfrac{12}{100} \times 200 \times 10^6$ = Rs. 24 × 10^6

Average load = Load factor × maximum demand

$= 0.4 \times 100 \times 10^3 = 40000$ kW

Energy supplied per year = Average load × (365 × 24)

$= 40000 \times 365 \times 24 = 350.4 \times 10^6$ kWh

∴ Interest and depreciation charges *per unit of energy*

$$= \frac{24 \times 10^6}{350.4 \times 10^6} \times 100 = 6.85 \text{ p/kWh}$$

∴ *Total cost per unit* $= 6 + 6.85 =$ **12.85 p/kWh. (Ans.)**

(*ii*) **Steam station in conjunction with pump-storage plant :**

The load supplied by the steam plant $= 100 - 40 = 60$ MW

∴ Capital cost of steam plant $= 60 \times 1000 \times 2000 = \text{Rs. } 120 \times 10^6$

Capital cost of pump storage plant $= 40 \times 1000 \times 1300 = \text{Rs. } 52 \times 10^6$

∴ Total capital cost of combined station $= 120 \times 10^6 + 52 \times 10^6 = \text{Rs. } 172 \times 10^6$

Interest and depreciation charges on capital investment

$$= \frac{12}{100} \times 172 \times 10^6 = \text{Rs. } 20.64 \times 10^6$$

∴ Operating cost of pump storage plant $= \dfrac{0.5}{100} \times 130 \times 10^6 = \text{Rs. } 0.65 \times 10^6$

The energy units supplied by steam station

= Total units required – energy units supplied by pump storage plant

$= 350.4 \times 10^6 - 130 \times 10^6 = 220.4 \times 10^6$ kWh

Operating cost of the steam station

$$= \frac{6}{100} \times 220.4 \times 10^6 = \text{Rs. } 13.22 \times 10^6$$

Total cost per year = Rs. $(20.64 \times 10^6 + 0.65 \times 10^6 + 13.22 \times 10^6) = \text{Rs. } 34.51 \times 10^6$

Total cost per unit $= \dfrac{34.51 \times 10^6}{350.4 \times 10^6} \times 100 =$ **9.85 p/kWh. (Ans.)**

Note. If the above example is repeated with a load factor of 0.7 it will be observed from the results that the *cost of generation becomes less with higher load factor irrespective of the type of the plant.*

Example 9.35. *The following data relate to a 2000 kW diesel power station :*

The peak load on the plant	*= 1500* kW
Load factor	*= 0.4*
Capital cost per kW installed	*= Rs. 1200*
Annual costs	*= 15 per cent of capital*
Annual operating costs	*= Rs. 50000*
Annual maintenance costs :	
(*i*) *Fixed*	*= Rs. 9000*
(*ii*) *Variable*	*= Rs. 18000*
Cost of fuel	*= Rs. 0.45 per kg*
Cost of lubricating oil	*= Rs. 1.3 per kg*
C.V. of fuel	*= 41800 kJ/kg*
Consumption of fuel	*= 0.45 kg/kWh*
Consumption of lubricating oil	*= 0.002 kg/kWh*

Determine the following :

(i) The annual energy generated.

(ii) The cost of generation per kWh.

Solution. Capital cost of the plant $= 2000 \times 1200 = \text{Rs. } 2.4 \times 10^6$ per year

Interest on capital $= \frac{15}{100} \times 2.4 \times 10^6 = \text{Re. } 0.36 \times 10^6$ per year.

(*i*) **Annual energy generated** = Load factor × maximum demand × (365 × 24)

$= 0.4 \times 1500 \times 365 \times 24 =$ **5.256×10^6 kWh. (Ans.)**

(*ii*) **Cost of generation :**

Fuel consumption $= 0.45 \times 5.256 \times 10^6 = 2.365 \times 10^6$ kg per year

Cost of fuel $= \text{Rs. } 0.45 \times 2.365 \times 10^6 = \text{Rs. } 1.064 \times 10^6$ per year

Lubricant consumption $= 0.002 \times 5.256 \times 10^6 = 10512$ kg per year

Cost of lubricating oil $= 1.3 \times 10512 = \text{Rs. } 13665$ per year

Total fixed cost = Interest + maintenance (fixed)

$= 0.36 \times 10^6 + 9000 = \text{Rs. } 369000$ per year

Total running or variable costs

= Fuel cost + lubricant cost + maintenance (running) + annual operating costs

$= 1.064 \times 10^6 + 13665 + 18000 + 50000 = \text{Rs. } 1145665$ per year

Total cost = Fixed cost + running cost = 369000 + 1145665 = Rs. 1514665

$$\text{Cost of generation} = \frac{1514665}{5.256 \times 10^6} \times 100 = \textbf{28.8 paise/kWh.} \quad \textbf{(Ans.)}$$

☞**Example 9.36.** *The annual costs of operating a 15 MW thermal plant are given below :*

Capital cost of plant	*= Rs. 1500/kW*
Interest, insurance and depreciation	*= 10 per cent of plant cost*
Capital cost of primary and secondary distribution	*= Rs. 20 × 10⁶*
Interest, insurance and depreciation on the capital cost of primary and secondary distribution	*= 5% the capital cost*
Plant maintenance cost	*= Rs. 100 × 10³ per year*
Maintenance cost of primary and secondary equipment	*= Rs. 2.2 × 10⁵ per year*
Salaries and wages	*= Rs. 6.5 × 10⁵ per year*
Consumption of coal	*= 40 × 10⁴ kN per year*
Cost of coal	*= Rs. 9 per kN*
Dividend to stockholders	*= Rs. 1.5 × 10⁶ per year*
Energy loss in transmission	*= 10 per cent*
Diversity factor	*= 1.5*
Load factor	*= 0.75*
Maximum demand	*= 12 MW*

(i) Devise a two-part tariff.

(ii) Find the average cost per kWh.

Solution. (*i*) **Two-part tariff :**

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

$\therefore$ Average load = Load factor × maximum demand
= $0.75 \times 12 \times 10^3 = 9000$ kW

Energy generated per year = $9000 \times (365 \times 24) = 78.84 \times 10^6$ kWh

Cost of the plant = $15 \times 10^3 \times 1500$ = Rs. 22.5×10^6

Interest, insurance and depreciation charges of the plant

$$= \frac{10}{100} \times 22.5 \times 10^6 = \text{Rs. } 2.25 \times 10^6$$

Interest, insurance and depreciation charges of primary and secondary equipments

$$= \frac{5}{100} \times 20 \times 10^6 = \text{Rs. } 1.0 \times 10^6$$

Total fixed cost = Insurance, interest and depreciation costs + dividend to stock-holders
= Rs. $(2.25 \times 10^6 + 1.5 \times 10^6)$ = Rs. 3.75×10^6

Sum of individual maximum demand
= Maximum demand × diversity factor
= $12 \times 10^3 \times 1.5 = 18000$ kW

$$\therefore \textit{ Fixed charges per kW} = \frac{3.75 \times 10^6}{18000} = \textbf{Rs. 208.3.}$$

Total variable charges = All maintenance costs + salaries and wages + fuel cost
= $(100 \times 10^3 + 2.2 \times 10^5) + 6.5 \times 10^5 + 40 \times 10^4 \times 9$
= $(1 \times 10^5 + 2.2 \times 10^5) + 6.5 \times 10^5 + 36 \times 10^5$
= Rs. 45.7×10^5 or Rs. 4.57×10^6

Energy transmitted = Energy generated × transmission efficiency

$$= 78.84 \times 10^6 \times \left(\frac{100 - \text{energy loss in transmission}}{100}\right)$$

$$= 78.84 \times 10^6 \times \frac{90}{100} = 70.956 \times 10^6 \text{ kWh}$$

$\therefore$ *Charges for energy consumption*

$$= \frac{4.57 \times 10^6}{70.956 \times 10^6} \times 100 = \textbf{6.44 paise/kWh.}$$

$\therefore$ *Two-part tariff* = **Rs. 208.3/kW + 6.44 paise/kWh. (Ans.)**

(*ii*) **Average cost per kWh :**

Total charges = Fixed charges + variable charges
= $3.75 \times 10^6 + 4.57 \times 10^6$ = Rs. 8.32×10^6

$$\textit{Average cost of supply} = \frac{8.32 \times 10^6}{70.956 \times 10^6} \times 100 = \textbf{11.72 paise/kWh. (Ans.)}$$

Example 9.37. *A 10 MW thermal power plant has the following data :*

Peak load = *8 MW*
Plant annual load factor = *0.72*
Cost of the plant = *Rs. 800/kW installed capacity*
Interest, insurance and depreciation = *10 per cent of the capital cost*
Cost of transmission and distribution system = *Rs.* 350×10^3
Interest, depreciation on distribution system = *5 per cent*

Operating cost	= *Rs.* 350×10^3 *per year*
Cost of coal	= *Rs. 6 per kN*
Plant maintenance cost	= *Rs. 30000/year (fixed)*
	= *Rs. 40000/year (running)*
Coal used	= *250000 kN/year*

Assume transmission and distribution costs are to be charged to generation

(i) Devise a two-part tariff.

(ii) Average cost of generation in paise/kWh.

