CONTENTS

CHAPTER

3

Variable Load on Power Stations

Introduction

The function of a power station is to deliver power to a large number of consumers. However, the power demands of different consumers vary in accordance with their activities. The result of this variation in demand is that load on a power station is never constant, rather it varies from time to time. Most of the complexities of modern power plant operation arise from the inherent variability of the load demanded by the users. Unfortunately, electrical power cannot be stored and, therefore, the power station must produce power as and when demanded to meet the requirements of the consumers. On one hand, the power engineer would like that the alternators in the power station should run at their rated capacity for maximum efficiency and on the other hand, the demands of the consumers have wide variations. This makes the design of a power station highly complex. In this chapter, we shall focus our attention on the problems of variable load on power stations.

3.1 Structure of Electric Power System

The function of an electric power system is to connect the power station to the consumers' loads

CONTENTS

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3.1 Structure of Electric Power System

The function of an electric power system is to connect the power station to the consumers' loads

(iv) The power demanded by the consumers is supplied by the power station through the transmission and distribution networks. As the consumers' load demand changes, the power supply by the power station changes accordingly.

Transmission line

3.2 Variable Load on Power Station

The load on a power station varies from time to time due to uncertain demands of the consumers and is known as **variable load on the station.**

A power station is designed to meet the load requirements of the consumers. An ideal load on the station, from stand point of equipment needed and operating routine, would be one of constant magnitude and steady duration. However, such a steady load on the station is never realised in actual practice. The consumers require their small or large block of power in accordance with the demands of their activities. Thus the load demand of one consumer at any time may be different from that of the other consumer. The result is that load on the power station varies from time to time.

Effects of variable load. The variable load on a power station introduces many perplexities in its operation. Some of the important effects of variable load on a power station are :

(i) **Need of additional equipment.** The variable load on a power station necessitates to have additional equipment. By way of illustration, consider a steam power station. Air, coal and water are the raw materials for this plant. In order to produce variable power, the supply of these materials will be required to be varied correspondingly. For instance, if the power demand on the plant increases, it must be followed by the increased flow of coal, air and water to the boiler in order to meet the increased demand. Therefore, additional equipment has to be installed to accomplish this job. As a matter of fact, in a modern power plant, there is much equipment devoted entirely to adjust the rates of supply of raw materials in accordance with the power demand made on the plant.

(ii) **Increase in production cost.** The variable load on the plant increases the cost of the production of electrical energy. An alternator operates at maximum efficiency near its rated capacity. If a single alternator is used, it will have poor efficiency during periods of light loads on the plant. Therefore, in actual practice, a number of alternators of different capacities are installed so that most of the alternators can be operated at nearly full load capacity. However, the use of a number of generating units increases the initial cost per kW of the plant capacity as well as floor area required. This leads to the increase in production cost of energy.

3.3 Load Curves

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

The load on a power station is never constant; it varies from time to time. These load variations during the whole day (*i.e.*, 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as *daily load curve* as it shows the variations of load *w.r.t.* time during the day. Fig. 3.2. shows a typical daily load curve of a power station. It is clear that load on the power station is varying, being maximum at 6 P.M. in this case. It may be seen that load curve indicates at a glance the general character of the load that is being imposed on the plant. Such a clear representation cannot be obtained from tabulated figures.

The *monthly load curve* can be obtained from the daily load curves of that month. For this purpose, average* values of power over a month at different times of the day are calculated and then plotted on the graph. The monthly load curve is generally used to fix the rates of energy. The *yearly load curve* is obtained by considering the monthly load curves of that particular year. The yearly load curve is generally used to determine the annual load factor.

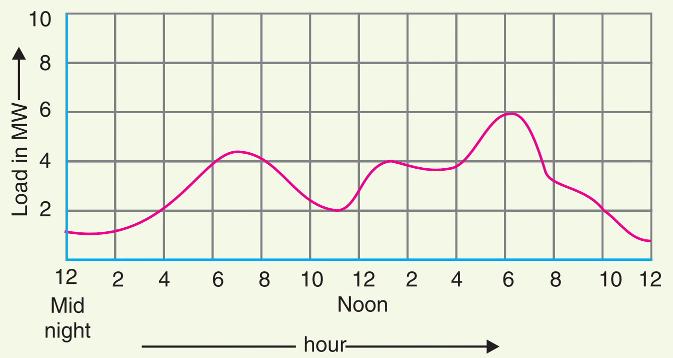


Fig. 3.2

Importance. The daily load curves have attained a great importance in generation as they supply the following information readily :

(i) The daily load curve shows the variations of load on the power station during different hours of the day.

(ii) The area under the daily load curve gives the number of units generated in the day.
Units generated/day = Area (in kWh) under daily load curve.

(iii) The highest point on the daily load curve represents the maximum demand on the station on that day.

(iv) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

$$\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{\text{24 hours}}$$

(v) The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{\text{Average load} \times 24}{\text{Max. demand} \times 24}$$

$$= \frac{\text{Area (in kWh) under daily load curve}}{\text{Total area of rectangle in which the load curve is contained}}$$

* For instance, if we consider the load on power station at mid-night during the various days of the month, it may vary slightly. Then the average will give the load at mid-night on the monthly curve.

(*vi*) The load curve helps in selecting* the size and number of generating units.

(*vii*) The load curve helps in preparing the operation schedule** of the station.

3.4 Important Terms and Factors

The variable load problem has introduced the following terms and factors in power plant engineering:

(*i*) **Connected load.** *It is the sum of continuous ratings of all the equipments connected to supply system.*

A power station supplies load to thousands of consumers. Each consumer has certain equipment installed in his premises. The sum of the continuous ratings of all the equipments in the consumer's premises is the "connected load" of the consumer. For instance, if a consumer has connections of five 100-watt lamps and a power point of 500 watts, then connected load of the consumer is $5 \times 100 + 500 = 1000$ watts. The sum of the connected loads of all the consumers is the connected load to the power station.

(*ii*) **Maximum demand** : *It is the greatest demand of load on the power station during a given period.*

The load on the power station varies from time to time. The maximum of all the demands that have occurred during a given period (*say* a day) is the maximum demand. Thus referring back to the load curve of Fig. 3.2, the maximum demand on the power station during the day is 6 MW and it occurs at 6 P.M. Maximum demand is generally less than the connected load because all the consumers do not switch on their connected load to the system at a time. The knowledge of maximum demand is very important as it helps in determining the installed capacity of the station. The station must be capable of meeting the maximum demand.

Maximum demand meter

(*iii*) **Demand factor.** *It is the ratio of maximum demand on the power station to its connected load i.e.,*

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

The value of demand factor is usually less than 1. It is expected because maximum demand on the power station is generally less than the connected load. If the maximum demand on the power station is 80 MW and the connected load is 100 MW, then demand factor = 80/100 = 0·8. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

Energy meter

(*iv*) **Average load.** *The average of loads occurring on the power station in a given period (day or month or year) is known as* **average load** *or* **average demand.**

* It will be shown in Art. 3.9 that number and size of the generating units are selected to fit the load curve. This helps in operating the generating units at or near the point of maximum efficiency.

** It is the sequence and time for which the various generating units (*i.e.*, alternators) in the plant will be put in operation.

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

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

$$\text{Yearly average load} = \frac{\text{No. of units (kWh) generated in a year}}{\text{8760 hours}}$$

(*v*) Load factor. *The ratio of average load to the maximum demand during a given period is known as* **load factor** *i.e.*,

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

If the plant is in operation for T hours,

$$\text{Load factor} = \frac{\text{Average load} \times \text{T}}{\text{Max. demand} \times \text{T}}$$

$$= \frac{\text{Units generated in T hours}}{\text{Max. demand} \times \text{T hours}}$$

The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year. Load factor is always less than 1 because average load is smaller than the maximum demand. The load factor plays key role in determining the overall cost per unit generated. Higher the load factor of the power station, lesser* will be the cost per unit generated.

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

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$$

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

(*vii*) Plant capacity factor. *It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period i.e.*,

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

$$= \frac{\text{Average demand} \times \text{T}^{**}}{\text{Plant capacity} \times \text{T}}$$

$$= \frac{\text{Average demand}}{\text{Plant capacity}}$$

---

* It is because higher load factor factor means lesser maximum demand. The station capacity is so selected that it must meet the maximum demand. Now, lower maximum demand means lower capacity of the plant which, therefore, reduces the cost of the plant.

† There is diversification in the individual maximum demands *i.e.*, the maximum demand of some consumers may occur at one time while that of others at some other time. Hence, the name diversity factor

‡ Greater diversity factor means lesser maximum demand. This in turn means that lesser plant capcity is required. Thus, the capital investment on the plant is reduced.

** Suppose the period is *T* hours.

Thus if the considered period is one year,

$$\text{Annual plant capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity} \times 8760}$$

The plant capacity factor is an indication of the reserve capacity of the plant. A power station is so designed that it has some reserve capacity for meeting the increased load demand in future. Therefore, the installed capacity of the plant is always somewhat greater than the maximum demand on the plant.

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

It is interesting to note that difference between load factor and plant capacity factor is an indication of reserve capacity. If the maximum demand on the plant is equal to the plant capacity, then load factor and plant capacity factor will have the same value. In such a case, the plant will have no reserve capacity.

