Power Distribution Systems

Lecture 3

Load Characteristics

Load

A device that uses electrical energy is said to impose a load on the system. The term load has number of applications such as

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

Load

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

Load on power systems is split into the following:

- *Domestic load* — light, fans, refrigerators, heaters, and television
- *Commercial load* — lighting for shops, fans, and electric appliances used in restaurant
- *Industrial load* — industrial load consists of load demand by industries

Load

- *Municipal load* — street lighting, power required for water supply, etc.
- *Irrigation load* — electric power required for pumps
- *Traction loads* — tram cars, trolley bus, and railways
- *Electronics loads* — switched-mode power supply and filter circuit (capacitive loading)

Variable Load

The function of a power station is to de- liver 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.

The load changes with time due to uncertain and variable demands of the consumers and is known as ***variable load*.**

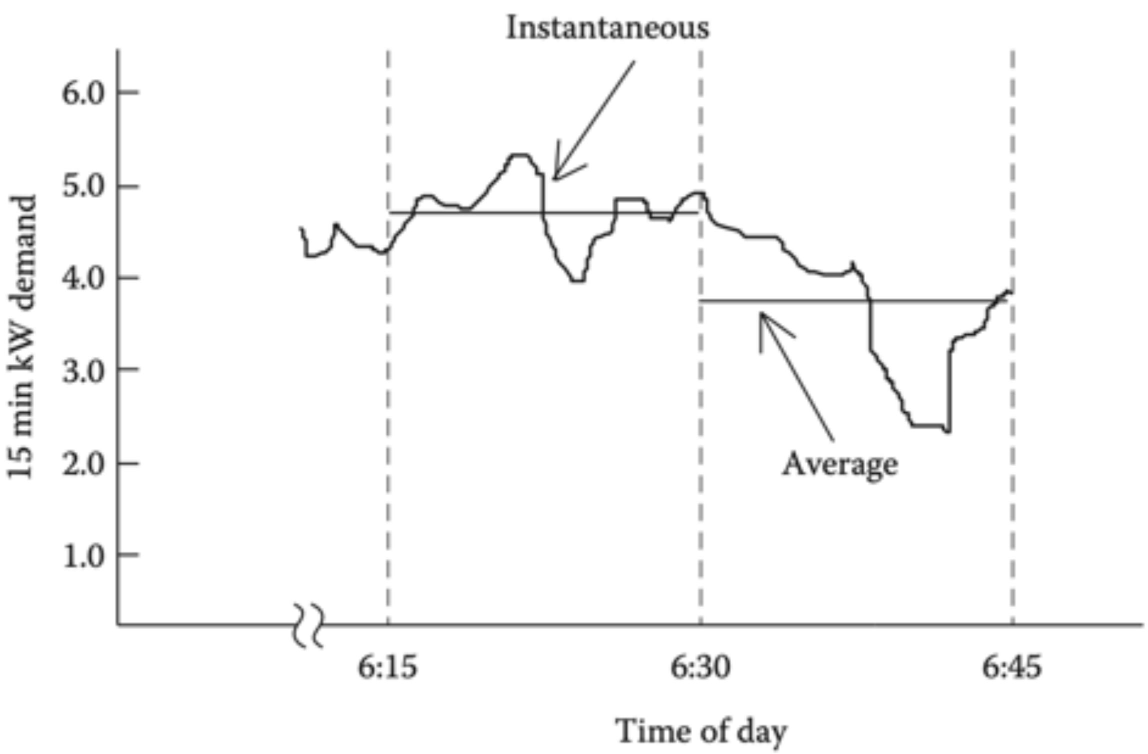
Effects of Variable Load

- *Need of Additional Equipment*
- *Increase in Production Cost*

Variable Load

Typical individual customer load variation is shown following figure. It is illustrated how the instantaneous kW load of a customer changes during two 15 min intervals.

