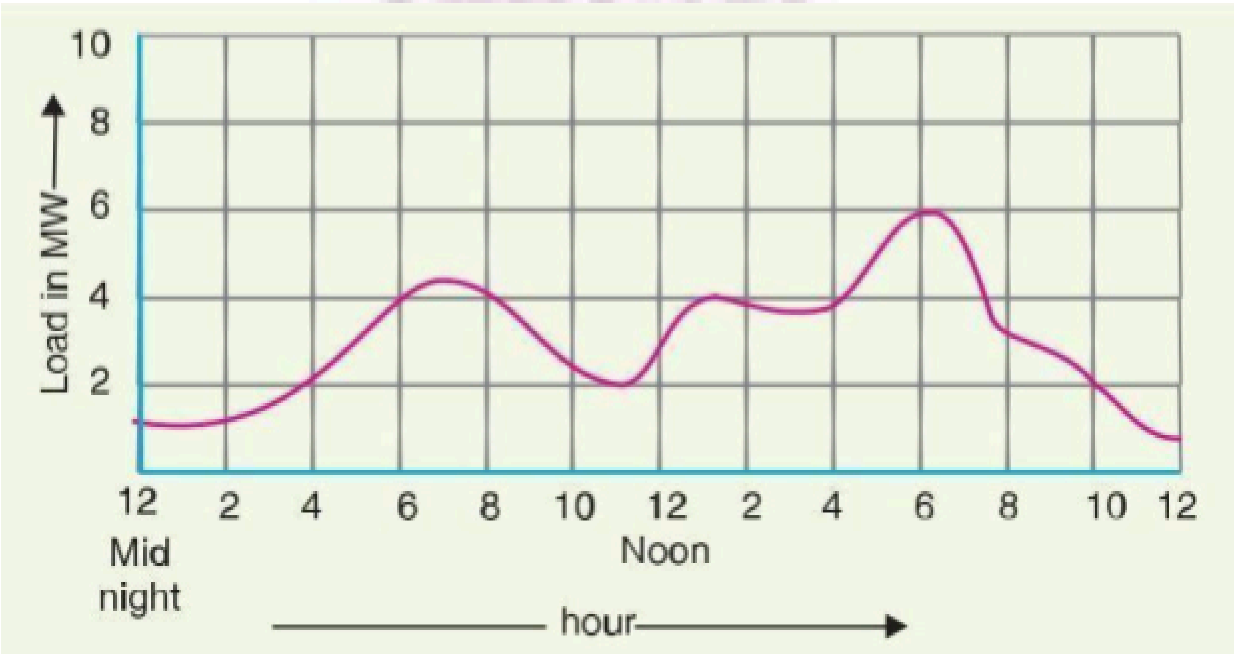
UNIT-2

Economic Aspects of Power Generation and Tariff Methods

Load Curves

The curve showing the variation of load on the power station with respect to (wrt) time is known as **load curve.**The load on a power station is never constant; it varies from time to time. These load variations during the whole day (ie, 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 wrt time during the day. Fig. 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 PM in this case. It may be seen that the 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.**



Im portance The daily load curves have attained a great importance in generation as they sup-ply 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

Average load=Area (in kWh) under daily load curve / 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

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

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

(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

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 × 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., the maximum demand on the power station during the day is 6 MW and it occurs at 6 PM 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

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

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

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

(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.**

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

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

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

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

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

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**

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

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

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max energy that could have been produced}} = \frac{\text{Average demand*T}}{\text{Plant capacity*T}}$$

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.