(*viii*) Plant use factor. *It is ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation i.e.*

$$\text{Plant use factor} = \frac{\text{Station output in kWh}}{\text{Plant capacity} \times \text{Hours of use}}$$

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

$$\text{Plant use factor} = \frac{7{\cdot}35 \times 10^6}{(20 \times 10^3) \times 2190} = 0{\cdot}167 = 16{\cdot}7\%$$

3.5 Units Generated per Annum

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

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

$$\therefore \quad \text{Average load} = \text{Max. demand} \times \text{L.F.}$$

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

$$= \text{Max. demand (in kW)} \times \text{L.F.} \times 8760$$

3.6 Load Duration Curve

When the load elements of a load curve are arranged in the order of descending magnitudes, the curve thus obtained is called a **load duration curve.**

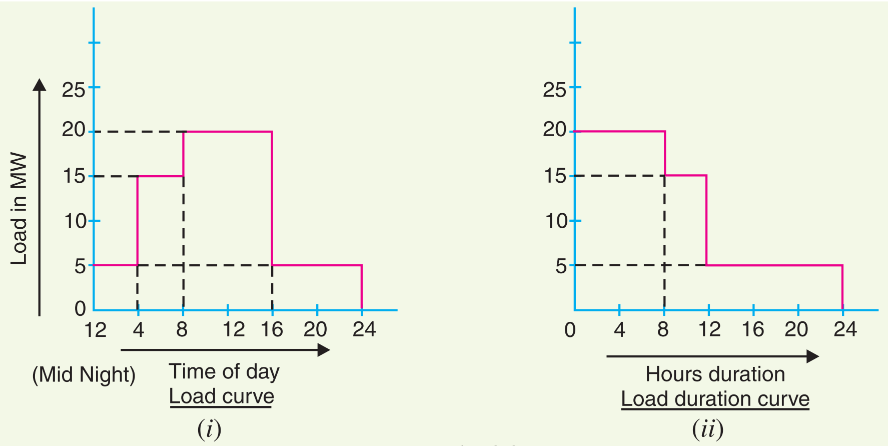


Fig. 3.3

The load duration curve is obtained from the same data as the load curve but the ordinates are arranged in the order of descending magnitudes. In other words, the maximum load is represented to the left and decreasing loads are represented to the right in the descending order. Hence the area under the load duration curve and the area under the load curve are equal. Fig. 3.3 (*i*) shows the daily load curve. The daily load duration curve can be readily obtained from it. It is clear from daily load curve [See Fig. 3.3. (*i*)], that load elements in order of descending magnitude are : 20 MW for 8 hours; 15 MW for 4 hours and 5 MW for 12 hours. Plotting these loads in order of descending magnitude, we get the daily load duration curve as shown in Fig. 3.3 (*ii*).

The following points may be noted about load duration curve :

(*i*) The load duration curve gives the data in a more presentable form. In other words, it readily shows the number of hours during which the given load has prevailed.

(*ii*) The area under the load duration curve is equal to that of the corresponding load curve. Obviously, area under daily load duration curve (in kWh) will give the units generated on that day.

(*iii*) The load duration curve can be extended to include any period of time. By laying out the abscissa from 0 hour to 8760 hours, the variation and distribution of demand for an entire year can be summarised in one curve. The curve thus obtained is called the *annual load duration curve.*

3.7 Types of Loads

A device which taps electrical energy from the electric power system is called a load on the system. The load may be resistive (*e.g.*, electric lamp), inductive (*e.g.*, induction motor), capacitive or some combination of them. The various types of loads on the power system are :

(*i*) **Domestic load.** Domestic load consists of lights, fans, refrigerators, heaters, television, small motors for pumping water etc. Most of the residential load occurs only for some hours during the day (*i.e.*, 24 hours) *e.g.*, lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%).

(*ii*) **Commercial load.** Commercial load consists of lighting for shops, fans and electric appliances used in restaurants etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of air-conditioners and space heaters.

(*iii*) **Industrial load.** Industrial load consists of load demand by industries. The magnitude of industrial load depends upon the type of industry. Thus small scale industry requires load upto 25 kW, medium scale industry between 25kW and 100 kW and large-scale industry requires load above 500 kW. Industrial loads are generally not weather dependent.

(*iv*) **Municipal load.** Municipal load consists of street lighting, power required for water supply and drainage purposes. Street lighting load is practically constant throughout the hours of the night. For water supply, water is pumped to overhead tanks by pumps driven by electric motors. Pumping is carried out during the off-peak period, usually occurring during the night. This helps to improve the load factor of the power system.

(*v*) **Irrigation load.** This type of load is the electric power needed for pumps driven by motors to supply water to fields. Generally this type of load is supplied for 12 hours during night.

(*vi*) **Traction load.** This type of load includes tram cars, trolley buses, railways etc. This class of load has wide variation. During the morning hour, it reaches peak value because people have to go to their work place. After morning hours, the load starts decreasing and again rises during evening since the people start coming to their homes.

3.8 Typical Demand and Diversity Factors

The demand factor and diversity factor depend on the type of load and its magnitude.

TYPICAL DEMAND FACTORS

Type of consumer		**Demand factor**
Residence lighting	$\frac{1}{4}$ kW	1·00
	$\frac{1}{2}$ kW	0·60
	Over 1 kW	0·50
Commercial lighting	Restaurants	0·70
	Theatres	0·60
	Hotels	0·50
	Schools	0·55
	Small industry	0·60
	Store	0·70
General power service	0–10 H.P.	0·75
	10–20 H.P.	0·65
	20–100 H.P.	0·55
	Over 100 H.P.	0·50

TYPICAL DIVERSITY FACTORS

	Residential lighting	*Commercial lighting*	*General power supply*
Between consumers	3 – 4	1·5	1·5
Between transformers	1·3	1·3	1·3
Between feeders	1·2	1·2	1·2
Between substations	1·1	1·1	1·1

Illustration. Load and demand factors are always less than 1 while diversity factors are more than unity. High load and diversity factors are the desirable qualities of the power system. Indeed, these factors are used to predict the load. Fig. 3.4 shows a small part of electric power system where a distribution transformer is supplying power to the consumers. For simplicity, only three consumers *a*, *b*, and *c* are shown in the figure. The maximum demand of consumer *a* is the product of its connected load and the appropriate demand factor. Same is the case for consumers *b* and *c*. The maximum demand on the transformer is the sum of *a*, *b* and *c*'s maximum demands divided by the diversity factors between the consumers. Similarly, the maximum demand on the feeder is the sum of maximum demands on the distribution transformers connected to it divided by the diversity factor between transformers. Likewise diversification between feeders is recognised when obtaining substation maximum demands and substation diversification when predicting maximum load on the power station. Note that diversity factor is the sum of the individual maximum demands of the subdivisions of a system taken as they may occur during the daily cycle divided by the maximum simultaneous demand of the system. The "system" may be a group of consumers served by a certain transformer, a group of transformers served by a feeder etc. Since individual variations have diminishing effect as one goes

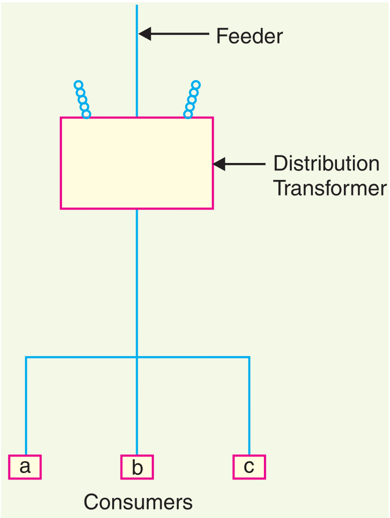


Fig. 3.4

farther from the ultimate consumer in making measurements, one should expect decreasing numerical values of diversity factor as the power plant end of the system is approached. This is clear from the above table showing diversity factors between different elements of the power system.

Example 3.1. *The maximum demand on a power station is 100 MW. If the annual load factor is 40% , calculate the total energy generated in a year.*

Solution.

$$\text{Energy generated/year} = \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}$$
$$= (100 \times 10^3) \times (0{\cdot}4) \times (24 \times 365) \text{ kWh}$$
$$= \mathbf{3504 \times 10^5 \text{ kWh}}$$

Example 3.2. *A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being 61·5 × 10^6 per annum. Calculate (i) the demand factor and (ii) load factor.*

Solution.

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

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

$$\therefore \quad \text{Load factor} = \frac{\text{Average demand}}{\text{Max. demand}} = \frac{7020}{20 \times 10^3} = \mathbf{0{\cdot}351} \text{ or } \mathbf{35{\cdot}1\%}$$

Example 3.3. *A 100 MW power station delivers 100 MW for 2 hours, 50 MW for 6 hours and is shut down for the rest of each day. It is also shut down for maintenance for 45 days each year. Calculate its annual load factor.*

Solution.

Energy supplied for each working day

$$= (100 \times 2) + (50 \times 6) = 500 \text{ MWh}$$

$$\text{Station operates for} = 365 - 45 = 320 \text{ days in a year}$$

$$\therefore \quad \text{Energy supplied/year} = 500 \times 320 = 160{,}000 \text{ MWh}$$

$$\text{Annual load factor} = \frac{\text{MWh supplied per annum}}{\text{Max. demand in MW} \times \text{Working hours}} \times 100$$
$$= \frac{160{,}000}{(100) \times (320 \times 24)} \times 100 = \mathbf{20{\cdot}8\%}$$

Example 3.4. *A generating station has a maximum demand of 25MW, a load factor of 60%, a plant capacity factor of 50% and a plant use factor of 72%. Find (i) the reserve capacity of the plant (ii) the daily energy produced and (iii) maximum energy that could be produced daily if the plant while running as per schedule, were fully loaded.*

Solution.

