Loads and Load Curves

2.1. INTRODUCTION

The usage of electricity is as per the needs of consumers. Load curves help is in understanding the changes in load requirements. Load factor, capacity factor and utilisation factor play an important role in generation planning one classification of power plants is base load and peak load plants.

2.2. ENERGY REQUIREMENTS

A power station feeds different types of consumers—domestic, commercial, industrial, agricultural etc. The present day power stations invariably feed a grid which delivers power to the load centres. The design of a power plant or system must take into account the future increase in load. For this purpose load forecasting studies have to be made to predict the increase in load in the next 30 years or so. A modern power station takes 5 to 10 years for completion and some hydro-electric stations take even longer time. As such the power system planning must be done about 20 years in advance. The estimate of power and the increase in generation capacity depend on maximum demand, the distribution and variation in demand and the energy requirements.

2.3. MAXIMUM DEMAND

Each device at the consumer terminals has its rated capacity. The connected load of a consumer means the sum of the continuous ratings of all the devices and outlets installed on his distribution circuit.

The maximum demand of a consumer means the maximum power that his circuit is likely to draw at any time. If all the devices and outlets were used simultaneously to the full extent, the maximum demand of the consumer would equal his connected load. Experience has shown that 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 maximum demand and the connected load are related by

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Connected Load}} \qquad \text{... (2.1)}$$

If a consumer has 10 bulbs each of 100 watt, his connected load is 1000 watt (assuming that no other electrical device exists in his premises). However he would not use all the 10 lamps simultaneously. At sometime of the day he may use only 3 bulbs, at another time only 2 and still at an another time six. If the maximum number of bulbs used by him simultaneously is six, his maximum demand is 600 watt and demand factor is 0.6.

Each device will run at its rated capacity at sometime during its operation. The demand factor indicates the contribution of the device towards the maximum demand of the consumer.

Demand factors for various types of loads vary within very wide limits. Some typical values are given in Table 2.1.

Table 2.1. Demand factors

Type of Load		*Demand Factor*
Residential	$\frac{1}{2}$ kW and less	0.7
	$\frac{1}{2}$ kW to 1 kW	0.6
	1 kW and above	0.5
Commercial		
	Restaurants, shops and offices,	0.7
	Educational institutions,	0.5
	Theatre, Cinema,	0.5
	Hotels	0.5
Industrial		
	Cottage (less than 5 kW)	0.8
	Small Scale (5 kW to 25 kW)	0.7
	Medium (25 kW to 100 kW)	0.6
	Large (More than 100 kW)	0.5

Example 2.1. A residential consumer has the following connected load: 8 bulbs of 100 W each, 2 fans of 60 W each and 2 light plug points of 100 W each. His use of electricity during a day is as under:

12 midnight to 5 am	one fan
5 am to 7 am	2 fans and one light point
7 am to 9 am	NIL
9 am to 6 pm	2 fans
6 pm to midnight	2 fans and 4 bulbs

Find (*a*) connected load (*b*) maximum demand (*c*) demand factor (*d*) energy consumed during 24 hours (*e*) energy consumed in 24 hours if all devices are used all the day.

Solution. (*a*) Connected load = 8 × 100 + 2 × 60 + 2 × 100 = 1120 W

(*b*) Total wattage at different times is

12 midnight to 5 am	60 W
5 AM to 7 am	2 × 60 + 1 × 100 = 220 W
7 AM to 9 am	NIL
9 AM to 6 pm	2 × 60 = 120 W
6 PM to midnight	2 × 60 + 4 × 100 = 520 W

The maximum demand is 520 W

(*c*) Demand factor $= \frac{520}{1120} = 0.464$

(*d*) Energy consumed

from 12 midnight to 5 am	60 × 5 = 300 Wh
from 5 am to 7 am	220 × 2 = 440 Wh
from 7 am to 9 am	NIL
from 9 am to 6 pm	120 × 9 = 1080 Wh
from 6 pm to 12 midnight	520 × 6 = 3120 Wh

Total energy consumed during 24 hours = 300 + 440 + 1080 + 3120
= 4940 Wh = 4.94 kWh

(*e*) If all devices are used throughout the day, the energy consumed is
= 1120 × 24 = 26880 Wh
= 26.88 kWh

2.3.1. Group Diversity Factor. The load actually used by a consumer at any time during a day depends on his requirements at that time. Since the requirements at different times are different, the load varies from instant to instant during the day.

The electric supply authorities have to make provision for generation, transmission and distribution facilities to supply loads to different consumers. The investment in all these facilities is proportional to kVA ratings of these equipments. Therefore every electric supply authority has to make a reasonable estimate of the maximum kVA demand of the area supplied by it.

In every area there are a number of consumers. Let the number of consumers served by one particular distribution transformer be 8. This group of 8 consumers will have different electrical gadgets at their premises and each consumer will use the gadgets as per his requirement. Each one of the consumers will have a certain maximum demand. However, it is likely that the maximum demands of different consumers occurs at different times. This is due to different habits and requirements of these 8 consumers. If this happens, the maximum demand of the group will be less than the sum of their maximum demands. The contribution of the maximum demand of a consumer to the power requirements of the group depends on the group diversity factor

$$\text{Group Diversity Factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand of the group}} \quad \text{... (2.2)}$$

The group diversity factor is always greater than unity. The consumers maximum demand divided by the group diversity factor will determine his effective demand at the distribution transformer.

Example 2.2. A group of 2 consumers has the following electricity demand pattern on a typical winter day:

Consumer A: Connected load	2.5 kW
Load from 12 midnight to 5 am	100 W
from 5 am to 6 am	1.1 kW
from 6 am to 8 am	200 W
from 8 am to 5 pm	NIL
from 5 pm to 12 midnight	500 W
Consumer B: Connected load	3 kW
Load from 11 pm to 7 am	NIL
from 7 am to 8 am	300 W
from 8 am to 10 am	1 kW
from 10 am to 6 pm	200 W
from 6 pm to 11 pm	600 W

(*a*) Calculate demand factors of both consumers. (*b*) Plot the variation in demand versus time of the day for each consumer and the group. (*c*) Find group diversity factor. (*d*) Find energy consumed by each consumer in 24 hours. (*e*) Find the maximum energy which each consumer would consume in 24 hours if his load were constant and equal to his maximum demand. (*f*) Find the ratio of actual energy to maximum energy for each.

Solution. (*a*) Maximum demand of consumer A = 1.1 kW

Demand factor of consumer A

$$= \frac{1.1}{2.5} = 0.44$$

Maximum demand of consumer B $= 1$ kW

Demand factor of consumer B $= \frac{1}{3} = 0.333$

(*b*) The variation in demand versus time curves are plotted and shown in Fig. 2.1. This curve is known as chronological load curve. This is further discussed in sections 2.5 and 2.6.

By adding the demands of the two consumers at different times, we can plot the chronological load curve of the group. This is shown in Fig. 2.2.

(*c*) From Fig 2.2 it is seen that maximum demand of the group is 1100 W

$$\text{Group diversity factor} = \frac{1100 + 1000}{1100} = 1.909$$

(d) Energy consumed by A during 24 hours

$$= 100 \times 5 + 1100 \times 1 + 200 \times 2 + 500 \times 7 = 5500 \text{ Wh} = 5.5 \text{ kWh}$$

It is seen that energy consumed by A is equal to the area under the chronological load curve A. Thus the area under a chronological load curve is equal to energy consumed during 24 hours.