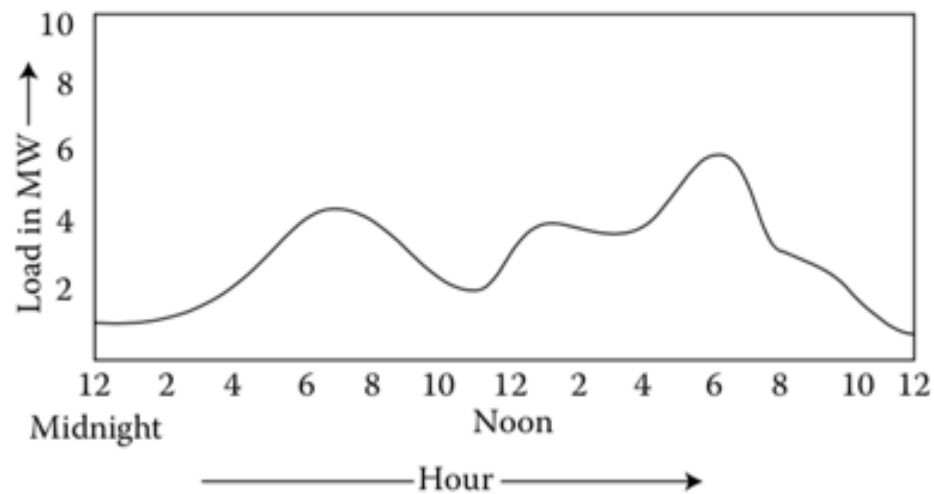
In order to define the load, the demand curve is broken into equal time intervals. In each interval, the average value of the demand is determined. The straight lines represent the average load in a time interval. The shorter the time interval, the more accurate will be the value of the load.



Load Curves

Load curve is a graphical representation between load (in kW or MW) and time (in hours). When it is plotted for 24 h a day, it is called *daily load curve*. If the time considered is 1 year (8760 h), then it is called the *annual load curve*.

It is to be noted that 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.



Load Curves

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

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

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

Load Curves

- 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 (LF).

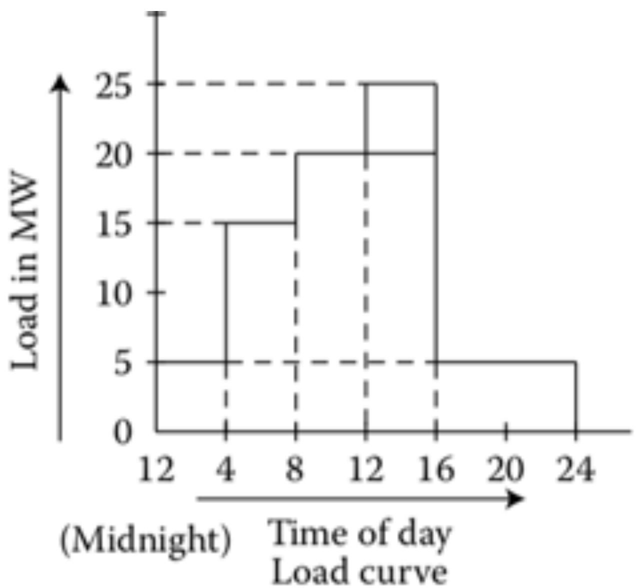
$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{\text{Average load} \times 24}{\text{Max. demand} \times 24}$$

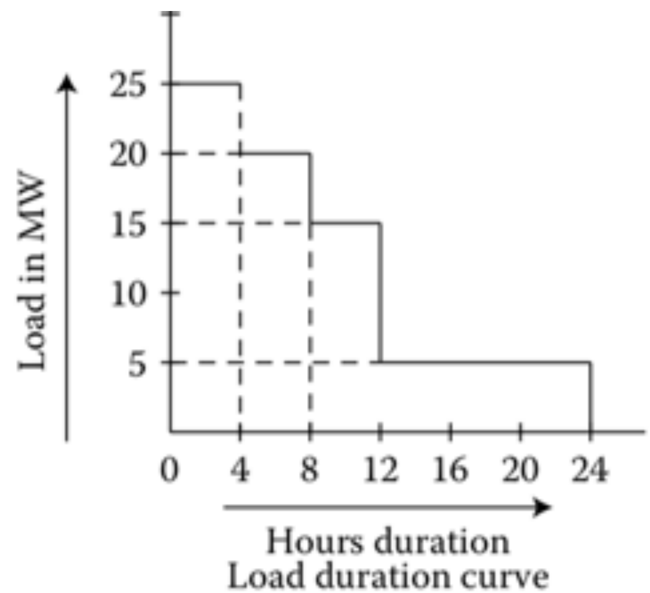
$$= \frac{\text{Area (in kWh) under daily load curve}}{\text{Total area of rectangle in which the load curve is contained}}$$

- The load curve helps in selecting the size and number of generating units.
- The load curve helps in preparing the operation schedule of the station.