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

or $$0{\cdot}60 = \frac{\text{Average demand}}{25}$$

$$\therefore \quad \text{Average demand} = 25 \times 0{\cdot}60 = 15 \text{ MW}$$

$$\text{Plant capacity factor} = \frac{\text{Average demand}}{\text{Plant capacity}}$$

$$\therefore \quad \text{Plant capacity} = \frac{\text{Average demand}}{\text{Plant capacity factor}} = \frac{15}{0{\cdot}5} = 30 \text{ MW}$$

$\therefore$ Reserve capacity of plant = Plant capacity – maximum demand

= 30 – 25 = **5 MW**

(ii) Daily energy produced = Average demand × 24

= 15 × 24 = **360 MWh**

(iii) Maximum energy that could be produced

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

$$= \frac{360}{0 \cdot 72} = \textbf{500 MWh/day}$$

Example 3.5. *A diesel station supplies the following loads to various consumers :*

Industrial consumer = 1500 kW ; Commercial establishment = 750 kW

Domestic power = 100 kW; Domestic light = 450 kW

If the maximum demand on the station is 2500 kW and the number of kWh generated per year is 45×10^5*, determine (i) the diversity factor and (ii) annual load factor.*

Solution.

(i) Diversity factor $= \dfrac{1500 + 750 + 100 + 450}{2500} = \textbf{1·12}$

(ii) Average demand $= \dfrac{\text{kWh generated / annum}}{\text{Hours in a year}} = 45 \times 10^5/8760 = 513·7$ kW

$\therefore$ Load factor $= \dfrac{\text{Average load}}{\text{Max. demand}} = \dfrac{513 \cdot 7}{2500} = 0·205 = \textbf{20·5\%}$

Example 3.6. *A power station has a maximum demand of 15000 kW. The annual load factor is 50% and plant capacity factor is 40%. Determine the reserve capacity of the plant.*

Solution.

Energy generated/annum = Max. demand × L.F. × Hours in a year

= (15000) × (0·5) × (8760) kWh

= $65·7 \times 10^6$ kWh

Plant capacity factor $= \dfrac{\text{Units generated / annum}}{\text{Plant capacity} \times \text{Hours in a year}}$

$\therefore$ Plant capacity $= \dfrac{65 \cdot 7 \times 10^6}{0 \cdot 4 \times 8760} = 18{,}750$ kW

Reserve capacity = Plant capacity – Max. demand

= 18,750 – 15000 = **3750 kW**

Example 3.7. *A power supply is having the following loads :*

Type of load	*Max. demand (k W)*	*Diversity of group*	*Demand factor*
Domestic	*1500*	*1·2*	*0·8*
Commercial	*2000*	*1·1*	*0·9*
Industrial	*10,000*	*1·25*	*1*

If the overall system diversity factor is 1·35, determine (i) the maximum demand and (ii) connected load of each type.

Solution.

(i) The sum of maximum demands of three types of loads is = 1500 + 2000 + 10,000 = 13,500 kW. As the system diversity factor is 1·35,

$\therefore$ Max. demand on supply system = 13,500/1·35 = **10,000 kW** (*ii*) Each type of load has its own diversity factor among its consumers.

Sum of max. demands of different domestic consumers

$= \text{Max. domestic demand} \times \text{diversity factor}$

$= 1500 \times 1{\cdot}2 = 1800 \text{ kW}$

$\therefore$ Connected domestic load $= 1800/0{\cdot}8 =$ **2250 kW**

Connected commercial load $= 2000 \times 1{\cdot}1/0{\cdot}9 =$ **2444 kW**

Connected industrial load $= 10{,}000 \times 1{\cdot}25/1 =$ **12,500 kW**

Example 3.8. *At the end of a power distribution system, a certain feeder supplies three distribution transformers, each one supplying a group of customers whose connected loads are as under:*

Transformer	*Load*	*Demand factor*	*Diversity of groups*
Transformer No. 1	*10 kW*	*0·65*	*1·5*
Transformer No. 2	*12 kW*	*0·6*	*3·5*
Transformer No. 3	*15 kW*	*0·7*	*1·5*

If the diversity factor among the transformers is 1·3, find the maximum load on the feeder.

Solution. Fig. 3.5 shows a feeder supplying three distribution transformers.

Sum of max. demands of customers on Transformer 1

$= \text{connected load} \times \text{demand factor} = 10 \times 0{\cdot}65 = 6{\cdot}5 \text{ kW}$

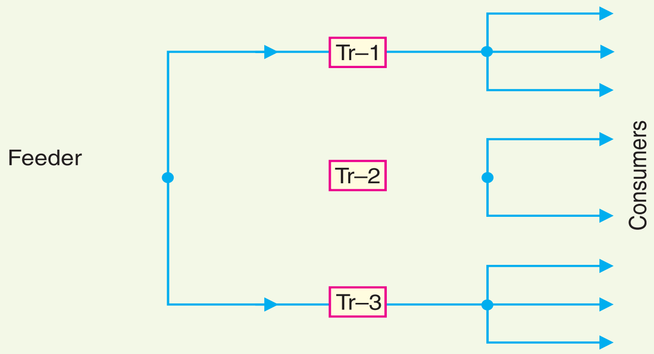


Fig. 3.5

As the diversity factor among consumers connected to transformer No. 1 is 1·5,

$\therefore$ Maximum demand on Transformer 1 $= 6{\cdot}5/1{\cdot}5 = 4{\cdot}33 \text{ kW}$

Maximum demand on Transformer 2 $= 12 \times 0{\cdot}6/3{\cdot}5 = 2{\cdot}057 \text{ kW}$

Maximum demand on Transformer 3 $= 15 \times 0{\cdot}7/1{\cdot}5 = 7 \text{ kW}$

As the diversity factor among transformers is 1·3,

$\therefore$ Maximum demand on feeder $= \dfrac{4{\cdot}33 + 2{\cdot}057 + 7}{1{\cdot}3} =$ **10·3 kW**

Example 3.9. *It has been desired to install a diesel power station to supply power in a suburban area having the following particulars :*

(*i*) *1000 houses with average connected load of 1·5 kW in each house. The demand factor and diversity factor being 0·4 and 2·5 respectively.*

(*ii*) *10 factories having overall maximum demand of 90 kW.*

(*iii*) *7 tubewells of 7 kW each and operating together in the morning.*

The diversity factor among above three types of consumers is 1·2. What should be the minimum capacity of power station ?

Solution.

Sum of max. demands of houses $= (1{\cdot}5 \times 0{\cdot}4) \times 1000 = 600$ kW

Max. demand for domestic load $= 600/2{\cdot}5 = 240$ kW

Max. demand for factories $= 90$ kW

Max. demand for tubewells $= 7^* \times 7 = 49$ kW

The sum of maximum demands of three types of loads is = 240 + 90 + 49 = 379 kW. As the diversity factor among the three types of loads is 1·2,

∴ Max. demand on station $= 379/1{\cdot}2 = 316$ kW

∴ Minimum capacity of station requried = **316 kW**

Example 3.10. *A generating station has the following daily load cycle :*

Time (Hours)	*0—6*	*6—10*	*10—12*	*12—16*	*16—20*	*20—24*
Load (M W)	*40*	*50*	*60*	*50*	*70*	*40*

Draw the load curve and find (i) maximum demand (ii) units generated per day (iii) average load and (iv) load factor.

Solution. Daily curve is drawn by taking the load along Y-axis and time along X-axis. For the given load cycle, the load curve is shown in Fig. 3.6.

(i) It is clear from the load curve that maximum demand on the power station is 70 MW and occurs during the period 16—20 hours.

∴ Maximum demand = **70 MW**

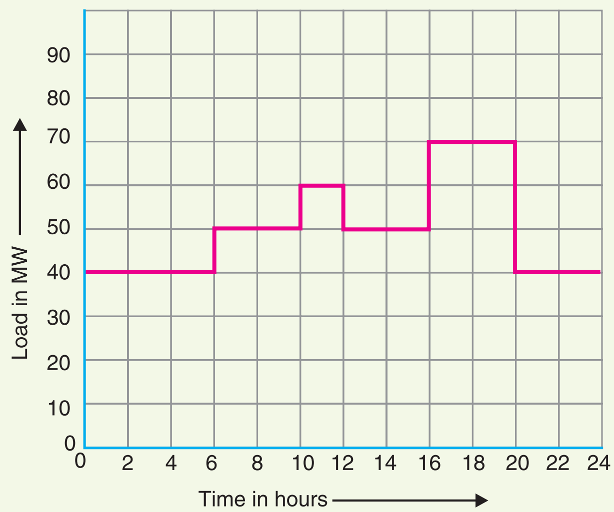


Fig. 3.6

(ii) Units generated/day = Area (in kWh) under the load curve

$= 10^3\,[40 \times 6 + 50 \times 4 + 60 \times 2 + 50 \times 4 + 70 \times 4 + 40 \times 4]$

$= 10^3\,[240 + 200 + 120 + 200 + 280 + 160]$ kWh

$=$ **12×10^5 kWh**

(iii) Average load $= \dfrac{\text{Units generated / day}}{24 \text{ hours}} = \dfrac{12 \times 10^5}{24} =$ **50,000 kW**

(iv) Load factor $= \dfrac{\text{Average load}}{\text{Max. demand}} = \dfrac{50{,}000}{70 \times 10^3} = 0{\cdot}714 =$ **71·4%**

* Since the tubewells operate together, the diversity factor is 1.