Energy consumed by B during 24 hours

$$= 300 \times 1 + 1000 \times 2 + 200 \times 8 + 600 \times 5 = 6900 \text{ Wh} = 6.9 \text{ kWh}$$

This is equal to the area under load curve B.

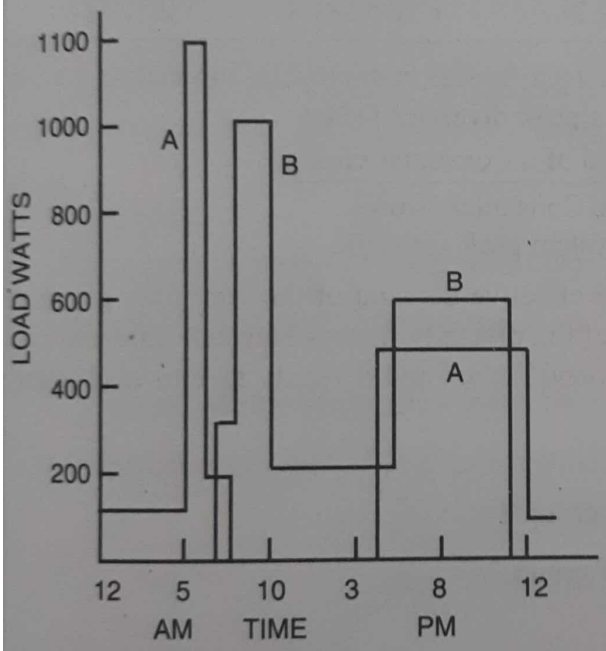

Fig. 2.1

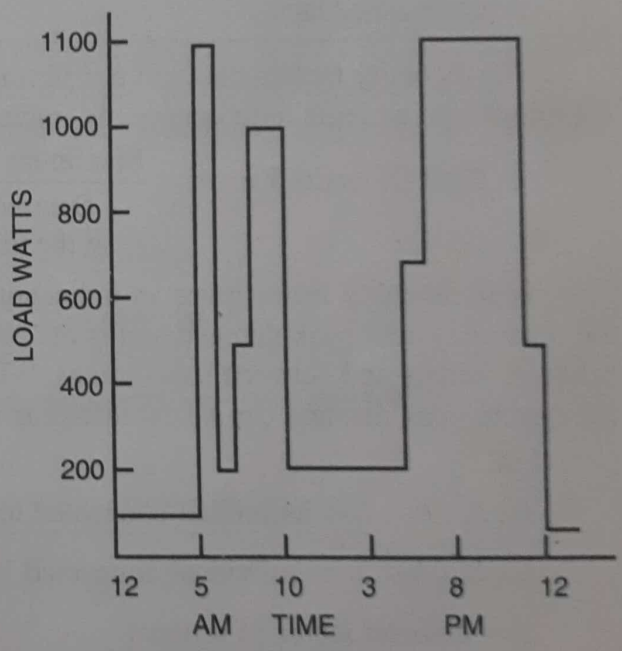

Fig. 2.2

(*e*) Maximum energy which A could consume in 24 hours $= 1.1 \times 24 = 26.4$ kWh

Maximum energy which B could consume in 24 hours $= 1 \times 24 = 24$ kWh

(*f*) For A, $\frac{\text{Actual energy}}{\text{Maximum energy}} = \frac{5.5}{26.4} = 0.2083$

For B, $\frac{\text{Actual energy}}{\text{Maximum energy}} = \frac{6.9}{24} = 0.2875$

The ratio of actual energy to maximum energy of a consumer is known as load factor of the consumer. Similarly the ratio of actual energy to maximum energy of a group of consumers is the load factor of the group. The ratio of the actual energy to maximum energy of a system is the load factor of the system. This is discussed again in section 2.9.

It is seen from the results of example 2.2 that diversity between the two consumers has reduced the maximum demand of this group of two consumers. If their pattern of using electricity were similar the total maximum demand would have been 2.1 kW. Diversity has reduced the

$$\text{System peak demand} = \frac{\Sigma L_1 \times d_1}{G_1 \times p_1} + \frac{\Sigma L_2 \times d_2}{G_2 \times p_2} \quad \text{... (2.8)}$$

Example 2.3. A new residential-cum-shopping complex is to be electrified from an existing distribution system. It will have 600 apartments each having a connected load of 5 kW. The shopping complex will have 20 general purpose shops each having a connected load of 2 kW with demand factor of 0.8 and will have the following services in addition:

Service	*Connected load*	*Demand factor*
1 Flour mill	10 kW	0.7
1 Saw Mill	5 kW	0.8
1 Laundry	20 kW	0.65
1 Cinema	80 kW	0.5

The street lighting for the complex will consist of 200 tube lights of 40 watt each.

The residential load demand factor, group diversity factor and peak diversity factor may be assumed as 0.5, 3.0 and 1.25 respectively. The group and peak diversity factors for the commercial load may be taken as 2.0 and 1.6. The street lighting demand, group and peak diversity factors, may be taken as unity. Find the increase in peak demand of the system resulting from this complex. [*K.U.* 1992]

Solution.

Maximum demand of each appartment $= 5 \times 0.5 = 2.5$ kW

Maximum demand of 600 apartments $= \dfrac{600 \times 2.5}{3} = 500$ kW

Demand of 600 apartments at the time of the system peak $= \dfrac{500}{1.25} = 400$ kW

Maximum demand of total commercial complex

$$= \frac{20\times2\times0.8+10\times0.7+5\times0.8+20\times0.65+80\times0.5}{2}$$

$$= \frac{32+7+4+13+40}{2}$$

$$= 48 \text{ kW}$$

Demand of the commercial load at the time of the system peak $= \dfrac{48}{1.6} = 30$ kW

Demand of street lighting at the time of the system peak $= \dfrac{200 \times 40}{1000} = 8$ kW

Increase in system peak demand $= 400 + 30 + 8 = 438$ kW

2.3.3. Types of Load. The main types of load on a system are domestic, industrial, commercial, municipal, traction, agriculture etc. A graph showing the hourly variation in demand during the 24 hours of the day is called a chronological load curve. The chronological load curves follow a typical pattern for each of the above loads. Fig. 2.3 shows some typical chronological load curves for different types of loads.

Domestic or Residential Load. Residential load consists of lights, fans and appliances like radios, heaters, electric irons, refrigerators, coolers, electric water heaters, washing machines etc.

The small consumers may generally use all the light points simultaneously giving a demand fac of unity.

