CHAPTER 1

Load Characteristics

1.1 INTRODUCTION

From the very outset energy has played a vital role in the development of civilization. There has been a universal basic drive towards better living through expanded utilization of energy. The history of civilization shows a close relationship between the utilization of energy and the progress of mankind. The degree of energy used is the symbol of the progress of a country. Energy consciousness in the people has created interests in them to tap new sources of energy from time to time. Of the various forms so far discovered the electrical energy has contributed a lot to the world's energy requirements.

1.2 ADVANTAGES OF ELECTRICAL ENERGY

Electrical energy is the most refined form of energy. The advantages derived from the electrical energy are many in number. Some of its important advantages over other forms of energy are :

1. It can be generated in large quantities at comparable cost with other types of energy.
2. It can be conveniently transmitted over long distances.
3. It can be utilized efficiently in a number of processes requiring energy.
4. It has got maximum flexibility and has most sensitive susceptibility control.

1.3 LOAD

A device which uses electrical energy is said to impose a load on the system. The term load is used in a number of ways.

- To indicate a device or collection of devices which consume electrical energy.
- To indicate power required from a given supply circuit.
- To indicate the current or power passing through a line or machine.

The load may be resistive, inductive, capacitive, or some combination of them.

Loads on power systems are divided into industrial, commercial, and residential. The industrial loads are composite loads, and induction motors form a high proportion of these loads. These composite loads are functions of voltage and frequency and form a major part of the system load. Commercial and residential loads consist largely of lighting, heating and cooling. These loads are independent of frequency and consume negligibly small reactive power.

1.4 CONNECTED LOAD

Connected load is the sum of continuous ratings of all loads connected to the system or any part thereof.

1.5 DEMAND

The demand of an installation of a 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.

The load may be given in kilowatts (kW), kilovars (kVAr), kilovoltamperes (kVA), or amperes (A).

1.6 DEMAND INTERVAL

Demand interval is the period over which the load is averaged. There are two demands :

(a) Instantaneous demand

(b) Sustained demand

The former is not very important because all the machines are designed for overloads. The sustained intervals are generally taken as 15 min, 30 min, or even longer. But 30 min is the basis time in India.

1.7 MAXIMUM DEMAND (MD) OR PEAK LOAD

The maximum demand of an installation or system is the greatest of all demands which have occurred during the specific period of time.

The maximum demand statement should also express the demand interval used to measure it. For example, the specified demand might be maximum of all demands such as daily, weekly, monthly, or annual.

Knowledge of maximum demand helps in determining the installed capacity of a generating station. The generating station must be capable of meeting the maximum demand. Hence the cost of plant and equipment increases with the increase in maximum demand.

1.8 DEMAND FACTOR DF

The demand factor is the ratio of the actual maximum demand of the system to the total connected load of the system. Therefore, the demand factor (DF) is

$$DF \triangleq \frac{\text{maximum demand}}{\text{total connected load}}$$

The demand factor can also be found for a part of the system. For example, an industrial or commercial consumer, instead of for the whole system.

In practice, consumers do not use all the devices at full load simultaneously. The maximum demand of each consumer is, therefore, less than his connected load. The demand factor depends upon the nature of load. Lighting loads have higher demand factors than power loads. The demand factor is usually less than 1.0.

1.9 AVERAGE LOAD OR AVERAGE DEMAND

It is the ratio of energy consumed in a given period of the time in hours.

$$\text{Average load} = \frac{\text{energy consumed in a given period}}{\text{hours in that time period}}$$

1.10 LOAD FACTOR

Load factor of a system is the ratio of the average load over a given period of time to the maximum demand (peak load) occurring in that period.

$$\text{Load factor} \triangleq \frac{\text{average load}}{\text{peak load}}$$

Multiplying the numerator and denominator by time T,

$$\text{Load factor} = \frac{\text{average} \times T}{\text{peak load} \times T} = \frac{\text{energy consumed during a time of } T \text{ hours}}{\text{peak load} \times T \text{ hours}}$$

This relation shows that the load factor can also be defined as the ratio of the actual energy consumed during a given period to the energy which would have been used if the maximum demand (peak load) had been continuously maintained throughout that period.

Depending upon the number of hours in days, weeks, months, or years we define different load factors. For daily load factor, the period of time T is taken as 24 hours and for annual load factor $T = 8760$ hours.