Example 3.11. *A power station has to meet the following demand :*

Group A : 200 kW between 8 A.M. and 6 P.M.

Group B : 100 kW between 6 A.M. and 10 A.M.

Group C : 50 kW between 6 A.M. and 10 A.M.

Group D : 100 kW between 10 A.M. and 6 P.M. and then between 6 P.M. and 6 A.M.

Plot the daily load curve and determine (i) diversity factor (ii) units generated per day (iii) load factor.

Solution. The given load cycle can be tabulated as under :

Time (Hours)	0—6	6—8	8—10	10—18	18—24
Group A	—	—	200 kW	200 kW	—
Group B	—	100 kW	100 kW	—	—
Group C	—	50 kW	50 kW	—	—
Group D	100 kW	—	—	100 kW	100 kW
Total load on power station	100 kW	150 kW	350 kW	300 kW	100 kW

From this table, it is clear that total load on power station is 100 kW for 0—6 hours, 150 kW for 6—8 hours, 350 kW for 8—10 hours, 300 kW for 10—18 hours and 100 kW for 18—24 hours. Plotting the load on power station versus time, we get the daily load curve as shown in Fig. 3.7. It is clear from the curve that maximum demand on the station is 350 kW and occurs from 8 A.M. to 10 A. M. *i.e.,*

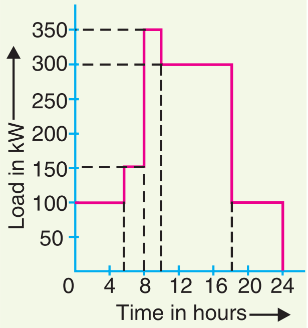


Fig. 3.7

Maximum demand = 350 kW

Sum of individual maximum demands of groups

= 200 + 100 + 50 + 100

= 450 kW

(*i*) Diversity factor $= \dfrac{\text{Sum of individual max. demands}}{\text{Max. demand on station}} = 450/350 =$ **1·286**

(*ii*) Units generated/day = Area (in kWh) under load curve

$= 100 \times 6 + 150 \times 2 + 350 \times 2 + 300 \times 8 + 100 \times 6$

= **4600 kWh**

(*iii*) Average load = 4600/24 = 191·7 kW

∴ Load factor $= \dfrac{191\cdot 7}{350} \times 100 =$ **54·8%**

Example 3.12. *The daily demands of three consumers are given below :*

Time	*Consumer 1*	*Consumer 2*	*Consumer 3*
12 midnight to 8 A.M.	*No load*	*200 W*	*No load*
8 A.M. to 2 P.M.	*600 W*	*No load*	*200 W*
2 P.M. to 4 P.M.	*200 W*	*1000 W*	*1200 W*
4 P.M. to 10 P.M.	*800 W*	*No load*	*No load*
10 P.M. to midnight	*No load*	*200 W*	*200 W*

Plot the load curve and find (i) maximum demand of individual consumer (ii) load factor of individual consumer (iii) diversity factor and (iv) load factor of the station.

Solution. Fig. 3.8 shows the load curve.

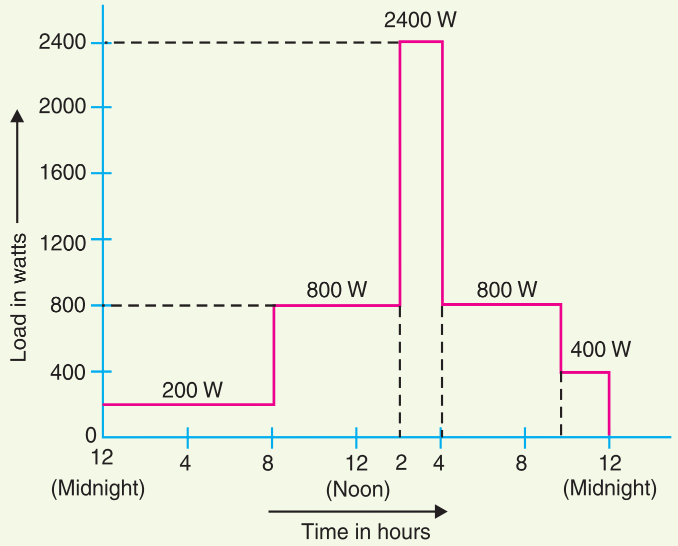


Fig. 3.8

(*i*) Max. demand of consumer 1 = **800 W**

Max. demand of consumer 2 = **1000 W**

Max. demand of consumer 3 = **1200 W**

(*ii*) L.F. of consumer 1 $= \dfrac{\text{Energy consumed / day}}{\text{Max. demand} \times \text{Hours in a day}} \times 100$

$= \dfrac{600 \times 6 + 200 \times 2 + 800 \times 6}{800 \times 24} \times 100 = \mathbf{45{\cdot}8\%}$

L.F. of consumer 2 $= \dfrac{200 \times 8 + 1000 \times 2 + 200 \times 2}{1000 \times 24} \times 100 = \mathbf{16{\cdot}7\%}$

L.F. of consumer 3 $= \dfrac{200 \times 6 + 1200 \times 2 + 200 \times 2}{1200 \times 24} \times 100 = \mathbf{13{\cdot}8\%}$

(*iii*) The simultaneous maximum demand on the station is 200 + 1000 + 1200 = 2400 W and occurs from 2 P.M. to 4 P.M.

∴ Diversity factor $= \dfrac{800 + 1000 + 1200}{2400} = \mathbf{1{\cdot}25}$

(*iv*) Station load factor $= \dfrac{\text{Total energy consumed / day}}{\text{Simultaneous max. demand} \times 24} \times 100$

$= \dfrac{8800 + 4000 + 4000}{2400 \times 24} \times 100 = \mathbf{29{\cdot}1\%}$

Example 3.13. *A daily load curve which exhibited a 15-minute peak of 3000 kW is drawn to scale of 1 cm = 2 hours and 1 cm = 1000 kW. The total area under the load curve is measured by planimeter and is found to be 12 cm^2. Calculate the load factor based on 15-min. peak.*

Solution.

1 cm^2 of load curve represents 1000 × 2 = 2000 kWh

Average demand $= \dfrac{2000 \times \text{Area of load curve}}{\text{Hours in a day}} = 2000 \times \dfrac{12}{24} = 1000 \text{ kW}$

$\therefore$ Load factor $= \dfrac{1000}{3000} \times 100 =$ **33·3%**

Example 3.14. *A power station has a daily load cycle as under :*

260 MW for 6 hours ; 200 MW for 8 hours : 160 MW for 4 hours, 100 MW for 6 hours.

If the power station is equipped with 4 sets of 75 MW each, calculate (i) daily load factor (ii) plant capacity factor and (iii) daily requirement if the calorific value of oil used were 10,000 kcal/kg and the average heat rate of station were 2860 kcal/kWh.

Solution. Max. demand on the station is 260×10^3 kW.

$$\text{Units supplied/day} = 10^3 [260 \times 6 + 200 \times 8 + 160 \times 4 + 100 \times 6] = 4400 \times 10^3 \text{ kWh}$$

(i)
$$\text{Daily load factor} = \frac{4400 \times 10^3}{260 \times 10^3 \times 24} \times 100 = \textbf{70·5\%}$$

(ii)
$$\text{Average demand/day} = 4400 \times 10^3/24 = 1{,}83{,}333 \text{ kW}$$
$$\text{Station capacity} = (75 \times 10^3) \times 4 = 300 \times 10^3 \text{ kW}$$
$$\therefore \text{ Plant capacity factor} = \frac{1{,}83{,}333}{300 \times 10^3} \times 100 = \textbf{61·1 \%}$$

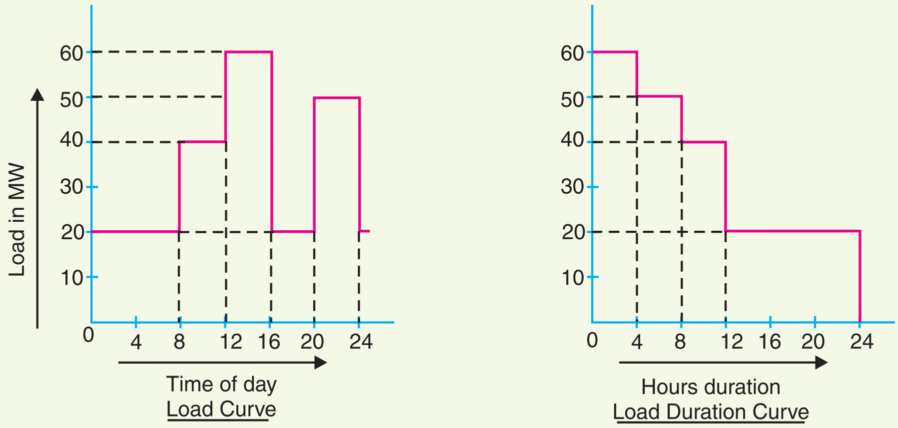
(iii)
$$\text{Heat required/day} = \text{Plant heat rate} \times \text{units per day} = (2860) \times (4400 \times 10^3) \text{ kcal}$$
$$\text{Fuel required/day} = \frac{2860 \times 4400 \times 10^3}{10000} = 1258{\cdot}4 \times 10^3 \text{ kg} = \textbf{1258·4 tons}$$

Example 3.15. *A power station has the following daily load cycle :*

Time in Hours	*6—8*	*8—12*	*12—16*	*16—20*	*20—24*	*24—6*
Load in MW	*20*	*40*	*60*	*20*	*50*	*20*

Plot the load curve and load duratoin curve. Also calculate the energy generated per day.