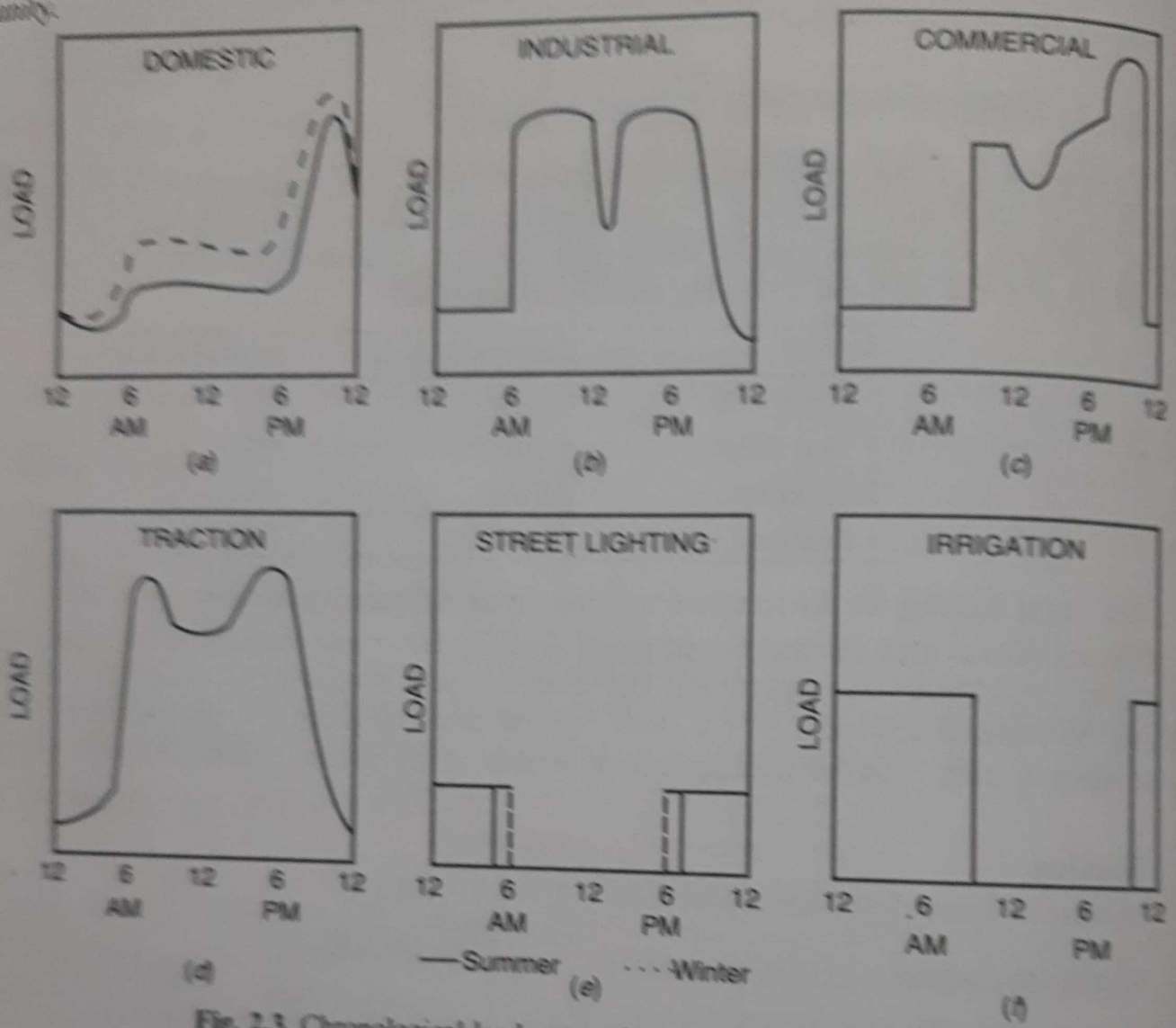

Fig. 2.3. Chronological load curves for different types of loads.

For big houses, the demand factor may be only around 0.5. During summer the major part domestic load may consist of referigerator load, fan load during day and light and fan load dur evenings. During winter, the major load is light load during evenings and early mornings and so heater load and referigerator load.

Industrial Load. The industrial load may be further sub-divided into small, medium a heavy. The chronological load curve for industrial load will depend on the number of shifts per d in the industry, the curve in Fig. 2.3 (*b*) referring to single shift industry. During night the load mostly lighting plus some loads like refrigeration load which require continuous supply. Around AM some machines start working and the load starts increasing. The shift starts at 8 AM and t load suddenly jumps to full value and remains almost constant throughout the day, except dur the lunch break, till the end of the shift. The demand factor may vary from about 0.8 for sm industries to about 0.5 for heavy industries. The demand factor, especially for small industri also depends on the nature of the industry.

Commercial Load. This load mainly consists of lighting, fans and small electric applianc The load is fairly constant from around 9 AM to 8 PM. During night the load may consist of so lighting load. The demand factor is fairly high.

Urban Traction Load. This load consists of tram cars, suburban trains and associated railw stations etc. From midnight to around 4 AM, the load is small and limited to [illegible] lighting lo Around 4 AM the trains start running and the load [illegible] and the maximum load [illegible]

start coming back to their homes. After 9 PM the load falls rapidly.

Municipal Load. This includes load for street lighting, water supply etc.

Street lighting load is practically constant during night thus giving a demand factor and diversity factor of unity. The switching on of the lights and their switching off is synchronised with dusk and dawn respectively. Hence the street lights function for a slightly shorter duration during summer than during winter. It is necessary to run separate distributors for street lighting to enable their switching simultaneously.

The load for water supply is for pumping water to the overhead tanks. It is generally possible to fit this load during system off-peak hours, usually occurring during night.

Irrigation Load. The load of the tube-wells used for irrigation may constitute a substantial portion of the system load. For some areas it may be more than even the industrial load. It is a general practice to energise tube-well feeders for about 12 hours a day during night. The demand factor and diversity factor are both almost unity.

2.4. VARIATION IN DEMAND, CHRONOLOGICAL LOAD CURVE

The system load which is a combination of all the above mentioned loads varies from instant to instant. A graph showing the variation of the system load during the 24 hours of the day is known as the system chronological load curve. The most important variations of this curve are the monthly and annual load curves each of which is the average of daily load curves over the period named.

A chronological load curve for a typical week day is different from that for a Sunday, that for a typical summer day being again different from that for a winter day. The curve for a typical metropolitan area is shown in Fig. 2.4.

During the early morning hours the demand is always low since almost all activities are at a low key. Around 5 am the load starts increasing as the industrial and traction loads start coming up. Around 9 am the load reaches a high value and remains almost constant till evening except for some dip at lunch time. The load again increases towards evenings as the residential and the traction loads increase. The system peak occurs around 5–8 pm and then the load decreases as almost all other loads, except residential, decrease after this time.

On Sundays the industrial loads are mostly absent and traction loads low. As such, Sundays depict a much lower demand. The loads on a Sunday being mostly residential, a Sunday load curve resembles a residential load curve.

During summer the residential loads come up at a time when industrial loads are over and traction loads are decreasing. As such the peak demand during summer is generally lower than that during winter.

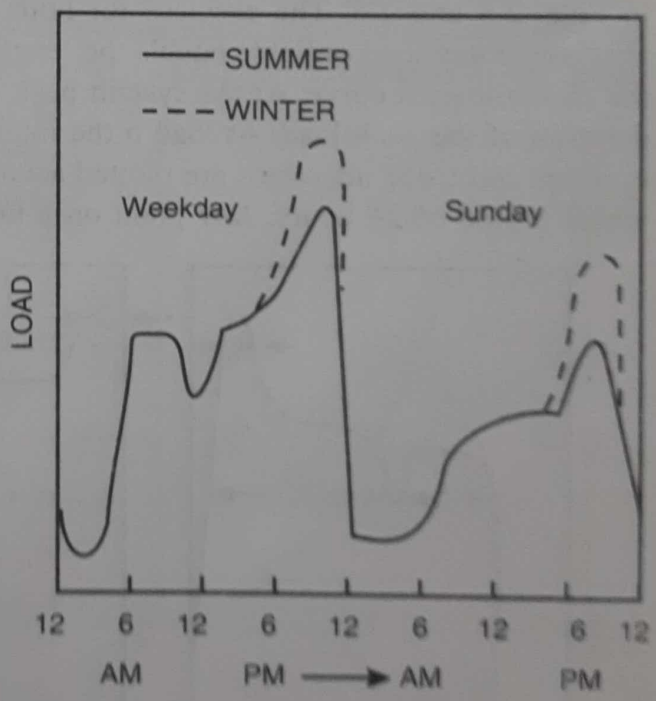

Fig. 2.4. Chronological load curve for a metropolitan area.