Reserve capacity = Plant capacity − 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 ie

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

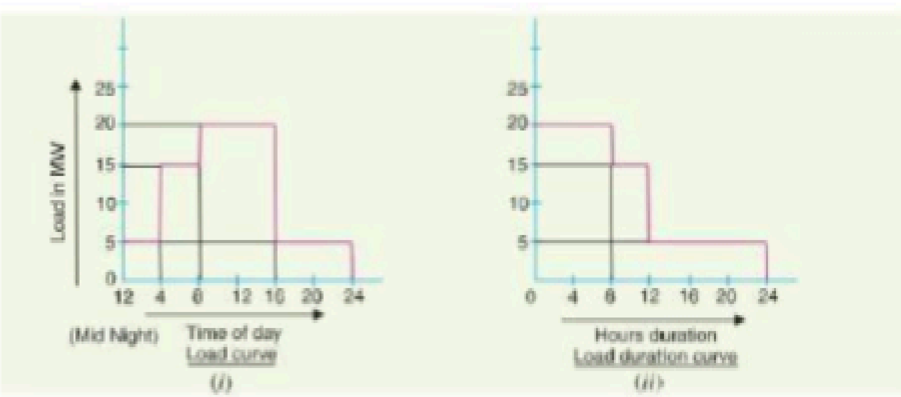
Units Generated per Annum

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

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

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.**



Load curve (i) Load duration curve (ii)

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. shows the daily load curve. The daily load duration curve can be readily obtained from it.It is clear from daily load curve, that load elements in order of descending magnitude are: 20MW for 8 hours; 15 MW for 4 hours and 5 MW for 12 hours.

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

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 (eg, electric lamp), inductive (eg, 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 (ie, 24 hours) eg, 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.

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 (ie, 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 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.

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.

(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.

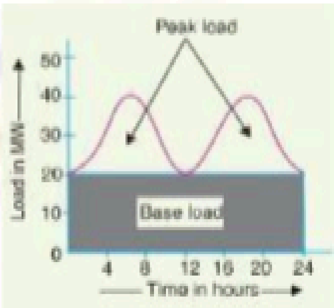
(v) The tendency to select a large number of units of smaller capacity in order to fit the load curve very accurately should be avoided. It is because the investment cost per kW of capacity increases as the size of the units decreases.

Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature Fig. 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



(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., it is clear that 20 MW of load has to be supplied by the station at all times of day and night ie 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., 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.

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.

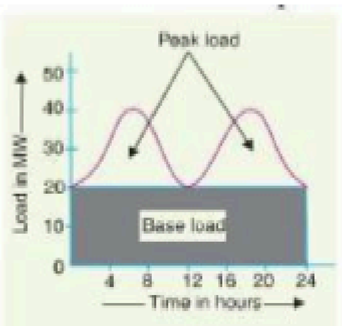
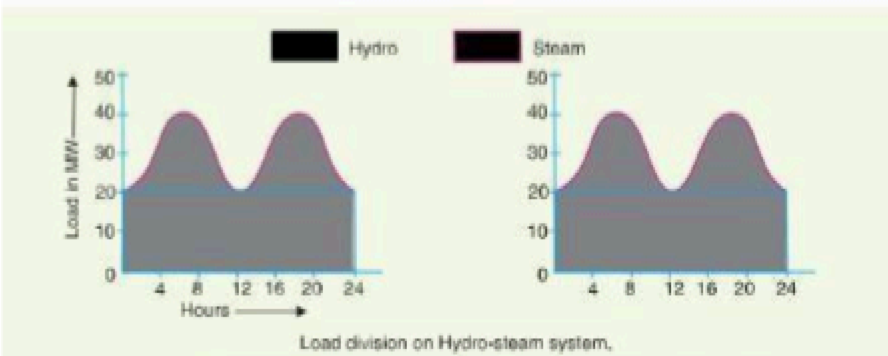


Illustration The interconnection of steam and hydro plants is a beautiful illustration to meet the load. When water is available in sufficient quantity as in summer and rainy season, the hydro-electric plant is used to carry the base load and the steam plant supplies the peak load as shown in Fig. (i).



Load division on Hydro-steam system.

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

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. (ii).

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.