Solution. Fig. 3.9 (*i*) shows the daily load curve, whereas Fig. 3.9 (*ii*) shows the daily load duraton curve. It can be readily seen that area under the two load curves is the same. Note that load duration curve is drawn by arranging the loads in the order of descending magnitudes.



(*i*) **Fig. 3.9** (*ii*)

$$\text{Units generated/day} = \text{Area (in kWh) under daily load curve}$$
$$= 10^3 [20 \times 8 + 40 \times 4 + 60 \times 4 + 20 \times 4 + 50 \times 4]$$
$$= \mathbf{840 \times 10^3 \ kWh}$$

Alternatively :

Units generated/day = Area (in kWh) under daily load duration curve

$= 10^3 [60 \times 4 + 50 \times 4 + 40 \times 4 + 20 \times 12]$

$= \mathbf{840 \times 10^3\ kWh}$

which is the same as above.

Example 3.16. *The annual load duration curve of a certain power station can be considered as a straight line from 20 MW to 4 MW. To meet this load, three turbine-generator units, two rated at 10 MW each and one rated at 5 MW are installed. Determine* (*i*) *installed capacity* (*ii*) *plant factor* (*iii*) *units generated per annum* (*iv*) *load factor and* (*v*) *utilisation factor.*

Solution. Fig. 3.10 shows the annual load duration curve of the power station.

(*i*) Installed capacity = 10 + 10 + 5 = **25 MW**

(*ii*) Referring to the load duration curve,

Average demand $= \frac{1}{2}[20 + 4] = 12$ MW

∴ Plant factor $= \frac{\text{Average demand}}{\text{Plant capacity}} = \frac{12}{25} = 0{\cdot}48 = \mathbf{48\%}$

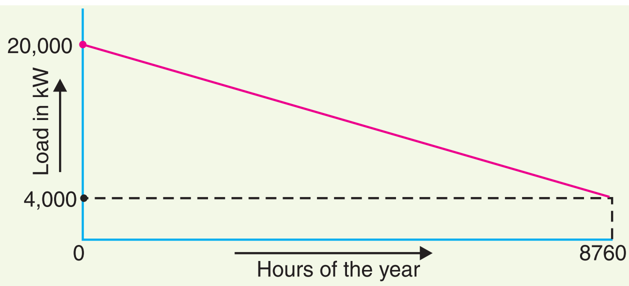


Fig. 3.10

(*iii*) Units generated/annum = Area (in kWh) under load duration curve

$= \frac{1}{2}[4000 + 20{,}000] \times 8760 \text{ kWh} = \mathbf{105{\cdot}12 \times 10^6\ kWh}$

(*iv*) Load factor $= \frac{12{,}000}{20{,}000} \times 100 = \mathbf{60\%}$

(*v*) Utilisation factor $= \frac{\text{Max. demand}}{\text{Plant capacity}} = \frac{20{,}000}{25000} = 0{\cdot}8 = \mathbf{80\%.}$

Example 3.17. *At the end of a power distribution system, a certain feeder supplies three distribution transformers, each one supplying a group of customers whose connected load are listed as follows :*

Transformer 1	*Transformer 2*	*Transformer 3*
General power service and lighting	*Residence lighting*	*Store lighting and power*
a : 10 H.P., 5 kW	*e : 5 kW*	*j : 10 kW, 5 H.P.*
b : 7·5 H.P., 4 kW	*f : 4 kW*	*k : 8 kW, 25 H.P.*
c : 15 H.P.	*g : 8 kW*	*l : 4 kW*
d : 5 H.P., 2 kW	*h : 15 kW*	
	i : 20 kW	

Use the factors given in Art. 3.8 and predict the maximum demand on the feeder. The H.P. load is motor load and assume an efficiency of 72%.

Solution. The individual maximum demands of the group of consumers connected to transformer 1are obtained with factors from the table on page 49.

$$a: \quad \left(10 \times \frac{0 \cdot 746}{0 \cdot 72}\right) \times 0{\cdot}65 + 5 \times 0{\cdot}60^{*} = 9{\cdot}74 \text{ kW}$$

$$b: \quad \left(7 \cdot 5 \times \frac{0 \cdot 746}{0 \cdot 72}\right) \times 0{\cdot}75 + 4 \times 0{\cdot}60 = 8{\cdot}23 \text{ kW}$$

$$c: \quad \left(15 \times \frac{0 \cdot 746}{0 \cdot 72}\right) \times 0{\cdot}65 = 10{\cdot}10 \text{ kW}$$

$$d: \quad \left(5 \times \frac{0 \cdot 746}{0 \cdot 72}\right) \times 0{\cdot}75 + 2 \times 0{\cdot}60 = 5{\cdot}09 \text{ kW}$$

$$\text{Total} = 33{\cdot}16 \text{ kW}$$

The diversity factor between consumers of this type of service is 1·5 (From the table of article 3.8).

$$\therefore \quad \text{Maximum demand on transformer 1} = \frac{33{\cdot}16}{1{\cdot}5} = 22{\cdot}10 \text{ kW}$$

In a similar manner, the other transformer loads are determined to be

	Total	*Simultaneous*
Transformer 2	26 kW	7·43 kW
Transformer 3	29·13 kW	19·40 kW

The diversity factor between transformers is 1·3.

$$\therefore \quad \text{Maximum load on feeder} = \frac{22 \cdot 10 + 7 \cdot 43 + 19 \cdot 40}{1 \cdot 3} = \frac{48 \cdot 93}{1 \cdot 3} = \mathbf{37{\cdot}64\ kW}$$

TUTORIAL PROBLEMS

1. A generating station has a connected load of 40 MW and a maximum demand of 20 MW : the units generated being 60×10^6. Calculate (*i*) the demand factor (*ii*) the load factor. **[(*i*) 0·5 (*ii*) 34·25%]**

2. A 100 MW powers stations delivers 100 MW for 2 hours, 50 MW for 8 hours and is shut down for the rest of each day. It is also shut down for maintenance for 60 days each year. Calculate its annual load factor. **[21%]**

3. A power station is to supply four regions of loads whose peak values are 10,000 kW, 5000 kW, 8000 kW and 7000 kW. The diversity factor of the load at the station is 1.5 and the average annual load factor is 60%. Calculate the maximum demand on the station and annual energy supplied from the station. **[20,000 kW ; $105{\cdot}12 \times 10^6$ kWh]**

4. A generating station supplies the following loads : 15000 kW, 12000 kW, 8500 kW, 6000 kW and 450 kW. The station has a maximum demand of 22000 kW. The annual load factor of the station is 48%. Calculate (*i*) the number of units supplied annually (*ii*) the diversity factor and (*iii*) the demand factor. **[(*i*) 925×10^5 kWh (*ii*) 52·4% (*iii*) 1·9]**

5. A generating station has a maximum demand of 20 MW, a load factor of 60%, a plant capacity factor of 48% and a plant use factor of 80% . Find :

(*i*) the daily energy produced

(*ii*) the reserve capacity of the plant

* Since demand factor for a particular load magnitude in not given in the table, it is reasonable to assume the average value *i.e.*

$$\text{Demand Factor} = \frac{0 \cdot 7 + 0 \cdot 5}{2} = \frac{1 \cdot 2}{2} = 0{\cdot}6$$

(*iii*) the maximum energy that could be produced daily if the plant was running all the time

(*iv*) the maximum energy that could be produced daily if the plant was running fully loaded and operating as per schedule. **[(*i*) 288 × 10^3 kWh (*ii*) 0 (*iii*) 4·80 × 10^3 kWh (*iv*) 600 × 10^3 kWh]**

6. A generating station has the following daily load cycle :

Time (hours)	0—6	6—10	10—12	12—16	16—20	20—24
Load (MW)	20	25	30	25	35	20

Draw the load curve and find

(*i*) maximum demand,

(*ii*) units generated per day,

(*iii*) average load,

(*iv*) load factor, **[(*i*) 35 MW (*ii*) 560 × 10^3 kWh (*iii*) 23333 kW (*iv*) 66·67%]**

7. A power station has to meet the following load demand :

Load *A*	50 kW	between	10 A.M. and 6 P.M.
Load *B*	30 kW	between	6 P.M. and 10 P.M.
Load *C*	20 kW	between	4 P.M. and 10 A.M.

Plot the daily load curve and determine (*i*) diversity factor (*ii*) units generated per day (*iii*) load factor.

[(*i*) 1·43 (*ii*) 880 kWh (*iii*) 52·38%]

8. A substation supplies power by four feeders to its consumers. Feeder no. 1 supplies six consumers whose individual daily maximum demands are 70 kW, 90 kW, 20 kW, 50 kW, 10 kW and 20 kW while the maximum demand on the feeder is 200 kW. Feeder no. 2 supplies four consumers whose daily maximum demands are 60 kW, 40 kW, 70 kW and 30 kW, while the maximum demand on the feeder is 160 kW. Feeder nos. 3 and 4 have a daily maximum demand of 150 kW and 200 kW respectively while the maximum demand on the station is 600 kW.