Solution. (*i*) **Two-part tariff :**

S. No.	Items	Fixed cost per year (in Rs.)	Running cost per year (in Rs.)
1.	Interest, depreciation etc. of the plant	$\frac{10}{100} \times 10000 \times 800$ = Rs. 800×10^3	—
2.	Interest, depreciation etc. of the transmission and distribution	$\frac{5}{100} \times 350 \times 10^3$ = 17.5×10^3	—
3.	Annual cost of coal	—	250000×6 = 1500×10^3
4.	Operating cost	—	= 350×10^3
5.	Plant maintenance cost	= 30×10^3	= 40×10^3
	Total cost	847.5×10^3	1890×10^3

$\therefore$ Grand total cost = Fixed cost + running cost

$= 847.5 \times 10^3 + 1890 \times 10^3 = \text{Rs. } 2737.5 \times 10^3$

Energy generated/year = Average load × (365 × 24)

= (Peak load × load factor) × (365 × 24)

$= (8 \times 10^3 \times 0.72) \times (365 \times 24) = 50.46 \times 10^6$ kWh

$$\therefore \textit{Two-part tariff} = \frac{\text{Fixed cost}}{\text{Maximum load}} + \frac{\text{Running cost}}{\text{Energy generated}}$$

$$= \frac{847.5 \times 10^3}{8 \times 10^3} + \frac{1890 \times 10^3}{50.46 \times 10^6} \times 100$$

= **Rs. 105.9/kW + paise 3.74/kWh. (Ans.)**

(*ii*) **Average cost generation in paise/kWh :**

$$\textit{Average generation cost} = \frac{\text{Grand total cost}}{\text{Energy generated}}$$

$$= \frac{2737.5 \times 10^3}{50.46 \times 10^6} \times 100 = \mathbf{5.42 \text{ paise/kWh.}} \quad \textbf{(Ans.)}$$

Example 9.38. *Determine the load factor at which the cost of supplying a unit of electricity is same in Diesel station as in a steam station if the respective annual fixed and running charges are given below :*

Diesel : *Rs. (40/kW + 0.06/kWh)*

Steam : *Rs. (160/kW + 0.015/kWh).*

Solution. Let P = Maximum load in kW, and

x = Load factor (same for both the stations).

Then, Average load $= P \times x$

Cost of diesel station,

$$C_{diesel} = 40\,P + 0.06 \times P \times x \times (365 \times 24)$$

Cost of steam station,

$$C_{steam} = 160\,P + 0.015 \times P \times x \times (365 \times 24)$$

As given in the problem,

Unit energy cost (diesel station) = Unit energy cost (steam station)

$$\therefore \quad \frac{40\,P + 0.06\,Px \times (365 \times 24)}{Px \times (365 \times 24)} = \frac{160\,P + 0.015\,Px \times (365 \times 24)}{Px \times (365 \times 24)}$$

$$\therefore \quad 40\,P + 0.06\,Px \times 8760 = 160\,P + 0.015\,Px \times 8760$$

or $$40\,P + 525.6\,Px = 160\,P + 131.4\,Px$$

or $$120\,P = 394.2\,Px \quad \text{or} \quad x = \frac{120}{394.2} = 0.3$$

i.e., *Load factor* = **0.3. (Ans.)**

Example 9.39. *A motor of 25 H.P. connected to a condensate pump has been burnt beyond economical repairs. Two alternatives have been proposed to replace it by :*

	Cost	***η at full load***	***η at half load***
Motor A :	*Rs. 5000*	*90%*	*85%*
Motor B :	*Rs. 3500*	*86%*	*80%*

The life of each motor is 20 years and its salvage value is 12 per cent of the initial cost. The rate of interest is 5 percent annually. The motor operates at full load for 30% of time and at half load for the remaining period. The annual maintenance cost of motor A is Rs. 400 and that of motor B is Rs. 200. The energy rate is 12 paise / kWh.

Which motor will be economical ?

Solution. Motor A :

Salvage value $= \frac{12}{100} \times 5000 = \text{Rs. } 600$

Depreciation $= \frac{5000 - 600}{20} = \text{Rs. } 220\text{/year}$

Interest $= \frac{5}{100} \times 5000 = \text{Rs. } 250\text{/year}$

Maintenance = Rs. 400

Energy given to motor $= \frac{\text{Load on motor} \times \text{time in hours}}{\text{Efficiency of the motor}}$

$\therefore$ Energy cost

$$= \left[\left(25 \times 0.7355 \times (365 \times 24) \times \frac{30}{100} \times \frac{1}{0.9}\right) + \left((25 \times 0.7355) \times \frac{1}{2} \times (365 \times 24) \times \frac{70}{100} \times \frac{1}{0.85}\right)\right] \times \frac{12}{100}$$

$$= (53691.5 + 66324.8) \times \frac{12}{100} = \text{Rs. } 14402\text{/year}$$

∴ *Total cost of motor A* $= 220 + 250 + 400 + 14402 =$ **Rs. 15272/year.**

Motor B :

Salvage value $= \frac{12}{100} \times 3500 = \text{Rs. } 420$

Depreciation $= \frac{3500 - 420}{20} = \text{Rs. } 154$

Interest $= \frac{5}{100} \times 3500 = \text{Rs. } 175$

Maintenance = Rs. 200

Energy cost
$$= \left[\left(25 \times 0.7355 \times (365 \times 24) \times \frac{30}{100} \times \frac{1}{0.86}\right) + \left(25 \times 0.7355 \times \frac{1}{2} \times (365 \times 24) \times \frac{70}{100} \times \frac{1}{0.8}\right)\right] \times \frac{12}{100}$$
$$= (56188.8 + 70470) \times \frac{12}{100} = \text{Rs. } 15199$$

Total cost of motor B $= 154 + 175 + 200 + 15199 =$ **Rs. 15728/year.**

Hence Motor A is economical since its annual cost is less than motor B.

☞**Example 9.40.** *The following proposals are under consideration for an industry which has a maximum demand of 45 MW and a load factor of 0.45 :*

(i) A steam plant having an initial cost of Rs. 1200/kW and maintenance cost of 2.4 paise/kWh. The coal of C.V. of 2550 kJ/N is used. The overall efficiency of the plant is 24 per cent.

(ii) An hydro-plant having a capital cost of Rs. 3600/kW and a running cost of 0.6 paise/kWh.

Assuming interest and depreciation rate of 10 per cent for steam plant and 8 per cent for hydro-plant, determine the price of coal above which steam station is uneconomical.

Solution. Energy required per year

$= \text{Peak load} \times \text{load factor} \times (365 \times 24)$

$= 45 \times 10^3 \times 0.45 \times (365 \times 24) = 177.39 \times 10^6$ kWh/year

(*i*) **Steam plant :**

Interest and depreciation $= \frac{10}{100} \times (45 \times 10^3) \times 1200 = \text{Rs. } 5.4 \times 10^6$

Maintenance cost $= \frac{2.4}{100} \times 177.39 \times 10^6 = \text{Rs. } 4.257 \times 10^6$

Let W_{coal} = Weight of coal in kN used/year, and

x = Cost of coal in Rs. per kN

∴ $W_{coal} \times 10^3 \times C.V. \times \eta_{overall} = 177.39 \times 10^6 \times 3.6 \times 10^3$ (∵ $1 \text{ kWh} = 3.6 \times 10^3$ kJ)

or $$W_{coal} = \frac{177.39 \times 10^6 \times (3.6 \times 10^3)}{10^3 \times 2550 \times 0.24} = 1.043 \times 10^6 \text{ kN/year}$$

Now, total cost of steam plant = Interest + maintenance cost + fuel cost

$= 5.4 \times 10^6 + 4.257 \times 10^6 + 1.043 \times 10^6 \times x$ ...(1)

(*ii*) **Hydel plant :**

Interest and depreciation $= 45 \times 10^3 \times 3600 \times \frac{8}{100} = \text{Rs. } 12.96 \times 10^6$

Running cost $= \frac{0.6}{100} \times 177.39 \times 10^6 = \text{Rs. } 1.064 \times 10^6$

Total cost of hydel plant $= 12.96 \times 10^6 + 1.064 \times 10^6 =$ Rs. 14.024×10^6 ...(2)

The steam and hydel station will be equally economical if the total cost/year remains same.

∴ Equating the values of (1) and (2), we get

$$5.4 \times 10^6 + 4.257 \times 10^6 + 1.043 \times 10^6 \times x = 14.024 \times 10^6$$

or $$5.4 + 4.257 + 1.043\,x = 14.024 \text{ (Dividing both sides by } 10^6)$$

∴ $$x = \frac{14.024 - 5.4 - 4.257}{1.043} = \text{Rs. } 4.19 \text{ kN}$$

Hence price coal above which steam station is uneconomical = **Rs. 4.19 per kN. (Ans.)**

Example 9.41. *An industrial consumer has a choice between low and high voltage supply available at the following rates :*

High voltage : *Rs. 50/kW per year + paise 4/kWh*

Low voltage : *Rs. 55/kW per year + paise 5/kWh*

In order to have high voltage supply, consumer has to install his own transformer which costs Rs. 110/kW. The losses in the transformer are 4 per cent of full load. Determine the number of working hours per week above which the high voltage supply will be economical.

Assume : interest and depreciation 12 per cent of capital, working weeks per year 50 and load of consumer as 1.5 MW.