Load Duration Curves

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*. The load duration curve is derived from the load curve and therefore, represents the same data as that of the load curve.





Load Duration Curves

Following information is obtained from load duration curve;

- It gives minimum load present throughout the given period.
- It enables the selection of base load and peak load power plants.
- Any point on the load duration curve gives the total duration in hours for the corresponding load and all loads of greater value.
- The areas under load curve and corresponding load duration curve are equal. Both areas represent the same associated energy during the period under consideration.

Connected Load and Demand

Connected load is the sum of continuous ratings of all loads connected to the system.
For instance, if a consumer has connections of five 200 W lamps and power point of 600 W, then connected load of the consumer is

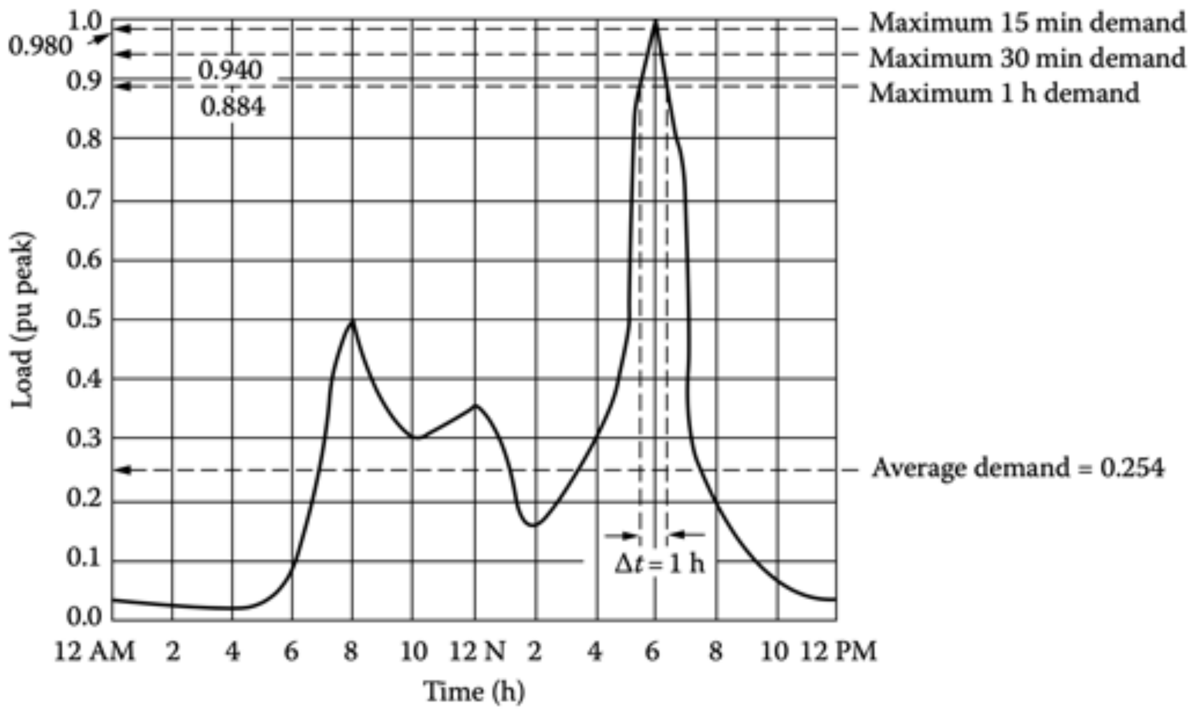
$$(5 \times 200 + 600 = 1600 \text{ W}).$$

The *demand* of a system is the load that is drawn from the source of supply at a receiving terminal averaged over a suitable and specified interval of time.
The load may be given in kW, kVAr, kVA, or ampere (A).