Chronological load curves reflect the activities of the population quite accurately. A cloudy or a rainy day shows a higher than normal load during the day and evening as compared to a clear day. Thunderstorms during the day usually result in sharp peak demands of short duration caused by switching on of the lights. Sometimes holiday crowds may tax the urban electric transport system, causing an increase an the load.

The industrial processes and domestic uses impose a highly variable load on the system. One consumer is likely to have a different load curve than the other and the third may have a still different one. This is all the result of the natural fact of the individual differences of the persons. However, as the number of consumers on a system increases, the effect of the individual differences and variations in daily activities is completely submerged into the effect of mass action. As such the daily load curve for one area is not likely to be much different from the curve for another similarly populated area.

The early morning dip in chronological load curve is typical of all metropolitan areas in all seasons. Some utilities, by offering low tariffs, persuade people to use energy during off-peak hours thereby easing the situation during system peak load hours. The generation cost to generate additional energy during light load periods is less than the average generation cost.

2.5. LOAD DURATION CURVE-ENERGY LOAD CURVE

Energy systems depict a considerable variation in demand. It is necessary, for system planning and operation, to know the total energy requirements and the duration of various loads.

The area under a chronological load curve gives the energy consumed (*i.e.* kWh) during the 24 hours.

A load duration curve is a re-arrangement of all the load elements of a chronological curve in a descending order. Thus it shows the total number of hours for which a particular load lasts during the day. The area under the load duration curve is, evidently, equal to the area under the chronological load curve. Since the curves are generally of irregular shape, the area can be determined only graphically.

A graphical method for obtaining a load duration curve from a chronological curve is shown in Figs. 2.5 and 2.6. The abscissa for both the curves is 24 hours. In load duration curve, the abscissa at any load ordinate equals the length of the abscissa intercepted by that load ordinate on the chronological curve. At the system peak load, the intercept is just a point, giving a zero hour duration of the peak load. At load b the intercept is b_1 hours and at load c the intercept is $c_1 + c_2$ hours and these intercepts are plotted accordingly. At minimum load L, the intercept covers the whole period of 24 hours. Any point on a load duration curve gives the number of hours, in the

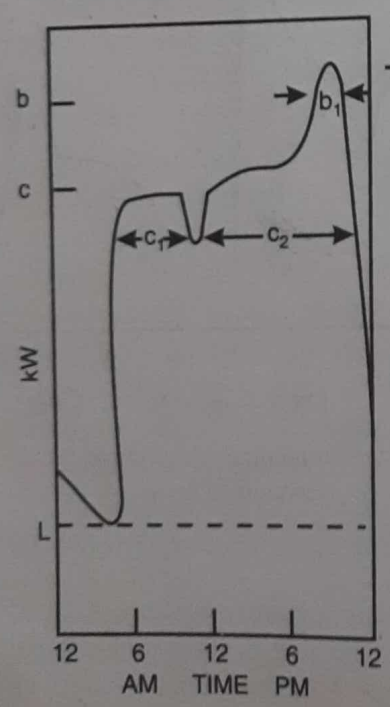

Fig. 2.5. Chronological curve.

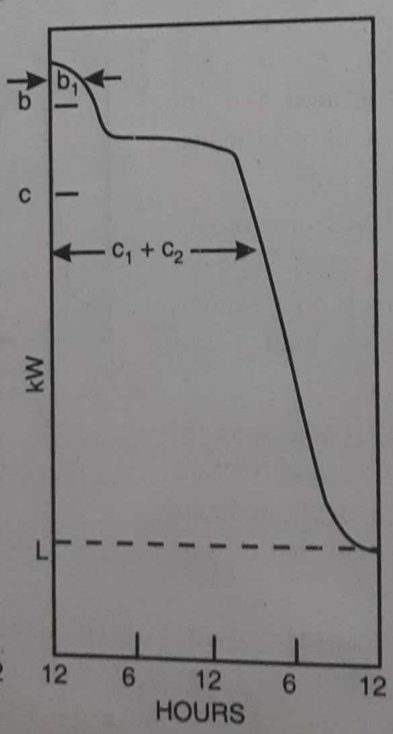

Fig. 2.6. Load duration curve.

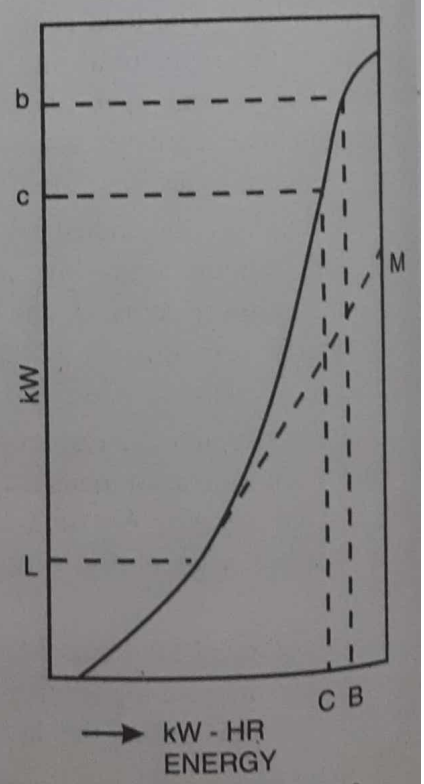

Fig. 2.7. Energy load curve.

24 hour period, during which the given load and higher loads prevail. If the loads were constant during the 24 hour period, both the chronological load curve and the load duration curve would be exactly similar and rectangular in shape. The load duration curve can be plotted for any period of time *e.g.* a week or a month or a year. The load duration curve plotted for 8760 hours *i.e.* a year is known as the yearly load duration curve (Fig. 2.8) and is particularly useful for economic studies of the stations. The abscissa can also be plotted as percentage of time (Fig. 2.8).

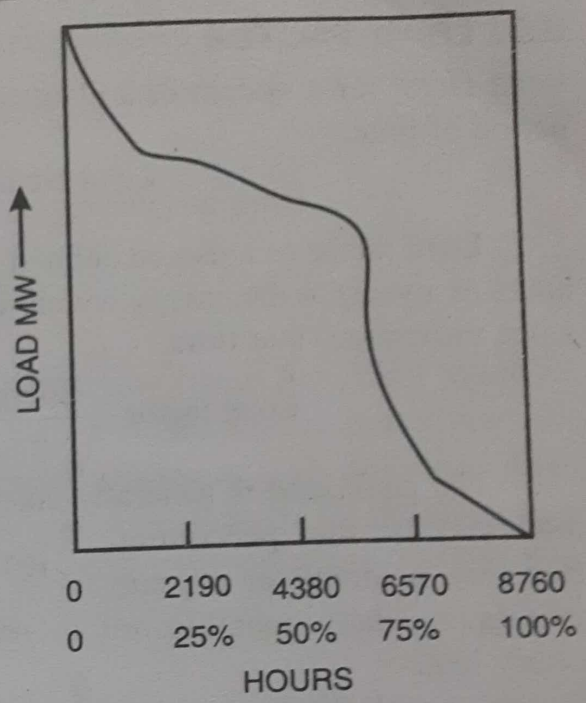

Fig. 2.8. Yearly load duration curve.