Solution. Consumer load = 1.5 MW = 1500 kW

Required rating of transformer $= \dfrac{1500}{(1 - 0.4)} = 1562$ kW

Cost of the transformer to the consumer

$$= 1562 \times 110 = \text{Rs. } 171820$$

Annual interest and depreciation $= \dfrac{12}{100} \times 171820 =$ Rs. 20618

Let the number of hours for which power is required by the consumer = x hours/week

∴ Number of hours for which power is used during the year = $50x$ hours

(*i*) Number of units consumed from low voltage side if the load is connected to low voltage

$$= 1500 \times 50x = 75000x \text{ kWh/year}$$

(*ii*) Number of units consumed from high voltage side if the load is connected to high voltage

$$= 1562 \times 50x = 78100x \text{ kWh/year}$$

Total cost from low voltage supply in rupees

$$= 1500 \times 55 + 75000x \times \frac{5}{100} = 82500 + 3750x \quad ...(1)$$

Total cost from high voltage supply in rupees

$$= 1562 \times 50 + 78100x \times \frac{4}{100} + 20618$$

$$= 98718 + 3124x \quad ...(2)$$

It both the systems cost the same to the consumer, then equating (1) and (2), we get

$$82500 + 3750x = 98718 + 3124x$$

i.e., $$x = \frac{98718 - 82500}{(3750 - 3124)} = \frac{16218}{626} = 25.9 \text{ hours.}$$

Hence the number of working hours above which the high voltage supply will be economical

= **25.9 hours. (Ans.)**

ADDITIONAL TYPICAL EXAMPLES

Example 9.42. *A diesel electric station has 4-generating sets, each of 500 kW and 1 of 400 kW capacity.*

The other data is given below :

Maximum demand	*1500 kW*
Load factor	*0.5*
Capital cost	*Rs. 10000/kW*
Annual cost (interest + depreciation + insurances and taxes)	*16% of capital cost*
Annual maintenance cost	*Rs. 45000*
Operation cost	*Rs. 8000*
Fuel used	*0.45 kg/kWh*
Cost of fuel	*Rs. 8/kg*
Lubricating oil used	*0.0024 kg/kWh*
Cost of lubricating oil	*Rs. 45/kg*
Calorific value of fuel used	*41000 kJ/kg*
Generator efficiency	*90%*

Determine the following :

(i) The rating of diesel engine, *(ii) Energy produced per year,*
(iii) Cost of generation, Rs/kWh, and *(iv) Overall efficiency of the plant.* **(N.U.)**

Solution. (*i*) **The rating of diesel engine :**

Rating of first 3-sets $= \frac{500}{0.9} =$ **555 kW. (Ans.)**

Rating of last set $= \frac{400}{0.9} =$ **445 kW. (Ans.)**

(*ii*) **Energy produced per year :**

Average demand = Maximum demand × load factor = 1500 × 0.5 = 750 kW

∴ Energy produced per year = 750 × 8760 = **6.57 × 10⁶ kWh. (Ans.)**

(*iii*) **Cost of generation, Rs./kWh :**

Fixed cost per year :

Capital cost $= (3 \times 500 + 1 \times 400) \times 10000 = \text{Rs. } 1.9 \times 10^7$

Annual fixed cost $= \frac{16}{100} \times 1.9 \times 10^7 = \text{Rs. } 0.304 \times 10^7$

Maintenance cost $= \text{Rs. } 45000 = \text{Rs. } 0.0045 \times 10^7$

Total fixed cost $= \text{Rs. } (0.304 + 0.0045) \times 10^7 = \text{Rs. } 0.3085 \times 10^7$

Variable cost per year :

Fuel cost $= (6.57 \times 10^6 \times 0.45) \times 8 = \text{Rs. } 23.65 \times 10^6$

Cost of lubricating oil $= (6.57 \times 10^6 \times 0.0024) \times 45 = \text{Rs. } 0.71 \times 10^6$

Total variable cost per year $= (23.65 + 0.71) \times 10^6 = \text{Rs. } 24.36 \times 10^6$

Total cost = Fixed cost + variable cost

$= 3.085 \times 10^6 + 24.36 \times 10^6 = \text{Rs. } 27.44 \times 10^6$

∴ **Cost per kWh generated** $= \frac{\text{Total cost}}{\text{Energy generated per year}}$

$= \frac{27.44 \times 10^6}{6.57 \times 10^6} \simeq$ **Rs. 4.18. (Ans.)**

(*iv*) **Overall efficiency of the plant, $\eta_{overall}$:**

$$\eta_{overall} = \frac{\text{Output}}{\text{Input}} = \frac{6.57 \times 10^6 \times 3600 \text{ (kJ)}}{6.57 \times 10^6 \times 0.45 \times 41000 \text{ (kJ)}} = 0.195 \text{ or } \mathbf{19.5\%.} \textbf{ (Ans.)}$$

Example 9.43. *A load curve of a factory follows a parabola and it works for 8 hours a day from 10 A.M. to 6 P.M. The maximum and minimum loads of the factory are $\sqrt{3}$ MW and 1 MW. The capacity of the diesel power plant supplying the power to the factory is 2 MW. Determine the following :*

(*i*) *Load factor and capacity factor of the plant supplying power to the factory.*

(*ii*) *Energy consumption of the factory per month assuming it works for 26 days per month and 8 hours per day.*

(*iii*) *Electrical charges to be paid by the factory if the charges are Rs. 60/kW for maximum load during a day and Rs. 2.75/kWh.*

The time at 6 A.M. may be taken as zero. **(M.U.)**

Solution. *Given* : Working hours per day = 8 (10 A.M. to 6 P.M.) ; Maximum load = $\sqrt{3}$ MW ; Minimum load = 1 MW ; Capacity of diesel power plant = 2 MW ; Tariff : Rs. 60/kW (maximum load) ; Rs. 2.75/kWh.

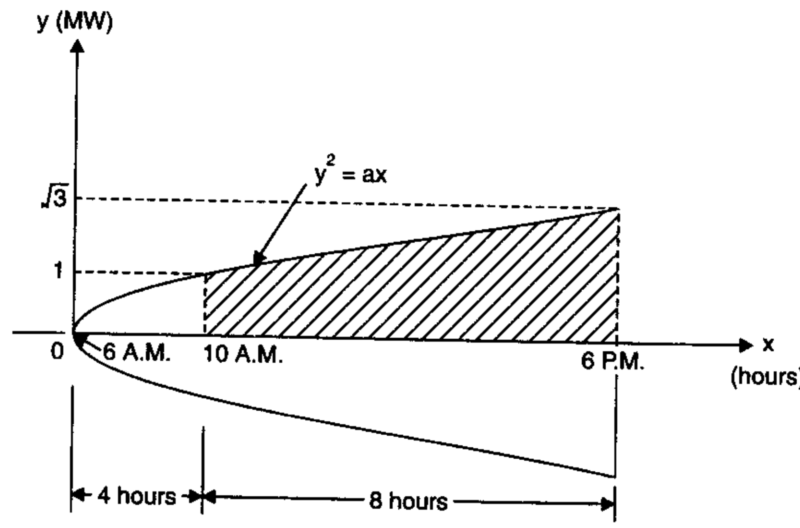


Fig. 9.18.

The load curve is shown in Fig. 9.18.

The load curve is given by :

$y^2 = ax$, where x and y represent hours and MW respectively.

The boundary conditions are :

At $x = 0, y = 0$; At $x = 4, y = 1$

$$\therefore \quad 1 = a \times 4 \quad \text{or} \quad a = \frac{1}{4}$$

$$\therefore \quad y^2 = \frac{x}{4} \quad \text{or} \quad y = \frac{\sqrt{x}}{2} \quad \text{(load curve)}$$

The above load curve also fulfills the another condition which is :

At $x = 12$, $y = \sqrt{3}$

$$\therefore \quad (\sqrt{3})^2 = \frac{12}{4} \quad \therefore \quad 3 = 3$$

The average load of the factory on the diesel power plant is given by :

$$L_{av} = \frac{1}{8}\int_4^{12} y \, . \, dx = \frac{1}{8}\int_4^{12} \frac{\sqrt{x}}{2} \, dx$$

$$= \frac{1}{16}\left[\frac{2}{3}(x)^{1.5}\right]_4^{12} = \frac{1}{24}\,[(12)^{1.5} - (4)^{1.5}] = 1.4 \text{ MW}$$

(*i*) **Load factor and capacity factor :**

Load factor $= \frac{L_{av}}{L_{max}} = \frac{1.4}{\sqrt{3}} = \mathbf{0.808.}$ **(Ans.)**

Capacity factor $= \frac{L_{max}}{\text{Plant capacity}} = \frac{\sqrt{3}}{2} = \mathbf{0.866.}$ **(Ans.)**

(*ii*) **Energy consumption per month :**

Energy consumption per month,

$$E = (L_{av} \times 8) \times 26 = (1.4 \times 8 \times 1000) \times 26 = 291200 \text{ kWh}$$

(*iii*) **Electrical charges to be paid by the factory :**

Electrical charges to be paid by the factory

$$= L_{max} \times 60 + E \times 2.75$$

$$= \sqrt{3} \times 60 + 291200 \times 2.75 = \textbf{Rs. 800904.} \quad \textbf{(Ans.)}$$

Example 9.44. *The daily load curve for a power plant is given by the following equation :*

$$L = 350 + 10t - t^2$$

where t is time in hours from 0 to 24 hours and L is in MW calculate :

(*i*) *Value of maximum load and when it occurs, and*

(*ii*) *Load factor of the plant.*

Draw load curve and load duration curve. **(P.U. May, 2001)**

Solution. Equation of the load curve,

$$L = 350 + 10t - t^2 \qquad \text{...(Given)}$$

(*i*) **Value of maximum load and when it occurs :**

The condition for finding the value of maximum load is $\frac{dL}{dt} = 0$

$$\therefore \quad \frac{d}{dt}(350 + 10t - t^2) = 0 \quad \text{or} \quad 10 - 2t = 0$$

$$\therefore \quad t = 5 \text{ hours.}$$

Thus, the *maximum load occurs at 5th hour during the day.* **(Ans.)**

$$\therefore \quad L_{max} = 350 + 10 \times 5 - 5^2 = \mathbf{375 \ MW.} \quad \textbf{(Ans.)}$$