The *demand interval* is the period over which the load is averaged. This selected Δt period may be 15 min, 30 min, 1 h, or even longer.

Connected Load and Demand

The demand statement should express the demand interval Δ*t* used to measure it. Following figure shows a daily demand variation curve, or load curve, as a function of demand intervals. Note that the selection of both Δ*t* and total time *t* is arbitrary. The load is expressed in per unit (pu) of peak load of the system. For example, the maximum of 15-min demands is 0.980 pu, and the maximum of 1-h demands is 0.884, whereas the average daily demand of the system is 0.254.



Maximum Demand

The *maximum demand* is the highest demand of load during a given period. It is also called *peak demand*.

The concept maximum demand 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. 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.

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.

Demand Factor

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

$$\mathrm{DF} = \frac{\text{Max. demand}}{\text{Total connected load}}$$

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

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.

Demand Factor

The value of demand factor is usually less than 1. The demand factor depends 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

Average Demand (Average Load)

The average load occurring in a given period (day, month, or year) is known as average load or average demand.

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

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

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

Load Factor

The ratio of average load to the maximum demand during a given period is known as *load factor* (LF).

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

If the plant is in operation for *T* hours,

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

It would be ideal to have a flat-load curve. But in practice, load curves are far from flat. For a flat-load curve, the LF will be higher. Higher LF means more uniform load pattern with less variation in load.

Higher the load factor of the power station, lesser will be the cost per unit generated.

Load Factor

<u>Example 3.1</u> *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.*

Load Factor

<u>Example 3.2</u> *A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being 61·5 × 106 per annum. Calculate*

a) the demand factor and

b) load factor.

Diversity Factor

The ratio of the individual sum of maximum demands to the maximum demand is known as *diversity factor* .

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

A power station supplies load to various types of consumers whose maximum demands generally are not the same at the same time. Therefore, the maximum demand on the power station is always less than the sum of maximum individual demands of the consumers.

Diversity Factor

The value of diversity factor is usually more than unity. The diversity factor depends on the type of load and its magnitude.

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

Diversity Factor

Example 3.3 *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 × 105, determine

a) *the diversity factor and*
b) *annual load factor.*

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.

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

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

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

If the period is considered to be 1 year, then

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

Plant Capacity Factor

The plant capacity factor is a measure of the reserve capacity of the plant. A power station must be designed in such a way 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 maximum demand on the plant.

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

Plant Use Factor

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

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

Suppose a plant having installed capacity of 20 MW produces annual output of 7.35×10^6 kWh and remains in operation for 2190 h in a year. Then

$$\text{Plant use factor} = \frac{7.35\times10^6}{20\times10^3\times2190} = 0.167 = 16.7\%$$

Units Generated per Annum

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

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

$$\text{Average load} = \text{Max. demand} \times \text{LF}$$

$$\begin{aligned}\text{Units generated/annum} &= \text{Average load (in kW)} \times \text{Hours in a year} \\ &= \text{Max. demand (in kW)} \\ &\quad \times \ \text{LF} \times 8760\end{aligned}$$

Plant Capacity Factor

<u>Example 3.4</u> *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.*

Diversity Factor

Example 3.5 *A power supply is having the following loads :*

Type of load	*Max. demand [kW]*	*Diversity of group*	*Demand factor*
Domestic	*1500*	*1.2*	0.8
Commercial	*2000*	*1.1*	*0.9*
Industrial	*10,000*	*1.25*	*1.0*

If the overall system diversity factor is 1.35, determine

a) the maximum demand and

b) connected load of each type.

Diversity Factor

<u>Example 3.6</u> *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 [kw]*	*Demand factor*	*Diversity of groups*
Transformer No. 1	*10*	*0.65*	1.5
Transformer No. 2	*12*	*0.6*	*3.5*
Transformer No. 3	*15*	*0.7*	*1.5*

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

Load Curve

Example 3.7 *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]	*40*	*50*	*60*	*50*	*70*	*40*

Draw the load curve and load duration curve, and find

a) *maximum demand*
b) *units generated per day*
c) *average load*
d) *load factor.*

Load Curve

Example 3.8 *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

a) *maximum demand of individual consumer*
b) *load factor of individual consumer*
c) *diversity factor*
d) *load factor of the station.*