Mathematically,

$$\text{Daily load factor} = \frac{\text{total kWh during 24 h of the day}}{(\text{peak load in kW}) \times 24 \text{ h}}$$

$$\text{Monthly load factor} = \frac{\text{total kWh during the month}}{(\text{peak load in kW}) \times (\text{number of hours in the month})}$$

$$\text{Annual load factor} = \frac{\text{total kWh during the year}}{(\text{peak load in kW}) \times (8760 \text{ hours})}$$

Load factor plays an important role on the cost of generation per unit (kWh). The higher the load factor, the lesser will be the cost of generation per unit for the same maximum demand.

1.11 DIVERSITY FACTOR F_D

The maximum demands of the individual consumers of a group are not likely to occur simultaneously. Thus, there is a diversity in the occurrence of the loads. Due to this diverse nature of the load, power is never required to supply all connected loads to their full capacity at the same time.

Diversity factor is the ratio of the sum of the individual maximum demands of the various subdivisions of a system to the maximum demand of the whole system. Thus,

$$\text{Diversity factor} \triangleq \frac{\text{(sum of individual maximum demands)}}{\text{(coincident maximum demand of the whole system)}}$$

$$F_D \triangleq \frac{D_1 + D_2 + \ldots + D_n}{D_g}$$

or

$$F_D = \frac{\sum_{i=1}^{n} D_i}{D_g}$$

where D_i = maximum demand of the load i, irrespective of the time of occurrence.

$D_g = D_{(1+2+\ldots+n)}$ = coincident maximum demand of group of n loads

Diversity factor can be defined for loads, substations, feeders, and generating stations. Usually the maximum demand of various consumers do not occur at the same time and the simultaneous (coincident) maximum demand is less than their total maximum demand. The diversity factor can be equal to or greater than 1.0. The value of the diversity factor is generally greater than 1.0 with a high value representing a good diversity and 1.0 represents a poor diversity.

A large diversity factor has the effect of reducing the maximum demand. Consequently, lesser plant capacity is required. Thus, the capital investment on the plant is reduced and the cost of generation is also reduced.

A high diversity factor may be obtained by giving incentives to industries and farmers to use electrical energy at night or light-load periods.

1.12 LOAD DIVERSITY

It is the difference between the sum of the peaks of two or more individual loads and the peak of the combined load.

$$\text{Load diversity} \triangleq \left(\sum_{i=1}^{n} D_i\right) - D_g$$

1.13 UTILIZATION FACTOR F_u

It is the ratio of maximum demand of a system to the rated capacity of the system.

$$F_u \triangleq \frac{\text{maximum demand}}{\text{rated system capacity}}$$

The utilization factor can also be found for a part of the system.

1.14 PLANT FACTOR OR CAPACITY FACTOR

It is the ratio of the total actual energy produced or supplied over a specified period of time to the energy that would have been produced or supplied if the plant (or unit) had operated continuously at maximum rating. The maximum plant rating in the total installed plant capacity including the reserve capacity.

$$\text{Plant factor} \triangleq \frac{\text{(actual energy produced or supplied in time } T)}{\text{maximum plant rating} \times T}$$

Plant factor is mostly used in generation studies. For example,

$$\text{annual plant factor} = \frac{\text{actual annual energy generation}}{\text{maximum plant rating} \times 8760}$$

The capacity factor indicates the extent of the use of the generating station. If the plant is always run at its rated capacity, the capacity factor is 1.0 (100%). It is different from load factor because of the fact that the rated capacity of each plant is always greater than the maximum demand. The power plants have always some reserve capacity to take into account the future expansion, increase in load and maintenance.

It is to be noted that

$$\text{capacity factor} = \frac{\text{peak load}}{\text{plant capacity}} \times \text{load factor}$$

Thus, if the rate plant capacity equals peak load, the capacity factor and load factor become identical. That is, in absence of reverse capacity.

$$\text{capacity factor} = \text{load factor}$$

1.15 LOSS FACTOR F_{LS}

It is the ratio of the average power loss to the peak-load power loss during the specified period of time.

$$F_{LS} \triangleq \frac{\text{average power loss}}{\text{power loss at peak load}}$$

This relationship is applicable for the copper losses of the system but not for the iron losses.