(*ii*) **Load factor of the plant :**

The average load on the plant is given by

$$L_{av} = \frac{1}{24}\int_0^{24} L \, . \, dt = \frac{1}{24}\int_0^{24} (350 + 10t - t^2) \, dt$$

$$= \frac{1}{24}\left[350t + 10 \times \frac{t^2}{2} - \frac{t^3}{3}\right]_0^{24} = \frac{1}{24}\left[350 \times 24 + 10 \times \frac{(24)^2}{2} - \frac{(24)^3}{3}\right] = 278 \text{ MW}$$

$\therefore$ Load factor $= \frac{L_{av}}{L_{max}} = \frac{278}{375} = $ **0.7413. (Ans.)**

Load curve and load duration curve :

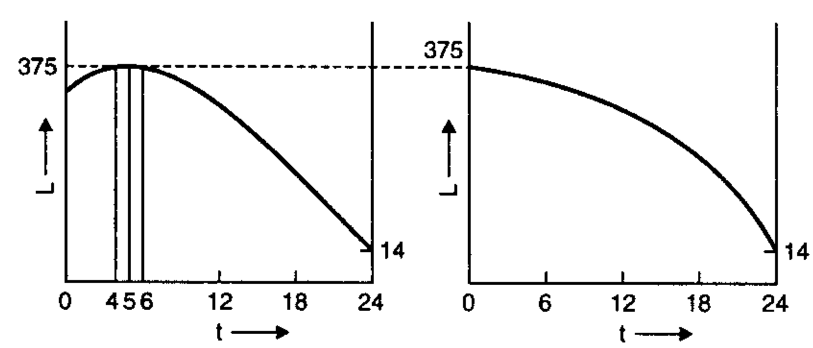
- The *'load curve is' the representation of load with respect to time.*
- The *'load duration curve' is the representation of load with respect to time in descending order.*

In order to draw these curves, we need to calculate the values of L when $t = 0, 1, 2, 3, \ldots. 24$ hours and these values are tabulated below :

(Eqn. of the load curve $L = 350 + 10t - t^2$), At $t = 0$, $L = 350$ MW

t (h)	L (MW)	t (h)	L (MW)
1	359	13	311
2	366	14	294
3	371	15	275
4	374	16	254
5	375	17	231
6	374	18	206
7	371	19	179
8	366	20	150
9	359	21	119
10	350	22	86
11	339	23	51
12	326	24	14

From the above data the load curve and load duration curve are drawn as shown in Fig. 9.19 (*a*) and (*b*) respectively.



(a) Load curve. (b) Load duration curve.

Fig. 9.19

HIGHLIGHTS

1. Types of loads : (*i*) Residential load (*ii*) Commercial load (*iii*) Industrial load (*iv*) Municipal load (*v*) Irrigation load and (*vi*) Traction load.
2. A *load curve* is a graphic record showing the power demands for every instant during a certain time interval. The area under the load curve represents the energy generated in the period considered.
3. The cost of a power system includes the following :

   A. *Capital cost or fixed cost :*

   (*i*) Initial cost (*ii*) Interest
   (*iii*) Depreciation cost (*iv*) Taxes
   (*v*) Insurance

   B. *Operational cost :*

   (*i*) Fuel cost (*ii*) Operating labour cost
   (*iii*) Maintenance cost (*iv*) Supplies
   (*v*) Supervision (*vi*) Operating taxes.
4. The following methods are used to calculate the depreciation cost :

   (*i*) Straight line method. (*ii*) Percentage method.
   (*iii*) Sinking fund method. (*iv*) Unit method.
5. The economics of power plant is greatly influenced by :

   (*i*) Load factor (*ii*) Demand factor
   (*iii*) Utilisation factor.
6. The performance of a plant can be precisely represented by the *input-output* curve from the tests conducted on individual power plant. In general input-output may be represented as follows :

   $$I = a + bL + cL^2 + dL^3$$

   where I = input (in millions of kcal/h or kJ/h in case of thermal plants and m^3/s of water in case of hydro-plants)
   L = output (in MW or kW)
   a, b, c, d = constants.
7. For minimum combined input to carry a given combined output, the slopes of the input-output curves for each unit must be equal. If there are n units supplying a constant load, then the required condition for the minimum input or maximum system efficiency is

   $$\frac{dI_1}{dL_1} = \frac{dI_2}{dL_2} = \frac{dI_3}{dL_3} = \ldots\ldots \frac{dI_n}{dL_n}.$$
8. The general tariff form is given by :

   $$z = a.x + b.y + c$$

   where, z = Total amount of bill for the period considered.
   x = Maximum demand in kW.
   y = Energy consumed in kWh during the period considered.
   a = Rate per kW of maximum demand.
   b = Energy rate per kWh.
   c = Constant amount charged to the consumer during each billing period. This charge is independent of demand or total energy because a consumer that remains connected to the line incurs expenses even if he does not use energy.
9. Various types of *tariff* are :

   (*i*) Flat demand rate (*ii*) Straight meter rate
   (*iii*) Block meter rate (*iv*) Hopkinson demand rate (Two-part tariff)
   (*v*) Doherty rate (Three-part tariff) (*vi*) Wright demand rate.

THEORETICAL QUESTIONS

1. Define the following terms :
   (i) Connected load (ii) Demand
   (iii) Demand factor (iv) Load factor
   (v) Diversity factor (vi) Utilisation factor.
2. Explain briefly the following :
   (i) Load curve (ii) Load duration curve.
3. What is the significance of load curves ?
4. Enumerate various types of loads.
5. List the factors which should be considered while designing a power plant.
6. What are the considerations on which the location of a power plant depends ?
7. List the points which should be taken care of while deciding about power plant building and its layout.
8. List the various costs which go to form the total cost of a power system.
9. Explain briefly the following :
   (i) Capital or fixed cost (ii) Operational cost.
10. What do you mean by depreciation ?
11. Enumerate and explain briefly various methods used to calculate the depreciation cost.
12. Name the elements that make up the operating expenditure of a power plant.
13. What points should be considered while choosing the type of generation ?
14. Discuss the economic loading of combined steam and hydro-plants.
15. How can the power generation cost be reduced ?
16. What do you understand by the term tariff ?
17. What are the objectives and requirements of tariff ?
18. Enumerate various types of tariff and explain any two of them.
19. Explain briefly the following tariff :
   (i) Straight meter rate (ii) Block meter rate
   (iii) Doherty rate (three-part tariff).

UNSOLVED EXAMPLES

1. The maximum demand of a power station is 80000 kW and the load curve is defined as follows :

Time (hours)	0—6	6—8	8—12	12—14	14—18	18—22	22—24
Load (MW)	40	50	60	50	70	80	40

   (i) Determine the load factor of power station.
   (ii) What is the load factor of standby equipment rated at 25 MW that takes up all load in excess of 60 MW ? Also calculate its use factor. **[Ans.** (i) 0.71 (ii) 0.75, 0.6]
2. The following load is to be supplied by a power station :

Load (MW)	30	90	60	100	50
Time (hours)	0—6	6—12	12—14	14—18	18—24

   (i) Draw the load curve.
   (ii) Draw the load duration curve.
   (iii) Choose suitable generating units to supply the load.
   (iv) Calculate the load factor.
   (v) Calculate plant capacity factor.
   [Ans. (iii) 30 MW (4 units including standby unit), 10 MW (one unit) (iv) 0.64 (v) 0.49]

3. The yearly duration curve of a certain plant can be considered as a straight line from 150 MW to 40 MW. Power is supplied with one generating unit of 100 MW capacity and two units of 50 MW capacity each. Determine :
   (*i*) Installed capacity (*ii*) Load factor
   (*iii*) Plant factor (*iv*) Maximum demand
   (*v*) Utilization factor. **[Ans.** (*i*) 200 MW (*ii*) 0.633 (*iii*) 0.475 (*iv*) 150 MW (*v*) 0.75]
4. A generating station has a maximum demand of 20 MW, a load factor of 0.6, a plant capacity of 0.48 and a plant use factor of 0.80. Find :
   (*i*) The daily energy produced.
   (*ii*) The reserve capacity of the plant.
   (*iii*) The maximum energy that could be produced if the plant were running all the time.
   (*iv*) The maximum energy that could be produced daily, if the plant when running, according to operating schedule, were fully loaded.
   [Ans. (*i*) 2.88×10^5 kWh (*ii*) 5000 kW (*iii*) 2.88×10^5 kWh (*iv*) 3.60×10^5 kWh]
5. A proposed power station has to supply load as follows :

Time (hours)	:	01—08	08—12	12—17	17—20	20—23	23—01
Load (MW)	:	10	20	25	18	35	20

   After drawing the load curve, find out the load factor. Also choose suitable generating units to supply this load, maintaining reliability of supply. Prepare operation schedule for the machine and calculate plant use factor. **[Ans.** 0.56, 0.92]
6. A generating station supplies the following loads :
   15 MW ; 12 MW ; 8 MW and 0.5 MW. The station has a maximum demand of 20 MW and the annual load factor is 0.5. Find :
   (*i*) Number of units supplied annually. (*ii*) Diversity factor.
   [Ans. (*i*) 876×10^5 kWh (*ii*) 1.775]
7. A base load power station and standby power station share a common load as follows :
   Base load station annual output = 150×10^6 kWh ; Base load station capacity = 35 MW ; Maximum demand on base load station = 30 MW ; Standby station capacity = 18 MW ; Standby station annual output = 140×10^6 kWh ; Maximum demand (peak load) on standby station = 15 MW. Determine the following for both power stations :
   (*i*) Load factor (*ii*) Capacity factor (plant factor).
   [**Ans.** Base load station : (*i*) 0.57 (*ii*) 0.49
   Standby power station : (*i*) 0.107 (*ii*) 0.09]
8. A power system has the following load particulars :