Determine the diversity factors for feeder no. 1. feeder no. 2 and for the four feeders. **[1·3, 1·25, 1·183]**

9. A central station is supplying energy to a community through two substations. Each substation feeds four feeders. The maximum daily recorded demands are :

POWER STATION........ 12,000 KW

Substation *A* ...... 6000 kW	Sub-station *B* .... 9000 kW
Feeder 1 .... 1700 kW	Feeder 1 .... 2820 kW
Feeder 2 .... 1800 kW	Feeder 2 .... 1500 kW
Feeder 3 .... 2800 kW	Feeder 3 .... 4000 kW
Feeder 4 .... 600 kW	Feeder 4 .... 2900 kW

Calculate the diversity factor between (*i*) substations (*ii*) feeders on substation A and (*iii*) feeders on substation B. **[(*i*) 1·25 (*ii*) 1·15 (*iii*) 1·24]**

10. The yearly load duration curve of a certain power station can be approximated as a straight line ; the maximum and minimum loads being 80 MW and 40 MW respectively. To meet this load, three turbine-generator units, two rated at 20 MW each and one at 10 MW are installed. Determine (*i*) installed capacity (*ii*) plant factor (*iii*) kWh output per year (*iv*) load factor.

[(*i*) 50MW (*ii*) 48% (*iii*) 210 × 10^6 (*iv*) 60%]

3.9 Load Curves and Selection of Generating Units

The load on a power station is seldom constant; it varies from time to time. Obviously, a single generating unit (*i.e.*, alternator) will not be an economical proposition to meet this varying load. It is because a single unit will have very poor* efficiency during the periods of light loads on the power station. Therefore, in actual practice, a number of generating units of different sizes are installed in a power station. The selection of the number and sizes of the units is decided from the annual load curve of the station. *The number and size of the units are selected in such a way that they correctly*

* The efficiency of a machine (alternator in this case) is maximum at nearly 75% of its rated capacity.

fit the station load curve. Once this underlying principle is adhered to, it becomes possible to operate the generating units at or near the point of maximum efficiency.

Illustration. The principle of selection of number and sizes of generating units with the help of load curve is illustrated in Fig. 3.11. In Fig. 3.11 (*i*), the annual load curve of the station is shown. It is clear form the curve that load on the station has wide variations ; the minimum load being somewhat near 50 kW and maximum load reaching the value of 500 kW. It hardly needs any mention that use of a single unit to meet this varying load will be highly uneconomical.

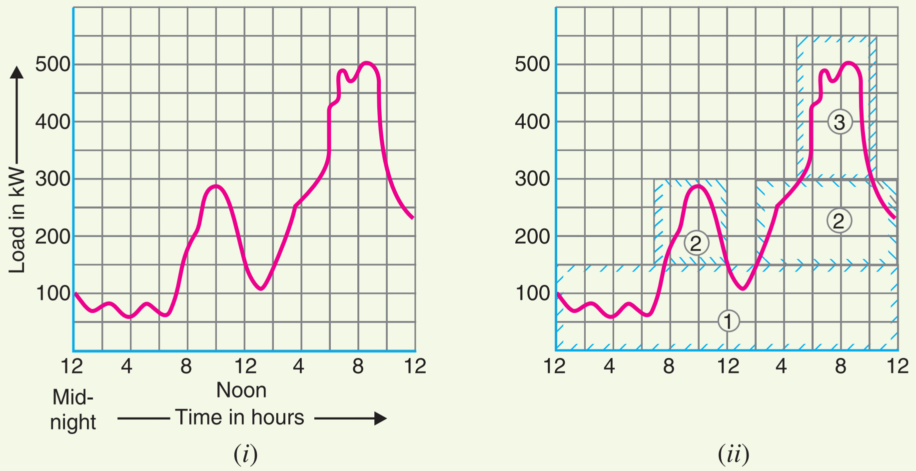


Fig. 3.11

As discussed earlier, the total plant capacity is divided into several generating units of different sizes to fit the load curve. This is illustrated in Fig. 3.11(*ii*) where the plant capacity is divided into three* units numbered as 1, 2 and 3. The cyan colour outline shows the units capacity being used. The three units employed have different capacities and are used according to the demand on the station. In this case, the operating schedule can be as under :

Time	*Units in operation*
From 12 midnight to 7 A.M.	Only unit no.1 is put in operation.
From 7 A.M. to 12.00 noon	Unit no. 2 is also started so that both units 1 and 2 are in operation.
From 12.00 noon to 2 P.M.	Unit no. 2 is stopped and only unit 1operates.
From 2 P.M. to 5 P.M.	Unit no. 2 is again started. Now units 1 and 2 are in operation.
From 5 P.M. to 10.30 P.M.	Units 1, 2 and 3 are put in operation.
From 10. 30 P.M. to 12.00 midnight	Units 1 and 2 are put in operation.

Thus by selecting the proper number and sizes of units, the generating units can be made to operate near maximum efficiency. This results in the overall reduction in the cost of production of electrical energy.

3.10 Important Points in the Selection of Units

While making the selection of number and sizes of the generating units, the following points should be kept in view :

(*i*) The number and sizes of the units should be so selected that they approximately fit the annual load curve of the station.

* It may be seen that the generating units can fit the load curve more closely if more units of smaller sizes are employed. However, using greater number of units increases the investment cost per kW of the capacity.

(ii) The units should be *preferably* of different capacities to meet the load requirements. Although use of identical units (*i.e.*, having same capacity) ensures saving* in cost, they often do not meet the load requirement.

(iii) The capacity of the plant should be made 15% to 20% more than the maximum demand to meet the future load requirements.

(iv) There should be a spare generating unit so that repairs and overhauling of the working units can be carried out.

(v) The tendency to select a large number of units of smaller capacity in order to fit the load curve very accurately should be avoided. It is because the investment cost per kW of capacity increases as the size of the units decreases.

Example 3.18. *A proposed station has the following daily load cycle :*

Time in hours	*6—8*	*8—11*	*11—16*	*16—19*	*19—22*	*22—24*	*24—6*
Load in MW	*20*	*40*	*50*	*35*	*70*	*40*	*20*

Draw the load curve and select suitable generator units from the 10,000, 20,000, 25,000, 30,000 kVA. Prepare the operation schedule for the machines selected and determine the load factor from the curve

Solution. The load curve of the power station can be drawn to some suitable scale as shown in Fig. 3.12.

Units generated per day = Area (in kWh) under the load curve

$= 10^3\,[20 \times 8 + 40 \times 3 + 50 \times 5 + 35 \times 3 + 70 \times 3 + 40 \times 2]$

$= 10^3\,[160 + 120 + 250 + 105 + 210 + 80]$ kWh

$= 925 \times 10^3$ kWh

$$\text{Average load} = \frac{925 \times 10^3}{24} = 38541{\cdot}7 \text{ kW}$$

$$\text{Load factor} = \frac{38541 \cdot 7}{70 \times 10^3} \times 100 = \mathbf{55{\cdot}06\%}$$

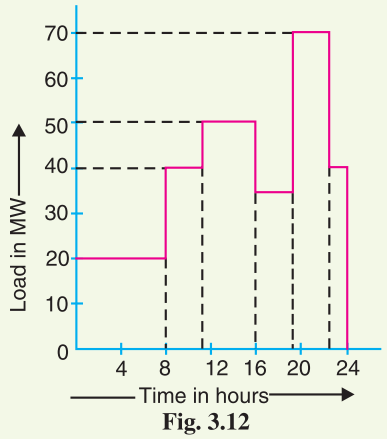


Fig. 3.12

Selection of number and sizes of units : Assuming power factor of the machines to be 0·8, the output of the generating units available will be 8, 16, 20 and 24 MW. There can be several possibilities. However, while selecting the size and number of units, it has to be borne in mind that ***(i)*** one set of highest capacity should be kept as standby unit ***(ii)*** the units should meet the maximum demand (70 MW in this case) on the station ***(iii)*** there should be overall economy.

Keeping in view the above facts, *4 sets of 24 MW each may be chosen*. Three sets will meet the maximum demand of 70 MW and one unit will serve as a standby unit.

Operational schedule. Referring to the load curve shown in Fig. 3.12, the operational schedule will be as under :

(i) Set No. 1 will run for 24 hours.

(ii) Set No. 2 will run from 8.00 hours to midnight.

(iii) Set No. 3 will run from 11.00 hours to 16 hours and again from 19 hours to 22 hours.

Example 3.19. *A generating station is to supply four regions of load whose peak loads are 10 MW, 5 MW, 8 MW and 7 MW. The diversity factor at the station is 1·5 and the average annual load factor is 60%. Calculate :*

* Due to duplication of sizes and dimensions of pipes, foundations etc.

(*i*) *the maximum demand on the station.*
(*ii*) *annual energy supplied by the station.*
(*iii*) *Suggest the installed capacity and the number of units.*

Solution.

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

$$= (10 + 5 + 8 + 7)/1{\cdot}5 = \mathbf{20\ MW}$$

(*ii*) $$\text{Units generated/annum} = \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}$$

$$= (20 \times 10^3) \times (0{\cdot}6) \times (8760)\ \text{kWh}$$

$$= \mathbf{105{\cdot}12 \times 10^6\ kWh}$$

(*iii*) The installed capacity of the station should be 15% to 20% more than the maximum demand in order to meet the future growth of load. Taking installed capacity to be 20% more than the maximum demand,

$$\text{Installed capacity} = 1{\cdot}2 \times \text{Max. demand} = 1{\cdot}2 \times 20 = \mathbf{24\ MW}$$

Suitable unit sizes are 4, each of 6 MW capacity.