1.16 LOAD CURVE

Load curve (or chronological load curve) is a graphical representation between load in kW (or MW) in proper time sequence and time in hours. It shows the variation of load on the power station. When it is plotted for 24 hours a day, it is called *daily load curve*. If the time considered is one year (8760 hours) then it is called the *annual load curve*.

It is to be noted that the daily load curve of a system is not the same for all days. It differs from day-to-day and season-to-season. In practice, two types of curves are drawn — one for summer and the other for winter.

1.17 INFORMATIONS OBTAINED FROM LOAD CURVES

The following informations are obtained from load curves :

1. Load variation during different hours of the day.
2. The peak load indicated by the load curve gives the maximum demand on the power station.
3. The area under the load curve gives the total energy generated in the period under consideration.
4. The area under the load curve divided by the total number of hours gives the average load.

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

It would be ideal to have a flat load curve. But in practice, load curved are far from flat. For a flat load curve, the load factor will be higher. Higher load factor means more uniform load pattern with less variations in load. This is desirable from the point of view of maximum utilization of associated equipment which are selected on the basis of maximum demand.

1.18 UTILITY OF LOAD CURVES

On the basis of above informations load curves are useful as follows :

(a) To decide the installed capacity of a power station.

(b) To choose the most economical sizes of various generating units.

(c) To estimate the generating cost.

(d) To decide the operating schedule of the power station, that is, the sequence in which different generating units should run.

1.19 LOAD-DURATION CURVE

A load duration curve is also a graph between load and time in which the ordinates representing the load are plotted in the order of descending magnitude, that is, with the greatest load at the left, lesser loads towards the right and the lowest load at the time extreme right. The load duration curve is derived from the load curve and therefore, represents the same data as that of the load curve. The load duration curve is constructed by selecting the maximum peak points and connecting them by a curve.

1.20 PROCEDURE FOR PLOTTING THE LOAD-DURATION CURVE

(a) From the data available from the load curve, determine the maximum load on the system and the duration for which it occurs.

(b) Take the next lower load and determine the total time, during which this and the previous greater load occurs.

(c) Plot the load against time during which it occurs.

The load-duration curve can be plotted for any duration of time, for example, a day or, a week, or a month, or a year. The abscissa of such a curve can also be chosen as per unit or percentage of time for which it occurs. The whole duration is taken as 1.0 pu or 100%.

The load duration curve plotted for 24 hours of day is called the *daily load duration curve*. Similarly, the load duration curve plotted for 8760 hours of a year is called the *annual load-duration curve*.

1.21 INFORMATIONS AVAILABLE FROM LOAD DURATION CURVE

(a) It gives the minimum load present throughout the given period.

(b) It enables the selection of base load and peak load power plants.

(c) Any point on the load duration curve gives the total duration in hours for the corresponding load and all loads of greater value.

(d) The areas under load curve and corresponding load duration curve are equal. Both areas represent the same associated energy during the period under consideration

(e) The average demand during some specified time period such as a day, or month, c can be obtained from the load duration curve as follows :

$$\text{Average demand} = \frac{\text{kWh (or MWh) consumed in a given time period}}{\text{hours in the time period}}$$

$$= \frac{\text{area under the load duration curve}}{\text{base of the load duration curve}}$$

Example 1.1 A consumer has the following connected load :

10 lamps each of 60 W

2 heaters each of 1000 W

Maximum demand 1500 W

On the average he uses 8 lamps for 5 hours per day, each heater 3 hours per day (a) average load, (b) monthly energy consumption, (c) load factor.

Solution

$$\text{Average load} = \frac{\text{actual energy consumed}}{\text{time duration}} = \frac{8 \times 60 \times 5 + 2 \times 1000 \times 3}{24} = 350 \text{ W}$$

$$\text{Monthly energy consumption} = (8 \times 60 \times 5 + 2 \times 1000 \times 3) \times 30 \text{ Wh} = 252 \text{ kWh}$$

$$\text{Load factor} = \frac{\text{average load}}{\text{maximum demand}} = \frac{350}{1500} = 0.2333$$

Example 1.2 There are four consumers of diversity having different load requireme different timings.

Consumer 1

Average load = 1 kW

Maximum demand = 5 kW at 8 p.m.

Consumer 2

Maximum demand = 2 kW at 9 p.m.

Demand of 1.6 kW at 8 p.m.

Daily load factor = 0.15

Consumer 3

Maximum demand = 2 kW at 12 noon

Load of 1 kW at 8 p.m.