	Maximum demand	**Load factor**	**Diversity between consumers**
1. Residential load :	1000 kW	0.2	1.3
2. Commercial load :	2000 kW	0.3	1.1
3. Industrial load :	5000 kW	0.8	1.2

   Overall diversity factor may be taken as 1.4.
   Determine the following :
   (*i*) Maximum demand on system.
   (*ii*) Daily energy consumption (total).
   (*iii*) Overall load factor.
   (*iv*) Connected load (total) assuming that demand factor for each load is unity.
9. The following data is available for a steam power station :
   Maximum demand = 25000 kW ; Load factor = 0.4 ; Coal consumption = 0.86 kg/kWh ; Boiler efficiency = 85% ; Turbine efficiency = 90% ; Price of coal = Rs. 55 per tonne.
   Determine the following :
   (*i*) Thermal efficiency of the station.
   (*ii*) Coal bill of the plant for one year. **[Ans.** (*i*) 76.5% (*ii*) Rs. 4143480]

10. The daily load curve of a power plant is given by the table below :

Time :	12	2	4	6	8	10	12	2	4	6	8	10	12
Load (MW) :	2	2.5	3	4	6	6.5	6.5	5	6	8	9	5	2

(*i*) Find the daily load factor.

(*ii*) All loads in excess of 400 kW are carried out by unit No. 2 rated at 600 kW. Find its use factor.

[**Ans.** (*i*) 0.814 (*ii*) 0.417]

11. The annual peak load on a 30 MW power station is 25 MW. The power station supplies load having maximum demands of 10 MW, 8.5 MW, 5 MW and 4.5 MW. The annual load factor is 0.45. Find :

(*i*) Average load (*ii*) Energy supplied per year

(*iii* Diversity factor (*iv*) Demand factor.

[**Ans.** (*i*) 11.25 MW (*ii*) 98.55 × 10^6 kWh (*iii*) 1.12 (*iv*) 0.9]

12. A generating station supplies the following loads :

15 MW, 12 MW, 8.5 MW, 6 MW and 0.45 MW. The station has a maximum demand of 22 MW. The annual load factor of the station is 0.48. Calculate :

(*i*) The number of units supplied annually

(*ii*) The diversity factor. (*iii*) The demand factor.

[**Ans.** (*i*) 92.5 × 10^6 kWh (*ii*) 1.907 (*iii*) 0.525]

13. A power station has a maximum demand of 15 MW, a load factor of 0.7, a plant capacity factor of 0.525 and a plant use factor of 0.85. Find :

(*i*) The daily energy produced.

(*ii*) The reserve capacity of the plant.

(*iii*) The maximum energy that could be produced daily if the plant operating schedule is fully loaded when in operation. [**Ans.** (*i*) 252000 kWh (*ii*) 5000 kW (*iii*) 296470 kWh]

14. Determine the annual cost of a feed water softner from the following data :

Cost = Rs. 80000 ; Salvage value = 5%, Life = 10 years ; Annual repair and maintenance cost = Rs. 2500 ; Annual cost of chemicals = Rs. 5000 ; Labour cost per month = Rs. 300 ; Interest on sinking fund = 5%.

[**Ans.** Rs. 17,140]

15. Estimate the generating cost per kWh delivered from a generating station from the following data :

Plant capacity	= 50 MW
Annual load factor	= 0.4
Capital cost	= Rs. 1.2 crores
Annual cost of wages, taxation etc.	= Rs. 4 lacs
Cost of fuel, lubrication, maintenance etc.	= 1.0 paise per kWh generated.

Interest 5% per annum, depreciation 5% per annum of initial value. [**Ans.** 1.91 paise/kWh delivered]

16. A 100 MW, steam power station is estimated to cost Rs. 20 crores. The operating expenses are estimated as follows :

Cost of fuel and oil	= Rs. 140 lacs per annum
Transportation and storage	= Rs. 20 lacs per annum
Salaries and wages	= Rs. 20 lacs per annum
Miscellaneous	= Rs. 20 lacs per annum

Reckoning interest and depreciation at 10% of the capital cost, calculate the cost of generation per unit, if the average load factor of the power station is 0.6.

What economics could be affected if the load factor was improved to 0.8, the operating expenses increasing by only 10% thereby. [**Ans.** 6 p/kWh, 21% reduction in cost of generation]

17. A steam station has two 110 MW units. Following cost data are given :

Particulars	**Unit A**	**Unit B**
Capital cost	Rs. 2000 per kW	Rs. 2500 per kW
Fixed charge rate	10 per cent	10 per cent
Capacity factor	0.55	0.6
Fuel consumption	1 kg/kWh	0.9 kg/kWh

Fuel cost	Rs. 80 per 1000 kg	Rs. 80 per 1000 kg
Annual cost of operating, labour, maintenance and supplies	20 per cent of annual cost	15 per cent of annual cost
Utilisation factor	1	1

Calculate the following :

(*i*) Annual plant cost and generation cost of unit A.

(*ii*) Annual plant cost and generation cost of unit B.

(*iii*) Overall generation cost of the station.

[**Ans.** (*i*) Rs. 7,28,78,080 ; 13.75 p/kWh (*ii*) Rs. 75.371648 × 10^6 ; 13.036 p/kWh (*iii*) 13.378 p/kWh]

18. The annual costs of operating a 15,000 kW thermal power station are as follows :

Cost of plant	= Rs. 900 per kW
Interest, insurance, taxes on plant	= 5 per cent
Depreciation	= 5 per cent
Cost of primary distribution system	= Rs. 500000
Interest, insurance, taxes and depreciation on primary distribution system	= 5 per cent
Cost of secondary distribution system	= Rs. 900000
Interest, taxes, insurance and depreciation on secondary distribution system	= 5 per cent
Maintenance of secondary distribution system	= Rs. 180000

Plant maintenance cost

(*i*) Fixed cost	= Rs. 30000
(*ii*) Variable cost	= Rs. 40000
Operating costs	= Rs. 600000
Cost of coal	= Rs. 60 per tonne
Consumption of coal	= 30000 tonnes
Dividend to stock-holders	= Rs. 1000000
Energy loss in transmission	= 10 per cent
Maximum demand	= 14000 kW
Diversity factor	= 1.5
Load factor	= 0.7

Determine : (*i*) Charge per kW per year (*ii*) Rate per kWh. [**Ans.** (*i*) Rs. 116.6 (*ii*) 3.4 p/kWh]

19. It is proposed to supply a load with a maximum demand of 100 MW and a load factor of 0.4. Choice is to be made from steam, hydro and nuclear power plants. Calculate the overall cost per kWh in case of each machine :

Cost	Steam power plant	Hydro power plant	Nuclear power plant
Capital cost per kW installed	Rs. 1800	Rs. 3600	Rs. 5000
Interest	12%	10%	10%
Depreciation	12%	8%	10%
Operating cost per kWh	15 paise	5 paise	10 paise
Transmission and distribution cost/kWh	0.2 paise	0.8 paise	0.2 paise

[**Ans.** 27.52 p ; 23.57 p ; 38.73 p]

20. A power plant of 150 MW installed capacity has the following data :

Capital cost = Rs. 1800/kW installed ; Interest and depreciation = 12 per cent ;

Annual load factor = 0.6 ; Annual capacity factor = 0.5 ; Annual running charges = Rs. 30 × 10^6 ; Energy consumed by the power plant auxiliaries = 6 per cent. Calculate :

(*i*) Reserve capacity (*ii*) Generating cost. [**Ans.** (*i*) 25 MW (*ii*) 10.10 paise]

21. Compare the annual cost of supplying a factory load having a maximum demand of 1 MW at a load factor of 50% by energy obtained from

(*a*) Nuclear power plant (*b*) Public supply

Nuclear power plant

Capital cost	= Rs. 50,000
Cost of fuel	= Rs. 600 per 1000 kg
Fuel consumption	= 30 g per kWh generated
Cost of maintenance etc.	= Re. 0.005 per kWh generated
Wages	= Rs. 20000 per annum
Interest and depreciation	= 10 per cent.

Public supply : Rs. 50 per kW + Re. 0.03 per kWh generated. **[Ans.** Rs. 170740 ; Rs. 181400]

22. A system with a maximum demand of 1,00,000 kW and a load factor of 30% is to be supplied by either (*a*) steam station alone or (*b*) a steam station in conjunction with a water storage scheme, the latter supplying 100 million units with a maximum output of 40000 kW. The capital cost of steam and storage stations are Rs. 600 per kW and Rs. 1,200 per kW respectively. The corresponding operating costs are 15 paise and 3 paise per kWh respectively. The interest on capital cost is 15% per annum. Calculate the overall generating cost per kWh and state which of the two projects will be economical.

[Ans. 18.425 p/kWh, 15.23 p/kWh]

23. A power station has the installed capacity of 120 MW. Calculate the cost of generation, other data pertaining to power station are given below :

Capital cost	= Rs. 200×10^6
Rate of interest and depreciation	= 18 per cent
Annual cost of fuel oil, salaries and taxation	= Rs. 24×10^6
Load factor	= 0.4

Also calculate the saving in cost per kWh if the annual load factor is raised to 0.5.