For hydro plants it is necessary to know the amount of energy between different demand levels. This can be found by plotting an energy load curve (Fig. 2.7) which can be derived from a chronological load curve or load duration curve. The energy load curve plots the cumulative integration of area under the load curve starting at zero load to the particular load. In Fig. 2.5 the minimum load is L-kW. Between zero and L, the energy is directly proportional to load and the energy load curve is a straight line. For each next element of load above the minimum load L, the elementary area is lesser because of the lesser duration for which the load lasts. As such the energy load curve depicts an increasing slope upto the peak load. The energy corresponding to the peak load is the total energy or the area under the load duration curve. The energy at loads *b* and *c* is B and C. Therefore, the energy included between the loads of *b* kW and *c* kW is (B – C) kWh. Extension of the initial straight line portion of the curve gives average load M. M represents the load value which the chronological and the load duration curve would have if they were of rectangular shape and contained the same total energy.

From the energy load curve, the kilowatts of load that can be carried on the base or peak, for a given number of kilowatt-hours per day available from a source like river flow, can be easily determined.

2.6. MASS CURVE

A mass curve is plotted with energy (say in kilowatt-hours) as ordinate and time as abscissa. Thus a mass curve gives the total energy used by the load upto each hour of the day. The mass curve can be easily plotted from the chronological load curve by summing up the energy consumed upto different times starting at the zero time. For the chronological curve of Fig. 2.5, the mass curve is as shown in Fig. 2.9.

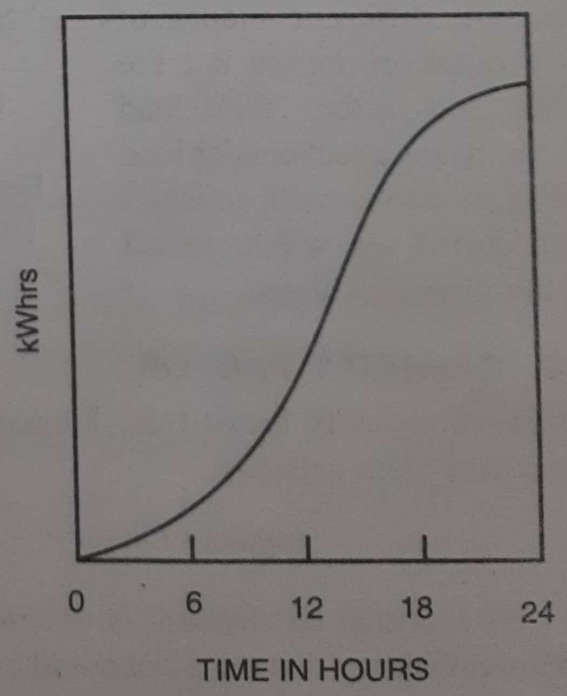

Fig. 2.9. Mass Curve.

2.7. LOAD FACTOR

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

$$\text{Load factor} = \frac{\text{Average load}}{\text{Peak Load}} \quad \text{... (2}$$

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

$$\text{Load factor} = \frac{\text{Energy consumed during a time of } t \text{ hours}}{\text{Peak load} \times t} \quad \text{... (2}$$

The peak load is generally taken as that prevailing for a half hour period and the aver load may be that pertaining to a day, a month or a year, thus giving daily, monthly or yearly load factor. Load factor has an effect on power plant design, operation and cost of generation as discussed in section 3.8.

The load factor depicts the variation of load during a certain period but it does not give any indication of the shape of the load duration curve. Fig. 2.10 depicts different systems having the same maximum demand, different shapes of load duration curves but the same load factor. 100% load factor means a rectangular load duration curve with constant load during the whole period of the time considered.

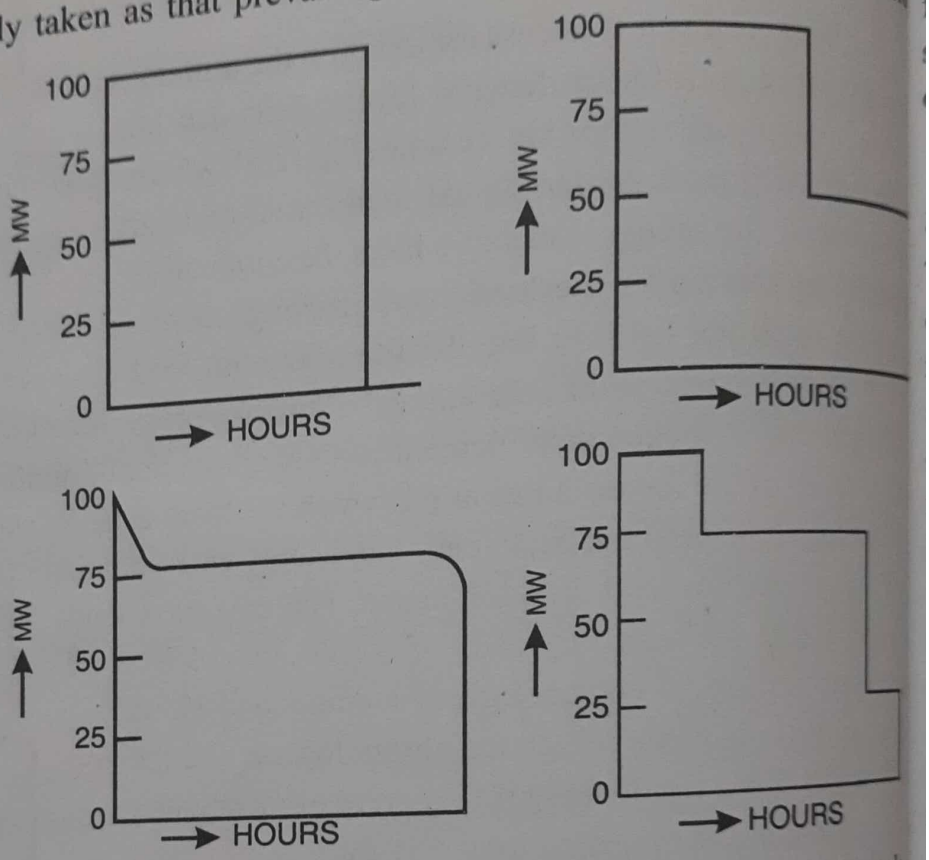

Fig. 2.10. Load duration curves having equal maximum demands (100 MW) and the same load factor (75%) but different shapes.