Average load of 500 W

Consumer 4

Maximum demand = 10 kW at 5 p.m.

Load of 5 kW at 8 p.m.

Daily load factor = 0.25

The maximum demand of the system occurs at 8 p.m. Determine

(a) the diversity factor,

(b) average load and load factor of each consumer,
(c) average load and load factor of the combined load.

Solution

Consumer 1

Average load = 1 kW

$$\text{Load factor} = \frac{\text{average load}}{\text{maximum demand}} = \frac{1}{5} = 0.2$$

Consumer 2

Load factor = 0.15

Average load = load factor × maximum demand = $0.15 \times 2 = 0.3$ kW = 300 W

Consumer 3

Average load = 500 W

$$\text{Load factor} = \frac{500}{2000} = 0.25$$

Consumer 4

Load factor = 0.25

Average load = L.F. × M.D. = $0.25 \times 10 = 2.5$ kW

Combined average load = 1000 + 300 + 500 + 2500 = 4300 W = 4.3 kW

Combined maximum demand = 5 + 2 + 2 + 10 = 19 kW

At 8 p.m. the maximum demand = 5 + 1.6 + 1 + 5 = 12.6 kW

$$\text{Diversity factor} = \frac{\text{combined maximum demand}}{\text{actual maximum demand}} = \frac{19}{12.6} = 1.507$$

$$\text{Load factor} = \frac{\text{combined average load}}{\text{actual maximum demand}} = \frac{4.3}{12.6} = 0.341$$

Example 1.3 Determine the maximum value of a load which consumes 600 kWh per day at a load factor of 0.45. If the consumer increases the load factor to 0.65 without increasing the maximum demand, determine the consumption of energy in kWh.

Solution

$$\text{Load factor} = \frac{\text{energy consumed in 24 h}}{(\text{maximum demand in kW}) \times 24}$$

$$0.45 = \frac{600}{(\text{maximum demand}) \times 24}$$

$$\therefore \quad \text{maximum demand} = \frac{600}{24 \times 0.45} = 55.55 \text{ kW}$$

In the second case the load factor is 0.65.

$$\text{Energy consumed in 24 h} = (\text{load factor}) \times (\text{maximum demand in kW}) \times 24$$
$$= 0.65 \times 55.55 \times 24 = 866.6 \text{ kWh}$$

Example 1.4 Plot the load duration curve from the chronological load curve shown in Fig. 1.1 (a).

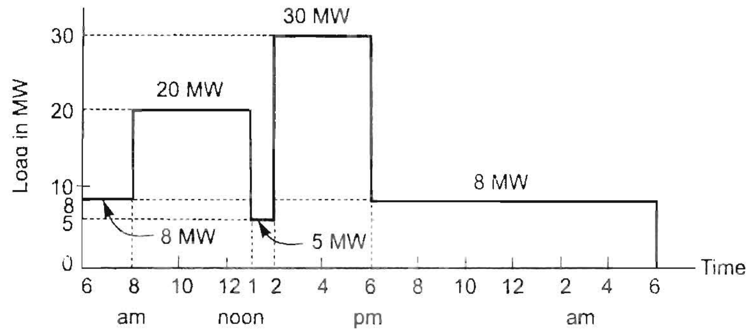

Fig. 1.1. (a) Chronological load curve.

Solution

The data available from the given chronological load curve are tabulated as follows. Here the total time is 24 hours or 100%.

Load in MW	Hours in a day	Time in percentage
30	4	$\frac{4}{24} \times 100 = 16.67\%$
20	4 + 5 = 9	$\frac{9}{24} \times 100 = 37.5\%$
8	2 + 4 + 5 + 12 = 23	$\frac{23}{24} \times 100 = 95.83\%$
5	4 + 5 + 2 + 12 + 1 = 24	$\frac{24}{24} \times 100 = 100\%$

The load duration curve is shown in Fig. 1.1 (b).