[Ans. 14.25 paise ; 2.84 paise]

24. A 50 MW generating station has the following data :

Capital cost = Rs. 15×10^6 ; Annual taxation = Rs. 0.4×10^6 ; Annual salaries and wages = Rs. 1.2×10^6 ; Cost of coal = Rs. 65 per tonne ; Calorific value of coal = 5500 kcal/kg ; Rate of interest and depreciation = 12 per cent ; plant heat rate = 33000 kcal/kWh at 100% capacity factor. Calculate the generating cost/kWh at 100% capacity factor. **[Ans.** 39.77 p/kWh]

25. An input output curve of a 10 MW thermal station is given by an equation

$$I = 10^6(18 + 12L + 0.5L^2) \text{ kcal/hour}$$

where I is in kcal/hour and L is the load on power plant in MW.

Find : (*i*) The load at which the efficiency of the plant will be maximum.

(*ii*) The increase in output required to increase the station output from 5 MW to 7 MW by using the input-output equation and by incremental rate curve. **[Ans.** (*i*) 6 MW (*ii*) 36×10^6 kcal/hour]

26. The input-output curve of a 60 MW power station is given by :

$$I = 10^6(8 + 8L + 0.4L^2) \text{ kcal/hour}$$

where I is the input in kcal/hour and L is load in MW.

(*i*) Determine the heat input per day to the power station if it works for 20 hours at full load and remaining period at no load.

(*ii*) Also find the saving per kWh of energy produced if the plant works at full load for all 24 hours generating the same amount of energy. **[Ans.** (*i*) 38592×10^6 kcal/day (*ii*) 4000 kcal/kWh]

27. The incremental fuel costs for two generating units 1 and 2 of a power plant are given by the following equations :

$$\frac{dF_1}{dP_1} = 0.06P_1 + 11.4$$

$$\frac{dF_2}{dP_2} = 0.07P_2 + 10$$

where P is in megawatts and F is in rupees per hour.

(*i*) Find the economic loading of the two units when the total load to be supplied by the power station is 150 MW.

(*ii*) Find the loss in fuel costs per hour if the load is equally shared by the two units.

[**Ans.** (*i*) $P_1 = 70$ MW, $P_2 = 80$ MW (*ii*) Rs. 1.63 per hour]

28. The incremental fuel costs for two generating units 1 and 2 of a power plant are given by the following equations :

$$\frac{dF_1}{dP_1} = 0.065P_1 + 25$$

$$\frac{dF_2}{dP_2} = 0.08P_2 + 20$$

where F is fuel cost in rupees per hour and P is power output in MW. Find :

(*i*) the economic loading of the two units when the total load supplied by the power plants is 160 MW.

(*ii*) the loss in fuel cost per hour if the load is equally shared by both units.

[**Ans.** $P_1 = 53.5$ MW, $P_2 = 106.5$ MW (*ii*) Rs. 35/hour]

29. Two steam turbines each of 20 MW capacity take a load of 30 MW. The steam consumption rates in kg per hour for both turbines are given by the following equations :

$$S_1 = 2000 + 10L_1 - 0.0001L_1^2$$

$$S_2 = 1000 + 7L_2 - 0.00005L_2^2$$

L represents the load in kW and S represents the steam consumption per hour.

Find the most economical loading when the load taken by both units is 30 MW.

[**Ans.** $L_1 = 20$ MW, $L_2 = 10$ MW]

30. Two electrical units used for the same purpose are compared for their economical working :

(*i*) Cost of Unit-1 is Rs. 5000 and it takes 100 kW.

(*ii*) Cost of Unit-2 is Rs. 14000 and it takes 60 kW.

Each of them has a useful life of 40000 hours. Which unit will prove economical if the energy is charged at Rs. 80 per kW of maximum demand per year and 5 p. per kWh ?

Assume both units run at full load.

[**Ans.** Unit-1 : Rs. 6.039 ; Unit-2 : Rs. 3.898, Unit-2 is more economical]

31. A new industry requires maximum demand of 800 kW at 30% load factor. The following two power supplies are available :

(*i*) *Public supply* charges Rs. 50/kW of maximum demand and 4 p. per kWh.

Capital cost	= Rs. 80000
Interest and depreciation	= 10 per cent.

(*ii*) *Private oil engine generating station.*

Capital cost	= Rs. 30000
Interest and depreciation	= 12 per cent
Maintenance and labour charges	= 1 p. per kWh energy generated
Fuel consumption	= 0.35 kg/kWh
Cost of fuel	= 8 paise/kg.

Find which supply will be more economical ?

[**Ans.** (*i*) 6.3 p/kWh (*ii*) 5.1 p/kWh ; oil engine generation is more preferable]

32. A load having a maximum demand of 80 MW and a load factor of 40% may be supplied by one of the following schemes :

(*i*) A steam station capable of supplying the whole load.

(*ii*) A steam station in conjunction with pump-storage plant which is capable of supplying 120×10^6 kWh energy per year with a maximum output of 30 MW.

Find out the cost of energy per unit in each of the two cases mentioned above. Use the following data :

Capital cost of steam station = Rs. 1800/kW of installed capacity ; Capital cost of pump storage plant = Rs. 1200/kW of installed capacity ; Operating cost of steam plant = 0.5 p/kWh ; Operating cost of pump storage plant = 0.4 p./kWh.

Interest and depreciation together on capital invested should be taken as 12 per cent.
Assume that no spare capacity is required. **[Ans.** (*i*) 11.16 p./kWh (*ii*) 8.42 p./kWh]

33. The monthly electricity consumption of a residence can be approximated as under :
Light load : 4 tube lights 40 watts each working for 3 hours daily ; *Fan load* : 4 fans 100 watts each working for 5 hours daily ; *Refrigerator load* : 1 kWh daily ; *Miscellaneous load* : 1 kW for one hour daily.
Find the monthly bill at the following tariff :
First 15 units : Re. 0.50/kWh, Next 25 units : Re. 0.40 per kWh ; Remaining units : Re. 0.30 per kWh ; Constant charge : Rs. 2.50 per month. Discount for prompt payment = 5% . **[Ans.** Rs. 45.20]

34. An industrial undertaking has a connected load of 110 kW. The maximum demand is 90 kW. On an average each machine works for 60 per cent time. Find the yearly expenditure on electricity if the tariff is :
Rs. 1000 + Rs. 100 per kW of maximum demand per year + Re. 0.10 per kWh. **[Ans.** Rs. 67186]

35. A Hopkinson demand rate is quoted as follows :
Demand rates

First 1 kW of maximum demand	= Rs. 5/kW/month
Next 4 kW of maximum demand	= Rs. 4/kW/month
Excess over 5 kW of maximum demand	= Rs. 3/kW/month

Energy rates

First 50 kWh	= 6 paise/kWh
Next 50 kWh	= 4 paise/kWh
Next 200 kWh	= 3 paise/kWh
Next 400 kWh	= 2.5 paise/kWh
Excess over 700 kWh	= 2 paise/kWh

Determine : (*i*) The monthly bill for a total consumption of 1500 kWh and a maximum demand of 12 kW. Also find the unit energy cost.
(*ii*) Lowest possible bill for a month and corresponding unit energy cost.
[Ans. (*i*) Rs. 79, 5.26 paise/kWh (*ii*) Rs. 46.33, 3.09 paise/kWh]

36. Find the cost of generation per kWh from the following data :

Capacity of the plant	= 120 MW
Capital cost	= Rs. 1200 per kW installed
Interest and depreciation	= 10 per cent on capital
Fuel consumption	= 1.2 kg/kWh
Fuel cost	= Rs. 40 per tonne
Salaries, wages, repairs and maintenance	= Rs. 600000 per year
The maximum demand	= 80 MW
Load factor	= 40%.

[Ans. 10.18 paise/kWh]

37. The following data relate to a 2200 kW diesel power station :

The peak load on the plant	= 1600 kW
Load factor	= 45%
Capital cost per kW installed	= Rs. 1000
Annual costs	= 15 per cent of capital
Annual operating costs	= Rs. 60000
Annual maintenance cost :	
(*i*) Fixed	= Rs. 10000
(*ii*) Variable	= Rs. 20000
Cost of fuel	= Re. 0.4 per kg
Cost of lubricating oil	= Rs. 1.25 per kg
C.V. of fuel	= 10000 kcal/kg

Consumption of fuel = 0.5 kg/kWh
Consumption of lubricating oil = 0.0025 kg/kWh
Determine the following :
(*i*) The annual energy generated.
(*ii*) The cost of generation (per kWh). [**Ans.** (*i*) 6.3×10^6 kWh/year (*ii*) 27 paise/kWh]

38. The following data relate to a steam power station of 120 MW capacity which takes 100 MW peak demand at 80% load factor :
Annual cost towards interest and depreciation = Rs. 100/kW installed ; Operating costs = Rs. 1200×10^3/year ; Maintenance costs = Rs. 200×10^3/year (fixed) and = Rs. 400×10^3/year (variable) ; Miscellaneous costs = Rs. 100×10^3/year ; Cost of coal used = Rs. 32/ton ; C.V. of fuel used = 6400 kcal/kg ; Overall efficiency of the plant = 20 per cent ; Steam consumption in kg/kWh = (0.8 + 3.5 × load factor).
Determine the following :
(*i*) Coal cost per year.
(*ii*) Overall cost of generation (paise/kWh). [**Ans.** (*i*) Rs. 15×10^6/year (*ii*) 4.12 paise/kWh]

39. A power system requires a maximum load of 80 MW at 35% load factor. It can be supplied by any of the following schemes :
(*i*) A steam plant capable to supply whole load.
(*ii*) A steam plant with hydel plant where energy supplied by steam plant is 120×10^6 kWh/year with a maximum load of 50 MW.