2.8. CAPACITY FACTOR

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

$$\text{Capacity Factor} = \frac{\text{Average Annual Load}}{\text{Rated Plant Capacity}} \quad \text{... (2}$$

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

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

$$\text{Capacity Factor} = \frac{\text{Maximum Load}}{\text{Plant Capacity}} \times \text{Load Factor} \quad \text{... (2}$$

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

2.9. UTILISATION FACTOR

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

$$\text{Utilisation factor} = \frac{\text{Maximum Load}}{\text{Rated Plant Capacity}} \quad \text{... (2.13)}$$

The utilisation factor for a plant depends on the use to which the plant is put. A low utilisation factor means that the plant is either a standby plant or has been installed to take into account the future increase in the load. For a power plant, in an integrated system, a high utilisation factor shows that the plant is probably the most efficient in the system. Since loads in excess of rated capacity are also carried, sometimes, utilisation factor may be more than unity. It is evident that

$$\text{Capacity Factor} = (\text{Load Factor}) \times (\text{Utilisation Factor}) \quad \text{... (2.14)}$$

2.10. BASE LOAD AND PEAK LOAD PLANTS

The system load varies from time to time. A typical chronological curve is as shown in Fig. 2.11. The maximum demand is *M*. If the total demand is supplied from one power plant having an installed capacity *M* (or somewhat higher to keep some reserve capacity), the plant will be running under loaded most of the time, thus making the operation uneconomical. A better method is to divide the load into two portions, one below the line AB and the other above the line AB. These loads are referred to as base load and peak load respectively. These two loads are supplied from separate plants called the base load plant and the peak load plant. A base load plant operates at a high load factor and should be one which has low operating costs. The peak load plant operates at a low load factor. Sometimes the load curve can be divided into three portions *i.e.* base load, intermediate load and peak load.

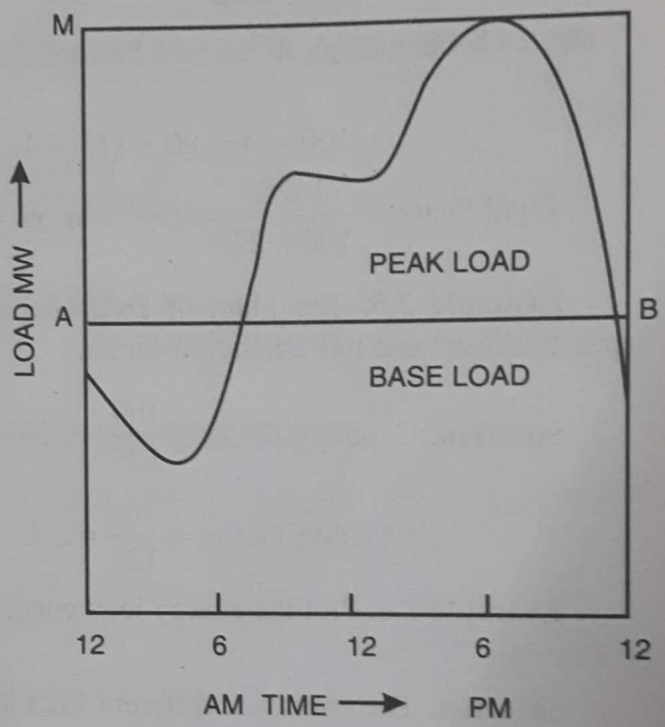

Fig. 2.11. Base load and peak load.

Example 2.4. The load on a power plant on a typical day is as under:

Time	12-5 am	5-9 am	9-6 pm	6 pm-10 pm	10 pm-12 am
Load (MW)	20	40	80	100	20

Plot the chronological load curve and load duration curve. Find the load factor of the plant and the energy supplied by the plant in 24 hours. **[AMIE 2004]**

Solution. The chronological load curve is plotted in Fig. 2.12. The duration of loads is as under:

Load (MW)	100	80 and above	40 and above	20 and above
Duration (Hours)	4	13	17	24

The load duration curve is plotted in Fig. 2.13. The energy produced by the plant in 24 hours is

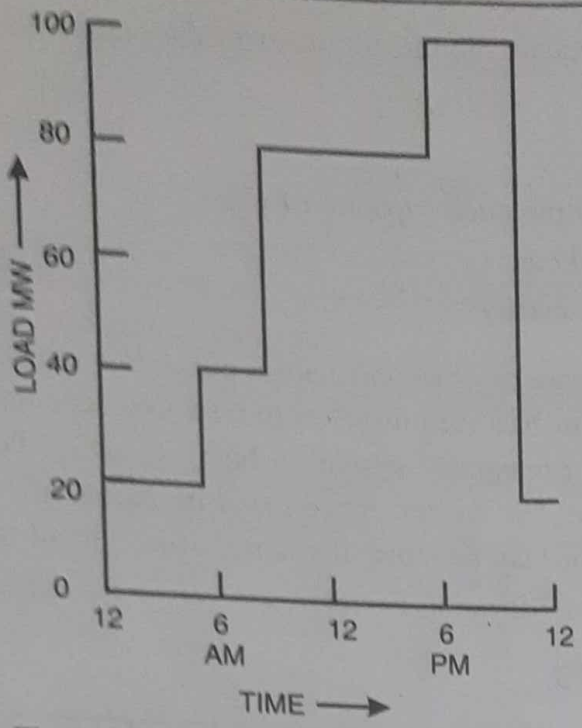

Fig. 2.12. Chronological curve for Example 2.4.

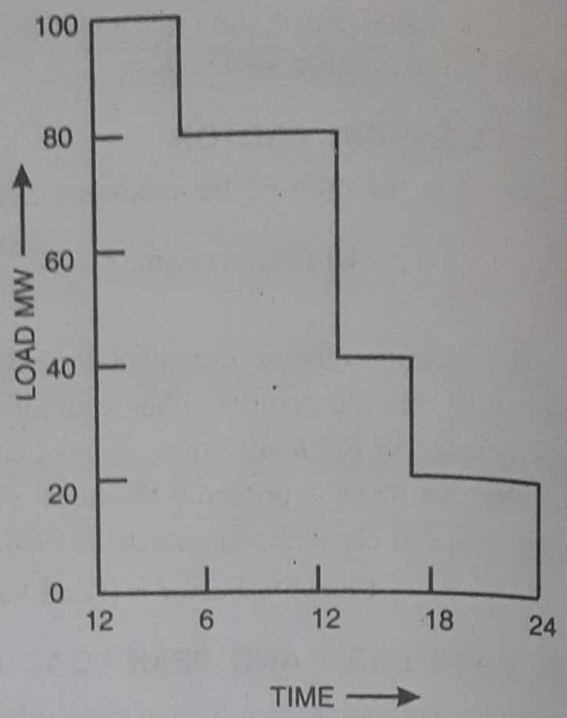

Fig. 2.13. Load duration curve for Example 2.4.

$$= 100 \times 4 + 80 \times (13 - 4) + 40\,(17 - 13) + 20\,(24 - 17) = 1420 \text{ MWh}$$

$$\text{Load factor} = \frac{1420}{100 \times 24} = 0.5917 \text{ or } 59.17\%$$

Example 2.5. The plant of Example 2.4 has an installed capacity of 125 MW. Find the capacity factor and the utilisation factor.

Solution. Capacity factor $= \frac{100}{125} \times 0.5917 = 0.473$

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

Example 2.6. Plot the energy load curve and the mass curve for the chronological load curve of Example 2.4.

Solution. The energy at different load levels is as under:

Load = 20 MW, Energy = $24 \times 20 = 480$ MWh

Load = 40 MW, Energy = $480 + 20 \times 17 = 820$ MWh → 24 − 7 (duration of 20 MW load)

Load = 80 MW, Energy = $820 + 40 \times 13 = 1340$ MWh − 24 − 7 − 4 = 13.