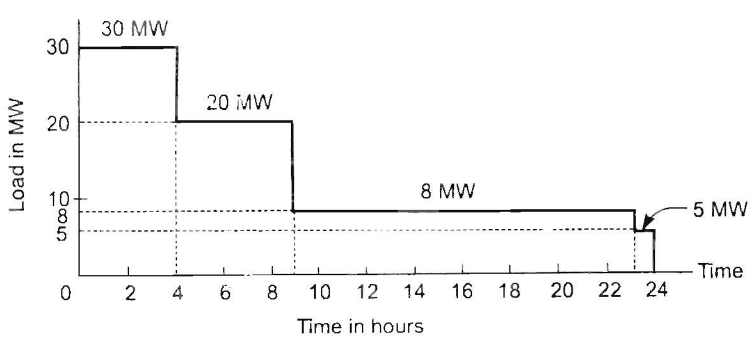

Fig. 1.1. (b) Load-duration curve.

Example 1.5 The load-duration curve for a system is shown in Fig. 1.2. Determine the load factor.

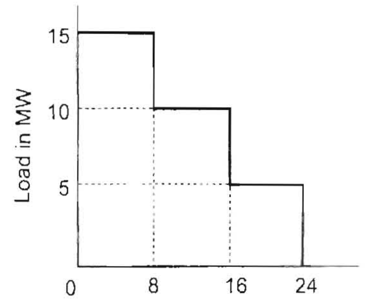

Fig. 1.2.

Solution

From the load-duration curve, the actual energy consumed $= 15 \times 8 + 10 \times 8 + 5 \times 8 = 240$ MWh

$$\text{Average load} = \frac{240}{24} = 10 \text{ MW}$$

Maximum demand = 15 MW

$$\text{Load factor} = \frac{\text{average load}}{\text{maximum demand}} = \frac{10}{15} = 0.666$$

Example 1.6 The yearly load duration curve of a power plant is a straight line. The maximum load is 500 MW and the minimum load is 400 MW. The capacity of the plant is 750 MW. Find (a) plant capacity factor, (b) load factor, (c) utilization factor, (d) reserve capacity.

Solution

$$\text{Average annual load} = \frac{500 + 400}{2} = 450 \text{ MW}$$

$$\text{Capacity factor} = \frac{\text{average annual load}}{\text{capacity of the plant}} = \frac{450}{750} = 0.6$$

$$\text{Load factor} = \frac{\text{average load}}{\text{maximum demand}} = \frac{450}{500} = 0.9$$

$$\text{Utilization factor} = \frac{\text{maximum demand}}{\text{capacity of the plant}} = \frac{500}{750} = 0.667$$

Reserve capacity = plant capacity – maximum demand = 750 - 500 = 250 MW

Example 1.7 A power system had the daily load curve given by the following table :

Time	Load in MW
12.00 night to 2 a.m.	20
2 a.m. to 8 a.m.	10
8 a.m. to 12.30 noon	50
12.30 noon to 1.00 p.m.	40
1.00 p.m. to 6 p.m.	50
6 p.m. to 12 night	70

Plot the following curves :

(a) Chronological load curve

(b) Load-duration curve

(c) Load-energy curve

Calculate the load factor and the utilization factor of the plant if the installed capacity MW.

Solution

The chronological load curve and load-duration curve are plotted in Figs. 1.3 (a) and respectively.

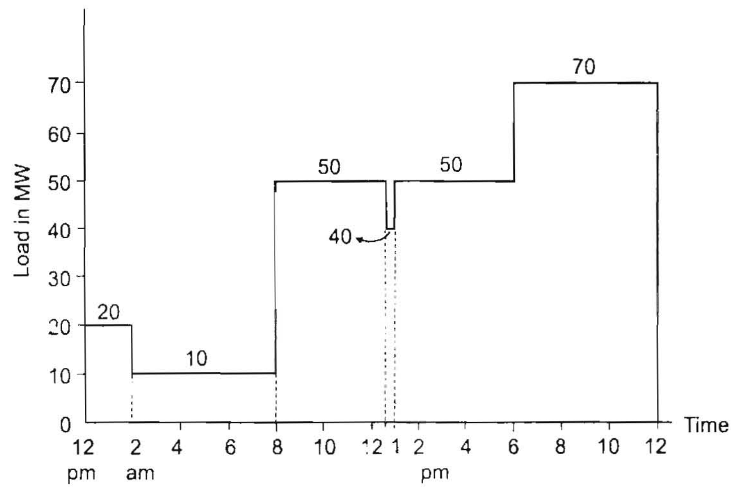

Fig. 1.3. (a) Chronological load curve.