Plant	Capital cost	Operating cost	Transmission cost
Steam plant	Rs. 600/kW installed	4.8 paise/kWh	Negligible
Hydro plant	Rs. 1400/kW installed	1.2 paise/kWh	0.3 paise/kWh

Assume interest and depreciation at 12 per cent of capital for steam plant and 10 per cent of capital for hydro plant. Calculate the overall cost per kWh.
(*iii*) If the whole load is supplied by a nuclear plant, determine annual cost. Take capital cost of Rs. 2500/kW and running cost of 2.5 paise/kWh. Assume interest and depreciation as 10 per cent per annum. [**Ans.** (*i*) 7.05 paise/kWh (*ii*) 5.98 paise/kWh (*iii*) 10.67 paise/kWh]

40. The following data relate to a power plant of 120 MW capacity :
Capital cost = Rs. 1500/kW ; Interest and depreciation = 10 per cent on capital ; Annual running charges = Rs. 20×10^6 ; Profit to be gained = 10 per cent of the capital ; The energy consumed by the power plant auxiliaries = 5 per cent of generated ; The annual load factor = 0.6 ; Annual capacity factor = 0.5.
Calculate the following :
(*i*) The reserve capacity.
(*ii*) The cost of generation per kWh. [**Ans.** (*i*) 20 MW (*ii*) 9.3 paise/kWh]

41. A small generating unit of 5,000 kW capacity supplies the following loads :
(*i*) Street-light load with maximum demand of 200 kW at 0.3 load factor.
(*ii*) Small industrial load with maximum demand of 1800 kW at a load factor of 0.5.
(*iii*) Domestic consumers with a maximum demand of 3000 kW at a load factor of 0.2.
Find the overall energy rate for each type of consumer using the following data :
Capital cost of the plant = Rs. 1,800/kW of installed capacity
Total running cost = Rs. 6,20,000 per year
Annual rate of depreciation and interest on capital cost is 10%.
[**Ans.** (*i*) 11.4 paise/kWh (*ii*) 8.65 paise/kWh (*iii*) 14.8 p/kWh]

42. The following data relate to a 15 MW thermal plant :
Capital cost of plant = Rs. 1200/kW ; Interest, insurance and depreciation = 10% of the plant ; Capital cost of primary and secondary distribution = Rs. 15×10^5 ; Interest, insurance and depreciation on the capital cost of primary and secondary distribution = 5% of capital cost ; Plant maintenance cost = Rs. 80×10^3 per year ; Maintenance cost of primary and secondary equipments = Rs. 2×10^5 per year ; Salaries and wages = Rs. 6×10^5 per year ; Consumption of coal = 40×10^3 tonnes per year ; Cost of coal

= Rs. 80 per tonne ; Dividend to stockholders = Rs. 12×10^5 per year ; Energy loss in transmission = 10% ; Diversity factor = 1.6 ; Load factor = 0.8 ; Maximum demand = 14 MW.

Devise a two-part tariff and find the average cost per kWh.

[**Ans.** Fixed charge per kW = 146, charge for energy consumption = 4.63 paise/kWh ; Average cost of supply = 8.1 paise/kWh]

43. The following data relate to a 12 MW capacity thermal plant :

Peak load	= 10 MW
Annual load factor	= 70%
Cost of the plant	= Rs. 700/kW installed capacity
Interest, insurance and depreciation	= 10 per cent of the capital cost
Cost of transmission and distribution system	= Rs. 300×10^3
Interest, depreciation on distribution system	= 5 per cent
Operating cost	= Rs. 300×10^3 per year
Cost of coal	= Rs. 50/ton
Plant maintenance cost	= Rs. 25,000 per year (fixed)
	= Rs. 35,000 per year (running)
Coal used	= 30,000 tons/year.

Assume transmission and distribution costs are to be charged to generation.

(*i*) Design a two-part tariff.

(*ii*) Determine overall cost of generation in paise/kWh.

[**Ans.** (*i*) Rs. 88/kW + 3 paise/kWh (*ii*) 4.43 paise/kWh]

44. Determine the load factor at which the cost of supplying a unit of electricity is same in Diesel station as in a Steam station if the respective annual fixed and running charges are as given below :

Diesel : Rs. (30/kW + 0.05/kWh)

Steam : Rs. (120/kW + 0.0125/kWh). [**Ans.** 0.275]

45. A 30 H.P. motor connected to a condensate pump has been burnt beyond economical repairs. Two alternatives have been proposed to replace it by :

	Cost	**η at full load**	**η at half load**
Motor A	Rs. 6000	90%	86%
Motor B	Rs. 4000	85%	82%

The life of each motor is 20 years and its salvage value is 10 per cent of the initial value. The rate of interest is 5 per cent annually. The motor operates at full load for 25 per cent of the time and at half load for the remaining period. The annual maintenance cost of motor *A* is Rs. 420 and that of motor *B* is Rs. 240. The energy rate is 10 paise/kWh.

Which motor will be economical ? [**Ans.** Motor A ; Total cost : Motor A = Rs. 14,777/year
Motor B = Rs. 15135/year]

46. The following proposals are under consideration for an industry which has a maximum demand of 50 MW and a load factor of 0.4.

(*i*) A steam plant having an initial cost of Rs. 1000/kW and maintenance cost is 2 paise/kWh. The coal of C.V. of 6150 kcal/kg is used. The overall efficiency of the plant is 25 percent.

(*ii*) A hydro-plant having a capital cost of Rs. 3000/kW and running cost of 0.5 paise/kWh.

Assuming interest and depreciation rate of 12 per cent for steam plant and 9 per cent for hydro-plant, determine the price of coal above which steam station is uneconomical. [**Ans.** Rs. 49.7/ton]

47. An industrial consumer has a choice between low and high voltage supply available at the following rates :

High voltage : Rs. 45/kW per year + paise 3.5/kWh

Low voltage : Rs. 47/kW per year + paise 4/kWh

In order to have high voltage supply, consumer has to install his own transformer which costs Rs. 100/kW. The losses in the transformer are 3 per cent of full load. Determine the number of working hours per week above which the high voltage supply will be economical. Assume interest and depreciation 10 per cent of capital and working weeks per year 50. Assume the load of the consumer as 1 MW.

[**Ans.** 49 hours per week]

48. The expected annual cost of power system supplying the energy to 40,000 consumers is tabulated below :

Fixed charges	= Rs. 2400×10^3
Energy charges	= Rs. 1716×10^3
Consumer charges	= Rs. 210×10^3
Profit	= Rs. 168×10^3
Maximum demand	= 5000 kW
Diversity factor	= 4
Energy supplied	= 17×10^6 kWh.

Devise a three-part tariff allowing 25% of the profit in fixed charges, 50% in energy charges and remaining 25% in customer charges.

[**Ans.** Rs. 122/kW per year + 11 paise/kWh + Rs. 6.3 per consumer per year]

COMPETITIVE EXAMINATIONS QUESTIONS

1. (*a*) Define 'connected load', 'maximum demand', 'demand factor' and 'load factor'. Explain the importance of each in total power system.

(*b*) What are the different methods of regulating voltage in a power supply system ?

2. (*a*) Define 'diversity factor' and state the advantages of diversity of load in a power system.

(*b*) What are the different methods used to meet the variable loads ? Explain in details.

3. Find the cost of generation per kWh from the following data :

Capacity of the plant	= 120 MW
Capital cost	= Rs. 1,200 per kW installed
Interest and depreciation	= 10% on capital
Fuel consumption	= 1.2 kg/kWh
Fuel Cost	= Rs. 40 per tonne
Salaries, wages, repair and maintenance	= Rs. 6,00,000 per year

The maximum demand is 80 MW and load factor is 40%.

4. (*a*) State the advantages of combined working of different types of power plants.

(*b*) State the function of control board equipment.

(*c*) Describe earthing of a power system.

5. A power plant has the following annual load factors :

Load factor	= 70%
Capacity factor	= 50%
Use factor	= 60%
Maximum demand	= 20 MW

Find out :

(*a*) Annual energy production ;

(*b*) Reserve capacity over and above peak load ;

(*c*) Hours during which the plant is not in service per year.

6. The motor of a 30 H.P. condensate pump has been burnt beyond economical repairs. Two alternatives have been proposed to replace it by :

Motor A	Cost	= Rs. 6,000
	η at full load	= 90%

	η at half load	= 86%
Motor B	Cost	= Rs. 4,000
	η at full load	= 85%
	η at half load	= 82%

The life of each motor is 20 years, and its salvage value is 10% of the initial cost. The rate of interest is 5% annually. The motor operates at full load for 25% of the time and at half load for the remaining period.

The annual maintenance cost of motor *A* is Rs. 420 and that of motor *B* is Rs. 240. The energy rate is 10 paise per kWh.

Which motor would you recommend ?

7. (*a*) Discuss in detail how the load between two alternators can be divided for best economy. Explain the effect of load factor of a plant on the cost/kWh generated.

(*b*) What are the functions of switch gears ? Discuss the advantages of outdoor installations over indoor switch gear installations.

8. A new industry requires a maximum demand of 800 kW at 30% load factor. The following two supplies are available :

(*a*) Public supply charges Rs. 50/kW of maximum demand and 4 paise/kWh. The capital cost is Rs. 80,000 and interest and depreciation charges are 10%.