3.11 Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature. Fig. 3.13. shows the typical load curve of a power station. It is clear that load on the power station varies from time to time. However, a close look at the load curve reveals that load on the power station can be considered in two parts, namely;

(*i*) Base load
(*ii*) Peak load

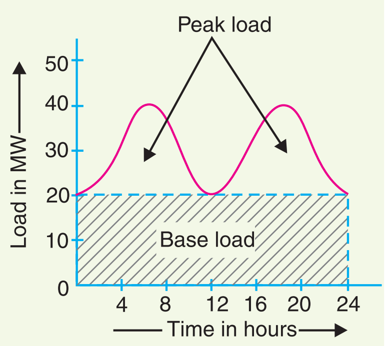


Fig. 3.13

(*i*) **Base load.** *The unvarying load which occurs almost the whole day on the station is known as* **base load.**

Referring to the load curve of Fig. 3.13, it is clear that 20 MW of load has to be supplied by the station at all times of day and night *i.e.* throughout 24 hours. Therefore, 20 MW is the base load of the station. As base load on the station is almost of constant nature, therefore, it can be suitably supplied (as discussed in the next Article) without facing the problems of variable load.

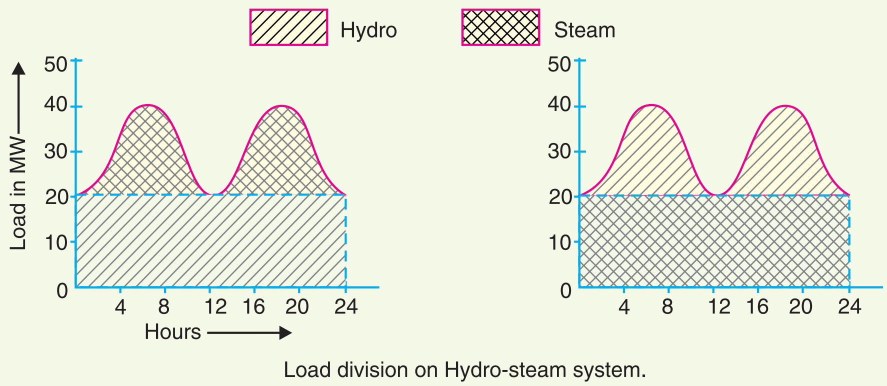
(*ii*) **Peak load.** *The various peak demands of load over and above the base load of the station is known as* **peak load.**

Referring to the load curve of Fig. 3.13, it is clear that there are peak demands of load excluding base load. These peak demands of the station generally form a small part of the total load and may occur throughout the day.

3.12 Method of Meeting the Load

The total load on a power station consists of two parts *viz*., base load and peak load. In order to achieve overall economy, *the best method to meet load is to interconnect two different power stations*. The more efficient plant is used to supply the base load and is known *as base load power station*. The less efficient plant is used to supply the peak loads and is known as *peak load power station*. There is no hard and fast rule for selection of base load and peak load stations as it would depend upon the particular situation. For example, both hydro-electric and steam power stations are quite efficient and can be used as base load as well as peak load station to meet a particular load requirement.

Illustration. The interconnection of steam and hydro plants is a beautiful illustration to meet the load. When water is available in sufficient quantity as in summer and rainy season, the hydro-electric plant is used to carry the base load and the steam plant supplies the peak load as shown in Fig 3.14 (*i*).



(*i*) High Flow day (*ii*) Low Flow day

Fig. 3.14

However, when the water is not available in sufficient quantity as in winter, the steam plant carries the base load, whereas the hydro-electric plant carries the peak load as shown in Fig. 3.14 (*ii*).

3.13 Interconnected Grid System

The connection of several generating stations in parallel is known as **interconnected grid system.**

The various problems facing the power engineers are considerably reduced by interconnecting different power stations in parallel. Although interconnection of station involves extra cost, yet considering the benefits derived from such an arrrangement, it is gaining much favour these days. Some of the advantages of interconnected system are listed below :

(*i*) *Exchange of peak loads* : An important advantage of interconnected system is that the peak load of the power station can be exchanged. If the load curve of a power station shows a peak demand that is greater than the rated capacity of the plant, then the excess load can be shared by other stations interconnected with it.

(*ii*) *Use of older plants :* The interconnected system makes it possible to use the older and less efficient plants to carry peak loads of short durations. Although such plants may be inadequate when used alone, yet they have sufficient capacity to carry short peaks of loads when interconnected with other modern plants. Therefore, interconnected system gives a direct key to the use of obsolete plants.

(*iii*) *Ensures economical operation :* The interconnected system makes the operation of concerned power stations quite economical. It is because sharing of load among the stations is arranged in such a way that more efficient stations work continuously throughouts the year at a high load factor and the less efficient plants work for peak load hours only.

(*iv*) *Increases diversity factor :* The load curves of different interconnected stations are generally different. The result is that the maximum demand on the system is much reduced as compared to the sum of individual maximum demands on different stations. In other words, the diversity factor of the system is improved, thereby increasing the effective capacity of the system.

(*v*) *Reduces plant reserve capacity* : Every power station is required to have a standby unit for emergencies. However, when several power stations are connected in parallel, the reserve capacity of the system is much reduced. This increases the efficiency of the system.

(*vi*) *Increases reliability of supply* : The interconnected system increases the reliability of supply. If a major breakdown occurs in one station, continuity of supply can be maintained by other healthy stations.

Example 3.20. *A base load station having a capacity of 18 MW and a standby station having a capacity of 20 MW share a common load. Find the annual load factors and plant capacity factors of two power stations from the following data :*

Annual standby station output $= 7{\cdot}35 \times 10^6$ *kWh*
Annual base load station output $= 101{\cdot}35 \times 10^6$ *kWh*
Peak load on standby station = *12 MW*
Hours of use by standby station/year = *2190 hours*

Solution.

Installed capacity of standby unit

$$= 20 \text{ MW} = 20 \times 10^3 \text{ kW}$$

Installed capacity of base load plant

$$= 18 \text{ MW} = 18 \times 10^3 \text{ kW}$$

Standby station

$$\text{Annual load factor} = \frac{\text{kWh generated / annum}}{\text{Max. demand} \times \text{Annual working hours}} \times 100$$

$$= \frac{7{\cdot}35 \times 10^6}{(12 \times 10^3) \times 2190} \times 100 = \mathbf{28\%}$$

$$\text{Annual plant capacity factor} = \frac{\text{kWh output / annum}}{\text{Installed capacity} \times \text{Hours in a year}} \times 100$$

$$= \frac{7{\cdot}35 \times 10^6}{(20 \times 10^3) \times 8760} \times 100 = \mathbf{4{\cdot}2\%}$$

Base load station. It is reasonable to assume that the maximum demand on the base load station is equal to the installed capacity (*i.e.*, 18 MW). It operates throughout the year *i.e.*, for 8760 hours.

$$\therefore \quad \text{Annual load factor} = \frac{101{\cdot}35 \times 10^6}{(18 \times 10^3) \times 8760} = \mathbf{64{\cdot}2\%}$$

As the base load station has no reserves above peak load and it is in continuous operation, therefore, its capacity factor is also **64.2%**.

Example 3.21. *The load duration curve for a typical heavy load being served by a combined hydro-steam system may be approximated by a straight line; maximum and minimum loads being 60,000 kW and 20,000 kW respectively. The hydro power available at the time of minimum regulated flow is just sufficient to take a peak load of 50,000 kWh per day. It is observed that it will be economical to pump water from tail race to the reservoir by utilising the steam power plant during the off-peak periods and thus running the station at 100% load factor. Determine the maximum capacity of each type of plant. Assume the efficiency of steam conversion to be 60%.*

Solution. *OCBA* represents the load duration curve for the combined system as shown in Fig. 3.15. The total maximum demand (*i.e.*, 60,000 kW) is represented by *OC*, whereas the minimum demand (*i.e.*, 20,000 kW) is represented by *OD*.

Let *OE* = Capacity of steam plant
EC = Capacity of hydro plant
Area *CHI* = The energy available from hydro plant in the low flow period.

$$\text{Area } FGB = \text{The off-peak* period energy available from steam plant}$$

Obviously, the energy of hydro plant represented by area *HEFI* and available from reservoir has been supplied by steam power plant represented by area *FGB*. As steam electric conversion is 60%,

$$\therefore \quad \text{Area } HEFI = 0{\cdot}6 \times \text{Area } FGB \quad \text{... }(i)$$

$$\text{But} \quad \text{Area } HEFI = \text{Area } CFE - \text{Area } CHI$$

$$= \frac{1}{2}\, xy - 50{,}000\dagger$$

$$\text{Now} \quad \text{Area } FGB = \frac{1}{2} \times FG \times GB = \frac{1}{2}(24 - x)(40{,}000 - y)$$

Putting the various values in exp. (*i*), we get,

$$\frac{1}{2}\, xy - 50{,}000 = 0 \cdot 6\left[\frac{1}{2}(24 - x)(40{,}000 - y)\right]$$

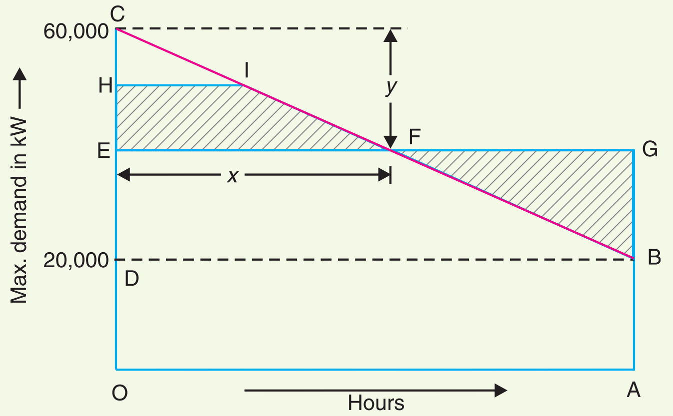


Fig. 3.15

$$\text{or} \quad 0{\cdot}2\, xy + 12000\, x + 7{\cdot}2\, y - 3{,}38{,}000 = 0 \quad \text{... }(ii)$$