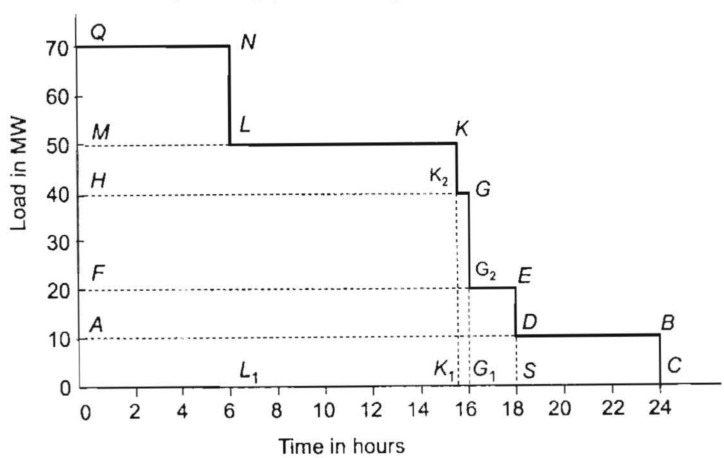

Fig. 1.3. (b) Load-duration curve.

Maximum demand of the system = 70 MW

Energy produced by the system in 24 hours = area under chronological load curve

= area under load duration curve

$= 70 \times 6 + 50 \times 9.5 + 40 \times 0.5 + 200 \times 2 + 1$

= 1015 MWh

$$\text{Daily load factor} = \frac{\text{total energy generated}}{\text{maximum demand} \times 24} = \frac{1015}{70 \times 24} = 0.604$$

$$\text{Utilization factor} = \frac{\text{maximum demand}}{\text{installed capacity}} = \frac{70}{100} = 0.7$$

Plotting of load energy curve

The load energy curve is the plot of the cumulative integration of the area under the load curve starting from zero load versus the particular load. The load energy curve is derived easily from the load-duration curve. The table is prepared by taking the area of the curve under successive loads as follows :

Table for plotting load-duration curve

Load	70	50	40	20	10
Duration in hours	6	9.5	0.5	2	6

Table for plotting load-energy curve

Load (MW)	Area (Energy at different load levels) (MWh)	Corresponding point on the graph
0	$0 = 0$	O
10	$\text{OABC} = A_1 = 240$	P_1
20	$\text{OFES} + A_1 = 420$	P_2
40	$\text{OHGG}_1 + A_2 + A_1 = 740$	P_3
50	$\text{OMKK}_1 + A_3 + A_2 + A_1 = 895$	P_4
70	$\text{OQNL}_1 + A_4 + A_3 + A_2 + A_1 = 1015$	P_5

The different areas are calculated as follows :

$$\text{Area OABC} = \text{OA} \times \text{AB} = 10 \times 24 = 240 \text{ MWh}$$

$$\text{Area } A_1 = \text{SD} \times \text{DB} = 10 \times 6 = 60 \text{ MWh}$$

$$\text{Area } A_2 = \text{G}_1\text{G}_2 \times \text{G}_2\text{E} = 20 \times 2 = 40 \text{ MWh}$$

$$\text{Area } A_3 = \text{K}_2\text{K}_1 \times \text{K}_2\text{G} = 40 \times 0.5 = 20 \text{ MWh}$$

$$\text{Area } A_4 = \text{L}_1\text{L} \times \text{LK} = 50 \times 9.5 = 475 \text{ MWh}$$

$$\text{Area } A_5 = \text{OQ} \times \text{QN} = 70 \times 6 = 420 \text{ MWh}$$

The load energy curve is plotted by taking load as abscissa and energy as ordinate. This curve is shown in Fig. 1.3 (c).

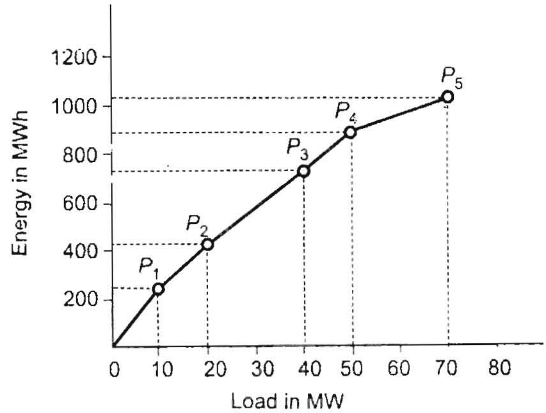

Fig. 1.3. (c) Load-energy curve.