(*b*) A private oil engine station requires a capital of Rs. 3,00,000. The interest and depreciation on capital is 12%. The maintenance and labour charges are 1 p/kWh of energy generated. The fuel consumption is 0.35 kg/kWh and cost of fuel is 8 paise/kg.

Find out which supply is more economical.

9. (*a*) Explain the principle of economic distribution of load between generating stations.

(*b*) A small generating unit of 5,000 kW capacity supplies the following loads :

(*i*) Domestic consumers with a maximum demand of 3,000 kW at a load factor of 20 per cent ;

(*ii*) Small industrial load with a maximum demand of 2,000 kW at a load factor of 50 per cent.

Find the overall energy rate for both types of consumers.

Use the following data :

Capital cost of the plant	= Rs. 2,000 per kW of installed capacity
Total running cost	= Rs. 6,00,000 per year

Annual rate of depreciation and interest on capital cost is 10 per cent.

10. (*a*) What are the advantages of combined working of thermal power plant and hydro-electric plant ? Discuss briefly the need for coordination of these plants in power system.

(*b*) The maximum demand of a factor is 1000 kW at 30% load factor. The following two power supplies are available :

(*i*) **Public supply :** It charges Rs. 80/kW of maximum demand and 5 p/kWh. The capital cost is Rs. 1,00,000 and depreciation charges on the capital are 12%.

(*ii*) **Private oil engine station :** It requires Rs. 4,00,000 as capital and depreciation on capital is 10%. The maintenance and labour charges are 2 p/kWh energy generated. The fuel consumption is 0.3 kg/kWh and fuel cost is 20 p/kg.

Determine which supply is more economical.

11. (*a*) What is the effect of variable load on the power plant design and operation ?

(*b*) The loads on a power plant with respect to time for 24 hours are listed below :

Time (Hrs) :	0—6	6—10	10—12	12—16	16—20	20—24
Load (MW) :	30	50	60	70	80	40

Draw the load curve and find out the load factor of the power plant. If the load above 50 MW are taken by a stand-by unit of 30 MW capacity, find out the load factor of the stand-by unit.

12. (*a*) Explain the principle of circuit interruption and its application in circuit brakers. Define the 'interruption capacity' and 'recovery voltage' of a circuit braker.

(*b*) What are the advantages of combined operation of power plants in a power system ? Explain with examples.

13. (*a*) Explain the effect of variable load on power plant operation and power plant design.

(*b*) The following data relate to a 10 MW thermal station :

Cost of plant	= Rs. 3,000 per kW
Interest and taxes on cost of plant	= 8% per anum
Depreciation of plant	= 5% per annum
Cost of primary distribution	= Rs. 800000
Interest, taxes, depreciation on cost of primary distribution system	= 5%
Cost of coal with transportation	= Rs. 100 per tonne
Operating cost	= Rs. 800000 per annum
Plant maintenance cost (*i*) fixed	= Rs. 40000 per annum
Plant maintenance cost (*ii*) variable	= Rs. 50000 per annum
Installed capacity of plant	= 10 MW
Maximum demand	= 9 MW
Annual load factor	= 70%
Consumption of coal per annum	= 25000 tonnes.

Find : (*i*) the fixed cost of power generation per kW per annum ; (*ii*) the total cost of power generation per kWh. Cost of primary distribution is chargeable to generation.

14. (*a*) What is meant by powers plant economics ? What are the fixed and operating costs ?

(*b*) The following data relate to steam power station of 120 MW capacity which takes 100 MW peak demand at 80% load factor (L.F.).

Annual cost towards the interest and depreciation	= Rs. 100/kW installed
Annual operating costs	= Rs. 1200×10^3
Annual maintenance costs	= Rs. 200×10^2 (fixed)
	= Rs. 400×10^3 (variable)
Annual miscellaneous costs	= Rs. 100×10^3
Cost of coal used	= Rs. 32/tonne
Calorific value of fuel used	= Rs. 6400 kcal/kg
Overall efficiency of the plant	= 20%
Steam consumption in kg/kWh	= $(0.8 + 3.5 \times \text{L.F.})$

Determine (*i*) costs per year and (*ii*) overall cost of generation paise/kWh.

(*c*) Explain the different methods used for finding out the depreciation cost of the power plant.

15. (*a*) Discuss the methods of determining the depreciation of electrical power plant.

(*b*) The following data for a 2200 kW diesel power station is given. The peak load on the plant is 1600 kW and its load factor is 45% :

Capital cost/kW installed	= Rs. 1000
Annual costs	= Rs. 15% of capital
Annual operating costs	= Rs. 60,000
Annual maintenance costs	= Fixed Rs. 10,000
	= Variable Rs. 20,000
Cost of fuel	= Rs. 0.4 per kg
Cost of lubricating oil	= Rs. 1.25 per kg
C.V. of fuel	= 10,000 kcal/kg
Consumption of fuel	= 0.5 kg/kWh
Consumption of lubricant oil	$= \frac{1}{400}$ kg/kWh

Determine (*i*) the annual energy generated and (*ii*) the cost of generation Rs./kWh.

16. (*a*) Explain with a neat sketch the water cooling system in diesel power plants using water softening plant and cooling tower.

(*b*) The annual costs of operating a 25 MW thermal plant are given below :

Capital cost of plant	= Rs. 1200/kW
Interest + insurance + depreciation	= 10% of plant cost
Capital cost of primary and secondary distribution	= Rs. 15 × 10^5
Interest + insurance + depreciation on the capital cost of primary and secondary distribution	= 5% of capital cost
Plant maintenance cost	= Rs. 80 × 10^3 per year
Maintenance cost of primary and secondary equipment	= Rs. 2 × 10^5 per year
Salaries and wages	= Rs. 6 × 10^5 per year
Consumption of coal	= 40 × 10^3 tonnes per year
Cost of coal	= Rs. 80 per tonne
Dividend to stockholders	= Rs. 12 × 10^5 per year
Energy loss in transmission	= 10%
Diversity factor	= 1.5
Load factor	= 80%
Maximum demand	= 14 MW.

Find the following :

(*i*) Total fixed cost ; (*ii*) Total variable charges ; (*iii*) Charges for energy consumption ; (*iv*) Average cost of supply.

17. (*a*) Explain load-duration curve. What are annual operating costs ? What are the factors that influence the depreciation of capital equipment ?

(*b*) The estimated total annual operating costs and capital charges for two power stations are given by the following expressions :

Annual cost for station *A* :

$$\text{Rs. } (10^5 + 60 \text{ kW} + 0.01 \text{ kWh})$$

Annual cost for station *B* :

$$\text{Rs. } (6 \times 10^4 + 35 \text{ kW} + 0.02 \text{ kWh})$$

where kW represents the capacity of the station and kWh represents the total annual energy generated.

The stations are to be used to supply a common load having annual load duration curve approximated by a straight line, maximum and minimum loads being 50 MW and zero respectively.

Find the following :

(*i*) Which station should be used to supply the peak load ?

(*ii*) What should be its installed capacity ?

(*iii*) For how many hours per year should it be in operation to give the minimum total cost per unit generated ?

Calculate also the total cost per unit generated under these conditions.

18. (*a*) What are fixed costs and operating costs ?

(*b*) Name the major items of fixed costs and operating costs.

(*c*) A new housing development is to be added to the lines of a public utility system. There are 1000 apartments, each having a connected load of 4 kW ; also stores and services are included as given below :

Stores or Services	Connected load in kW	Demand factor in per cent
Laundry, Drug stores, etc.	50	60
1 Restaurant	60	52
2 Churches	20 each	56
3 Theatre	100	50

The demand factor of the apartments is 45 per cent. The group diversity factor of the residential load for this system is 3.5 and the peak diversity factor is 1.4. The commercial load group diversity factor is 1.5 and the peak diversity factor is 1.1.

Find the increase in peak demand on the total system delivery from the station bus resulting from addition of this development on the distribution system. Assume line losses as 5 per cent of delivery energy.

19. (*a*) Define 'diversity factor' and state the advantages of the diversity load on a power supply system.

(*b*) A load having a maximum demand of 100 MW and a load factor of 30% may be supplied by one the following schemes :

Scheme A : A steam thermal plant capable of supplying the whole load.

Scheme B : A steam thermal plant in conjunction with a pump storage plant capable of supplying 108 kWh of energy per year with a maximum load of 40 MW.

Find the cost of energy per unit in each case.

Use the following data :

Capital cost of the steam plant	= Rs. 3000/kW of installed capacity
Capital cost of the pump storage plant	= Rs. 2000/kW of installed capacity
Operating cost of steam plant	= 20 p/kWh
Operating cost of pump storage plant	= 2 p/kWh

Interest and depreciation together on capital cost for both schemes = 15%

Assume reserve capacity of 20 MW for the steam plant in each scheme.

20. How do you define load factor, plant use factor and capacity factor ? What is the importance of diversity factor in the design of a steam power plant ?

21. (*a*) Explain the terms 'Maximum Demand' and 'Load Factor' with reference to a 'Power System'.

(*b*) A load having a maximum demand of 100 MW at 30% load factor may be supplied by one of the following schemes :

(*i*) A steam plant capable of supplying the whole load ;

(*ii*) A steam plant in conjunction with a pumped storage plant capable of supplying 10^6 kWh energy per year with a maximum load of 40 MW.

Using the following data, find the most economic scheme among the two

Capital cost of steam station is Rs. 1000/kW of installed capacity.

Capital cost of pumped storage plant is Rs. 700/kW of installed capacity. Operating cost of steam station = 2.5 NP/kWh. Interest and depreciation together on capital cost is 15%. Assume no reserve capacity is required for both the schemes.