Load = 100 MW, Energy = $1320 + 20 \times 4 = 1420$ MWh 13 − 9 = 4

The energy load curve is plotted in Fig. 2.14. The energy supplied upto different times of the day is as under:

Energy supplied upto 5 am = $20 \times 5 = 100$ MWh

Energy supplied upto 9 am = $100 + 40 \times 4 = 260$ MWh

Energy supplied upto 6 pm = $260 + 80 \times 9 = 980$ MWh

Energy supplied upto 10 pm = $980 + 100 \times 4 = 1380$ MWh

Energy supplied upto 12 pm = $1380 + 20 \times 2 = 1420$ MWh

The mass curve is plotted in Fig. 2.15.

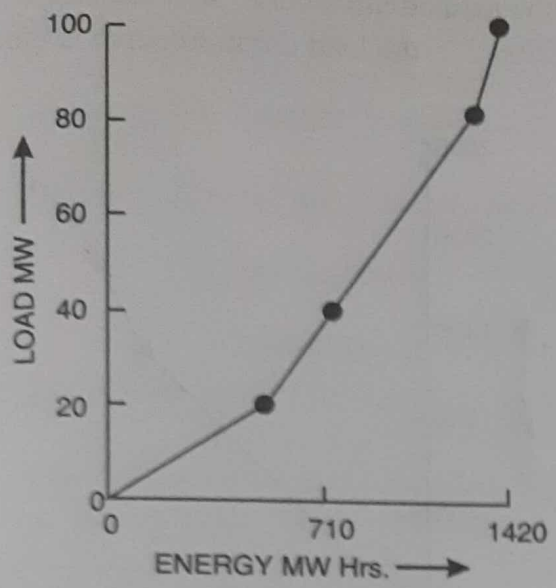

Fig. 2.14. Energy load curve for Example 2.4.

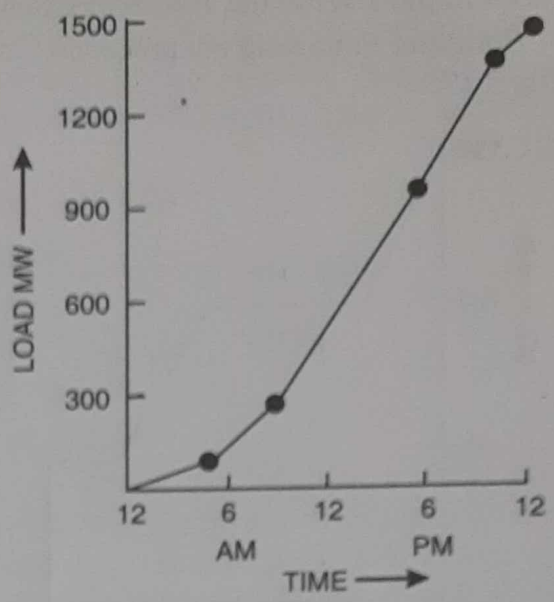

Fig 2.15. Mass curve for Example 2.4.

Example 2.7. The maximum demand of a power plant is 40 MW. The capacity factor is 0.5 and the utilisation factor is 0.8. Find (*a*) load factor (*b*) plant capacity (*c*) reserve capacity (*d*) annual energy production. [*P.U.* 1991]

Solution. (*a*) Load factor $= \dfrac{\text{Capacity factor}}{\text{Utilisation factor}} = \dfrac{0.5}{0.8} = 0.625$

(*b*) Plant capacity $= \dfrac{\text{Max. demand}}{\text{Utilisation factor}} = \dfrac{40}{0.8} = 50$ MW

(*c*) Reserve capacity = 50 – 40 = 10 MW

(*d*) Annual Energy Production = 40 × 0.625 × 8760 = 219000 MWh

Example 2.8. The load curve of an electrical system is linear with the following values at different times of the day:

Time	12	5 am	9	6	8 pm	10	12
Load (MW)	50	50	100	100	150	80	50

Plot chronological load curve. Find the energy required by the system in one day and the system daily load factor. [*P.U.* 1991]

Solution. The chronological load curve is plotted in Fig. 2.16.

Energy required by the system in 24 hours

$$= 50 \times 5 + \frac{100+50}{2} \times 4 + 100 \times 9 + \frac{100+150}{2} \times 2$$

$$+ \frac{150+80}{2} \times 2 + \frac{80+50}{2} \times 2$$

= 2060 MWh

Daily load factor $= \dfrac{2060}{150 \times 24} = 0.5722$ or 57.22%

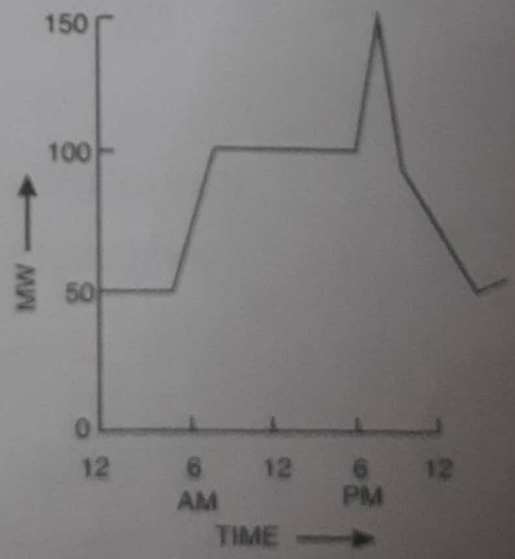

Fig. 2.16

Example 2.11. A power station is to supply 4 areas whose peak loads are 10000 kW, 6000 kW, 8000 kW and 7000 kW. The diversity factor of loads at the station is 1.5 and annual load factor is 65%. Find maximum demand on station and annual energy supplied. Suggest installed capacity, taking into account the increase in maximum demand by 60%, type of station and number and size of units. [*P.U.* 1994]

Solution. Sum of maximum demands = 31000 kW = 31 MW

$$\text{Maximum demand} = \frac{\text{Sum of max. demands}}{\text{Diversity factor}} = \frac{31}{1.5} = 20.667 \text{ MW}$$

$$\text{Annual energy} = 20.667 \times 8760 \times 0.65 = 117677.9 \text{ MWh}$$

$$\text{Increase in maximum demand} = 20.667 \times 0.6 = 12.4 \text{ MW}$$

$$\text{Installed capacity} = 20.667 + 12.4 = 33.067 \text{ MW}$$

For the above value of installed capacity the power station can be either a diesel station or a gas turbine plant. The diesel units are manufactured in small sizes and therefore this station will need too many units and the cost would be very high. A gas turbine plant with 2 units of 10 MW each and two units of 15 MW each would be suitable. The station will have a total installed capacity of 50 MW and thus will have sufficient reserve capacity also.

Example 2.12. The daily load curve data for a system is as under:

Week days

Time	12 – 5 am	–8 am	–12 noon	–1 pm	–5 pm	–9 pm	–12 pm
Load (MW)	100	150	250	100	250	350	150

Saturday and Sunday

Time	12 – 5 am	– 5 pm	– 9 pm	– 12
Load (MW)	100	150	200	150

Draw a load duration curve for the system for one week. Find the weekly load factor.

Solution. From the above data, the durations of different loads during one week are

Load	Duration
350 MW	$4 \times 5 = 20$ hours
250 MW	$20 + 8 \times 5 = 60$ hours
200 MW	$60 + 4 \times 2 = 68$ hours
150 MW	$68 + 6 \times 5 + 15 \times 2 = 128$ hours
100 MW	$128 + 6 \times 5 + 5 \times 2 = 168$ hours

The load duration curve is plotted in Fig. 2.19.