Example 1.8 Find the diversity factor of a power station which supplies the following loads :

Load A : Motor load of 150 kW between 10 a.m. to 7 p.m.
Load B : Lighting load of 50 kW between 7 p.m. and 11 p.m.
Load C : Pumping load of 55 kW between 3 p.m. and 10 a.m.

Solution

Sum of individual maximum demands = 150 + 50 + 55 = 255 kW

The total load on the power station is as follows :

Time	Load
10 a.m. to 3 a.m.	150 kW
3 p.m. to 7 p.m.	150 + 55 = 205 kW
7 p.m. to 11 p.m.	50 + 55 = 105 kW
11 p.m. to 10 a.m.	55 kW

The above table shows that the coincident maximum demand of the whole system is 205 kW.

$$\therefore \quad \text{diversity factor} = \frac{\text{sum of individual maximum demands}}{\text{coincident maximum demand of the whole system}} = \frac{255}{205} = 1.2439$$

Example 1.9 A power station supplies the peak loads of 25 MW, 20 MW, and 30 MW to three localities. The annual load factor is 0.60 pu and the diversity of the load at the station is 1.65. Calculate (a) the maximum demand on the station, (b) the installed capacity, and (c) the energy supplied in a year.

Solution

(a) $$\text{Diversity factor} = \frac{(\text{sum of individual maximum demands})}{(\text{maximum demand on the station})}$$

$\therefore$ maximum demand on the station $= \dfrac{\text{sum of individual maximum demands}}{\text{diversity factor}}$

$$= \frac{(25 + 20 + 30)}{1.65} = 45.45 \text{ MW}$$

(b) Installed capacity = 25 + 20 + 30 = 75 MW

(c) Average load = load factor × maximum demand $= 0.6 \times \dfrac{75}{1.65}$ MW

Energy supplied per year $= \dfrac{0.6 \times 75}{1.65} \times 8760 = 238909$ MWh

EXERCISES

1. Define the following terms :
   Connected load, maximum demand, demand factor. load factor.
   What is the effect of the load factor on the cost of generation?
2 Define the term diversity factor. Prove that the load factor of a power system is improved by an increase in diversity factor.
3. Define the terms plant capacity factor and plant use factor and explain their importance in an electrical power system.
4. The load curve of an electrical system is linear with the following values at different times of the day :

Time	12 midnight	4 a.m.	9 a.m.	12 noon	5 p.m.	8 p.m.	12 midnight
Load (MW)	40	40	100	100	120	150	40

   Plot the following curves :
   (a) Chronological load curve
   (b) Load-duration curve
   (c) Load-energy curve
   Calculate the energy required by the system in one day and the system daily load factor.
5. The load on a power station on a typical day is as follows :

Time	Load (MW)
12 midnight to 6 a.m.	40
6 a.m. to 10 a.m.	60
10 a.m. to 6 p.m.	120
6 p.m. to 10 p.m.	180
10 p.m. to 12 midnight	40

Plot the chronological load curve and load duration curve. Determine the load factor of the power station and the energy supplied by the power station in 24 hours.

If the installed capacity of the plant is 200 MW, determine the capacity factor and the utilization factor.

6. The maximum demand of a power station is 100 kW. The capacity factor is 0.6 and the utilization factor is 0.8. Find (a) load factor, (b) plant capacity, (c) reserve capacity, (d) annual energy production.
7. The maximum demand on a power station is 200 MW. If the annual load factor is 0.55, calculate the total energy generated in a year.
8. A generating station has a connected had of 600 MW and the maximum demand is 450 MW. The energy generated per year is 2×10^9 kWh. Calculate the demand factor and the load factor.
9. The yearly load duration curve of a power station is a straight line from 50 MW to 10 MW. Three alternators each of 20 MW are installed to meet the demand. Determine (a) the installed capacity, (b) plant factor, (c) maximum demand, (d) load factor and (e) utilization factor.

ANSWERS

4. 1995 MWh; 0.554 **5.** 0.518, 2240 MWh, 0.4667, 0.9

6. (a) 0.75, (b) 125 MW, (c) 25 MW, (d) 657000 MWh

7. 963600 MWh **8.** 0.75, 0.5074

9. (a) 60 MW, (b) 0.5, (c) 50 MW, (d) 0.6, (e) 0.833