Also from similar triangles *CEF* and *CDB*, we get,

$$\frac{y}{40{,}000} = \frac{x}{24}$$

$$\therefore \quad y = \frac{40{,}000\, x}{24} \quad \text{... }(iii)$$

Putting $y = 40{,}000\, x/24$ from exp. (*iii*) into exp. (*ii*), we get,

$$333\, x^2 + 24000\, x - 3{,}38{,}000 = 0$$

$$\text{or} \quad x^2 + 72x - 1015 = 0$$

$$\therefore \quad x = \frac{-72 \pm \sqrt{5184 + 4060}}{2} = \frac{-72 \pm 96}{24} = 12$$

$\therefore$ Capacity of the hydro plant is

$$y\ (= EC) = \frac{40{,}000 \times 12}{24} = \mathbf{20{,}000\ kW}$$

$$\text{Capacity of steam plant} = 60{,}000 - 20{,}000 = \mathbf{40{,}000\ kW}$$

Example 3.22. *The annual load duration curve for a typical heavy load being served by a steam station, a run-of-river station and a reservoir hydro-electric station is as shown in Fig. 3.16. The ratio of number of units supplied by these stations is as follows :*

* It is clear from load duration curve that the capacity of steam plant represented by area *FGB* is not being utilised efficiently. This steam energy can be used to pump water in tail race back to the reservoir.

† Because during minimum regulated flow, hydro energy supplied is 50,000 kWh.

Steam : Run-of-river : Reservoir : : 7 : 4 : 1

The run-of-river station is capable of generating power continuously and works as a base load station. The reservoir station works as a peak load station. Determine (*i*) *the maximum demand of each station and* (*ii*) *load factor of each station.*

Solution. *ODCA* is the annual load duration curve for the system as shown in Fig. 3.16. The energy supplied by the reservoir plant is represented by area *DFG* ; steam station by area *FGCBE* and run-of-river by area *OEBA*. The maximum and minimum loads on the system are 320 MW and 160 MW respectively.

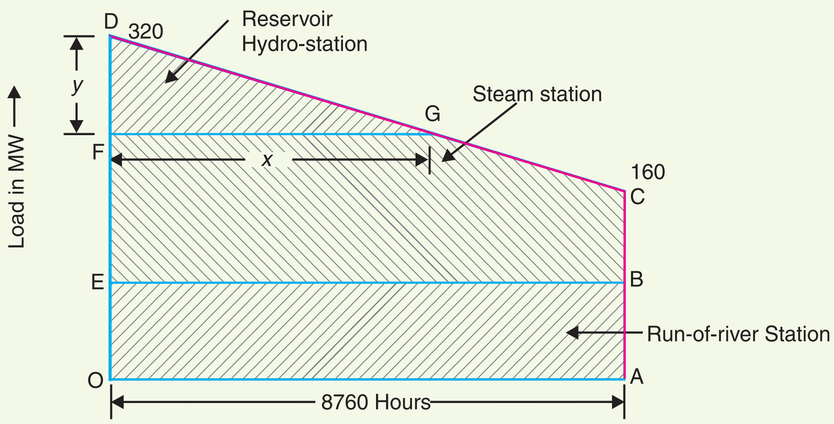


Fig. 3.16

$$\text{Units generated/annum} = \text{Area (in kWh) under annual load duration curve}$$

$$= 10^3\left[\frac{1}{2}(320+160)\times 8760\right]\text{ kWh} = 2102\cdot 4\times 10^6\text{ kWh}$$

As the steam plant, run-of-river plant and hydro plant generate units in the ratio of 7 : 4 : 1, therefore, units generated by each plant are given by :

$$\text{Steam plant} = 2102{\cdot}4\times 10^6\times 7/12 = 1226{\cdot}4\times 10^6\text{ kWh}$$

$$\text{Run-of-river plant} = 2102{\cdot}4\times 10^6\times 4/12 = 700{\cdot}8\times 10^6\text{ kWh}$$

$$\text{Reservoir plant} = 2102{\cdot}4\times 10^6\times 1/12 = 175{\cdot}2\times 10^6\text{ kWh}$$

(*i*) Maximum demand on run-of-river plant

$$= \frac{\text{Area } OEBA}{OA} = \frac{700\cdot 8\times 10^6}{8760} = \mathbf{80{,}000\ kW}$$

Suppose the maximum demand of reservoir plant is *y* MW and it operates for *x* hours (See Fig. 3.16).

Then,
$$\frac{y}{160} = \frac{x}{8760} \quad\text{or}\quad x = \frac{8760\,y}{160}$$

Units generated per annum by reservoir plant

$$= \text{Area (in kWh) } DFG$$

$$= 10^3\left(\frac{1}{2}xy\right) = 10^3\left(\frac{1}{2}\times\frac{8760\,y}{160}\,y\right)$$

$$= \frac{y^2}{32}\times 8{,}76{,}000$$

But the units generated by reservoir plant are $175{\cdot}2\times 10^6$ kWh.

$$\therefore \qquad \frac{y^2}{32}\times 8{,}76{,}000 = 175{\cdot}2\times 10^6$$

$$y^2 = 6400 \quad \text{or} \quad y = \sqrt{6400} = 80 \text{ MW}$$

∴ Maximum demand on reservoir station is

$$FD = \mathbf{80\ MW}$$

Maximum demand on steam station is

$$EF = 320 - 80 - 80 = \mathbf{160\ MW}$$

(ii) L.F. of run of river plant = **100* %**

$$\text{L.F. of reservoir plant} = \frac{\text{Units generated / annum}}{\text{Maximum demand} \times 8760} \times 100$$

$$= \frac{175 \cdot 2 \times 10^6}{(80 \times 10^3) \times 8760} \times 100 = \mathbf{25\%}$$

$$\text{L.F. of steam plant} = \frac{1226 \cdot 4 \times 10^6}{(160 \times 10^3) \times 8760} \times 100 = \mathbf{87.5\%}$$

SELF - TEST

1. Fill in the blanks by inserting appropriate words/figures :

(i) The area under the daily load curve gives ....
(ii) The connected load is generally .... than the maximum demand.
(iii) The value of demand factor is .... than 1.
(iv) The higher the load factor of a power station, the .... is the cost per unit generated.
(v) The value of diversity factor is .... than 1.
(vi) The lesser the diversity factor, the .... is the cost of generation of power.
(vii) A generating unit operates with maximum efficiency at about .... % of its rated capacity.
(viii) According to Indian Electricity Supply Act (1948), the capacity of the spare set should be ....
(ix) In an annual load curve, ... is taken along Y-axis and .... along X-axis.
(x) Base load occurs on the power station for .... hours in a day.

2. Pick up the correct words/figures from the brackets and fill in the blanks :

(i) Area under the daily load curve divided by 24 gives .... (*average load, maximum demand, units generated*)
(ii) The knowledge of diversity factor helps in determining .... (*average load, units generated, plant capacity*)
(iii) More efficient plants are used as .... (*base load stations, peak load stations*)
(iv) A diesel power plant is generally used as a .... (*base load station, peak load station*)
(v) In a hydro-steam system, steam power station carries the base load during .... (*high flow day, low flow day*)
(vi) In an interconnected grid system, the diversity factor of the whole system .... (*increases, decreases, remains constant*)
(vii) Installed capacity of a power station is .... then the maximum demand. (*less, more*)
(viii) Annual load factor is determined from .... load curve. (*daily, monthly, annual*)

ANSWERS TO SELF-TEST

1. (*i*) units generated in the day (*ii*) more (*iii*) less (*iv*) lesser (*v*) more (*vi*) greater (*vii*) 75% (*viii*) highest of all sets (*ix*) load, hours (*x*) 24.

2. (*i*) average load (*ii*) plant capacity (*iii*) base load stations (*iv*) peak load station (*v*) low flow day (*vi*) increases (*vii*) more (*viii*) annual.

* Since it operates continuously at rated capacity (*i.e.* it is a base load station).

CHAPTER REVIEW TOPICS

1. Why is the load on a power station variable ? What are the effects of variable load on the operation of the power station ?
2. What do you understand by the load curve ? What informations are conveyed by a load curve ?
3. Define and explain the importance of the following terms in generation :
   (*i*) connected load (*ii*) maximum demand (*iii*) demand factor (*iv*) average load.
4. Explain the terms load factor and divesity factor. How do these factors influence the cost of generation?
5. Explain how load curves help in the selection of size and number of generating units.
6. Discuss the important points to be taken into consideration while selecting the size and number of units.
7. What do you understand by (*i*) base load and (*ii*) peak load of a power station ?
8. Discuss the method of meeting the peak load of an electrified area.
9. Discuss the advantages of interconnected grid system.
10. Write short notes on the following :
    (*i*) load curves,
    (*ii*) load division on hydro-steam system,
    (*iii*) load factor,
    (*iv*) plant capacity factor,

DISCUSSION QUESTIONS

1. Why are load curves drawn ?
2. How will you improve the diversity factor of a power station ?
3. What is the importance of load factor ?
4. What is the importance of diversity factor ?
5. The values of demand factor and load factor are always less than 1. Why ?

GO To FIRST