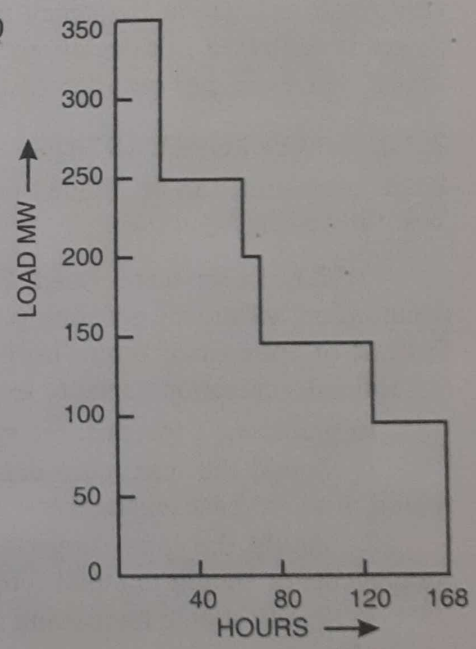

Fig. 2.19.

The total area under the load duration curve is 31600 MWh which represents the energy consumption in one week.

$$\text{Load Factor} = \frac{31600}{350 \times 24 \times 7} \times 100 = 53.7\%$$

Example 2.13. Find the annual load factor if the average daily load factor is 0.825, the ratio of average daily peak load to monthly peak load is 0.87 and the ratio of average monthly peak load to annual peak load is 0.78.

Solution. Annual load factor = $0.825 \times 0.87 \times 0.78 = 0.5598$.

2.11. EFFECT OF VOLTAGE AND FREQUENCY ON LOADS

The variation of active and reactive components of power with voltage and frequency is an important aspect of power system analysis and operation. The composite load at a sub-station

usually consists of: Induction motors 50-70%, Lighting and heating 20-10%, Transmission losses etc. 10-20%.

2.11.1. Effect of Voltage.

(*a*) *Lighting load.* Lighting loads do not consume any reactive power. Since the resistance of lighting devices is not constant, the active power does not vary as (voltage)^2 but approximately as (voltage)$^{1.6}$.

(*b*) *Heating*. The resistance is almost constant and active power varies as (voltage)^2.

(*c*) *Induction motors*. The performance of an induction motor can be analysed from its equivalent circuit. The active and reactive power vary with voltage in a rather complex manner. The effect also depends on whether the shaft torque is constant or varies with speed and also whether the motor is running at full load or less than full load. The decrease of voltage causes an increase in current so that the effect on power is small. If the shaft torque is constant, a 10% drop in voltage at full load condition may cause about 0.5% decrease in power. However if the voltage decreases appreciably (to about 0.8 pu) the power increases with further reduction in voltage.

(*d*) *Synchronous motors*. The active power does not depend on voltage and remains, more or less, constant. A reduction in voltage causes the vars to increase in the leading direction.

In most of the analysis the composite sub-station loads are represented by constant impedances so that both P and Q are assumed to vary as (voltage)^2 However it is only an approximate representation.

2.11.2. Effect of Frequency. The power consumed by a resistive load does not depend on frequency. However most of the loads are inductive in nature. The impedance of an inductive load depends on the frequency and therefore the power drawn by an inductive load depends on frequency. The analysis of the effect of frequency on motor load is rather complex. Since only very small changes in frequency are permissible, the effect of frequency on active and reactive power is neglected in calculations. However in load frequency control studies it is generally assumed that a one per cent decrease in frequency causes a one per cent decrease in active power.

2.12. LOAD FORECASTING

Load forecasting can be divided into two categories: Long term load forecasting and Short term load forecasting.

2.12.1. Long term Load Forecasting. It takes a pretty long time to plan, install and commission additional generating capacity. Generation system expansion planning starts with a forecast of anticipated future load requirements. Proper long term load forecasting is necessary for optimal generation capacity expansion.

In preparing a forecast, the system planner is confronted with the following questions:

1. Should the maximum demand be forecast using forecasted energy and load factors or should it be forecast separately.

2. Should the total forecast be obtained by combining the forecast of appropriate load components or should the total forecast be directly obtained from the historical load data.

3. Should simple forecasting method be used or should more formal mathematical procedures be employed.

Each of the above methodologies has its own advantages and limitations. No one approach is used by all the utilities consistently. Choosing the best method for a given system requires good judgement of the planner.

One method, used by many utilities, for long range load forecasting is extrapolation. Extrapolation technique involves fitting trend curves to basic historical data adjusted to reflect the growth trend itself. Once the trend curve is known, the forecast is found by evaluating the trend curve function at the desired future point. Some of the functions used in trend curve fitting are:

Straight line	$y = A + Bx$
Parabola	$y = A + Bx + Cx^2$
s curve	$y = A + Bx + Cx^2 + Dx^3$
Exponential	$y = Ce^{Dx}$
Gompertz	$y = ln^{-1} (A + Ce^{Dx})$
Combination	$y = A + Bx + Ce^{Dx}$

where y is the load in year x (with base year zero) and A, B, C, D are constants computed, generally, by the method of least squares.

If the uncertainty of extrapolated results is to be quantified using statistical entities like mean and variance, the basic technique becomes probabilistic extrapolation. The use of stochastic models to generate a forecast from random inputs derived from historical data has also been suggested but is not used in actual practice.

Another technique for load forecasting is correlation. This technique relates system loads to various demographic and economic factors. Typically factors like population, employment, industrial licenses, appliance saturation, weather data etc. are used in correlation techniques. However the forecasting of the demographic and economic factors is rather difficult.

2.12.2. Short term Load Forecasting. A precise short term load forecast is essentially for monitoring and controlling power system operation. The hourly load forecast with lead time upto one week in advance is necessary for on line solution of scheduling problems. A 24 hour load forecast is needed for successful operation of the power system. One hour forecast is important for on line real time control and security evaluation of a large power system.

Short term load forecasting techniques generally involve physical decomposition of load into components. The load is decomposed into a daily pattern reflecting the difference in activity level during the day, a weekly pattern representing the day of the week effect on load, a trend component concerning the seasonal growth in load and a weather sensitive component reflecting the deviations in load due to weather fluctuations. The random error can be statistically analysed to obtain a stochastic model for error estimation.

Thus the expected hourly load forecast is divided into five components and written as

$$Y(i, j) = ADP(j) + AWP(k, j) + WSC(i, j) + TR(i) + SEC(i, j) \quad \text{... (2.15)}$$

Where $Y(i, j)$ = load forecast for j th hour of i th day

$ADP(j)$ = average daily load pattern at j th hour

$AWP(k, j)$ = average weekly load increment pattern at j the hour and k th day of the week ($k = 1, 2... 7$)

$WSC(i, j)$ = weather sensitive component at j th hour of i th day

$TR(i)$ = trend component of load on i th day

$SEC(i, j)$ = stochastic error component which is assumed to be normally distributed.

The average daily pattern represents the hour of the day effect. It is an average of the daily load pattern over an optimal number of past days.

The average weekly pattern reflects the day of the week effect. It is calculated as the average of the weekly cycles over a certain number of past weeks.

The weather sensitive component represents the changes in customer requirements according to variations in weather conditions. Generally temperature is considered as the only weather variable since data banks for other weather variables like wind, humidity etc. are, usually, not available.

The trend component includes three components: a long term growth trend, a short term trend dependent on the economic cycle and a time of the year pattern.