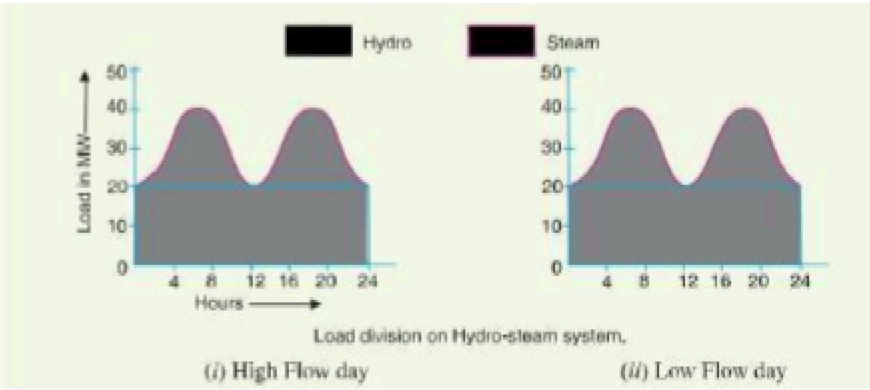
(ii) Use of older plants: The interconnected system makes it possible to use the older and less efficient plants to carry peak loads of short durations. Although such plants may be inadequate when used alone, yet they have sufficient capacity to carry short peaks of loads when interconnected with other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

(iv) 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.



Load division on Hydro-steam system.

Tariff

The rate at which electrical energy is supplied to a consumer is known as **tariff.**
Although tariff should include the total cost of producing and supplying electrical energy plus the profit, yet it cannot be the same for all types of consumers. It is because the cost of producing electrical energy depends to a considerable extent upon the magnitude of electrical energy consumed by the user and his load conditions. Therefore, in all fairness, due consideration has to be given to different types of consumers (eg, industrial, domestic and commercial) while fixing the tariff. This makes the problem of suitable rate making highly complicated.

Objectives of tariff Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items:

(i) Recovery of cost of producing electrical energy at the power station

(ii) Recovery of cost on the capital investment in transmission and distribution systems

(iii) Recovery of cost of operation and maintenance of supply of electrical energy eg, metering equipment, billing etc

(iv) A suitable profit on the capital investment

Desirable Characteristics of a Tariff

A tariff must have the following desirable characteristics:

(i) Proper return: The tariff should be such that it ensures the proper return from each consumer. In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.

(ii) Fairness: The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy. Similarly, a consumer whose load conditions do not deviate much from the ideal (ie, non-variable) should be charged at a lower rate than the one whose load conditions change appreciably from the ideal.

(iii) Simplicity: The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

(iv) Reasonable profit: The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. There-fore, the investment is relatively safe due to non-competition in the market This calls for the profit to be restricted to 8% or so per annum.

(v) Attractive: The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy. Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

Types of Tariff

There are several types of tariff. However, the following are the commonly used types of tariff:

Simple tariff When there is a fixed rate per unit of energy consumed, it is called a **simple tariff** or **uniform rate tariff.**

In this type of tariff, the price charged per unit is constant ie, it does not vary with increase or decrease in number of units consumed. The consumption of electrical energy at the consumer's terminals is recorded by means of an energy meter. This is the simplest of all tariffs and is readily understood by the consumers.

Disadvantages

(i) There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed charges.

(ii) The cost per unit delivered is high.

(iii) It does not encourage the use of electricity.

Flat rate tariff: When different types of consumers are charged at different uniform per unit rates, it is called a **flat rate tariff.**

In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate. For instance, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less (say 55 paise per kWh) for power load. The different classes of consumers are made taking into account their diversity and load factors. The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

Disadvantages

(i) Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

(ii) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

Block rate tariff: When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a **block rate tariff.** In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy. For example, the first 30 units may be charged at the rate of 60 paise per unit; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced. However, its principal defect is that it lacks a measure of the consumer's demand.This type of tariff is being used for majority of residential and small commercial consumers.

Two-part tariff: When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a **two-part tariff.**

In two-part tariff, the total charge to be made from the consumer is split into two components.viz, fixed charges and running charges. The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer. Thus, the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed.

Total charges = Rs $(b \times kW + c \times kWh)$

where, b = charge per kW of maximum demand and c = charge per kWh of energy consumed.This type of tariff is mostly applicable to industrial consumers who have appreciable maximum Demand.

Advantages

- It is easily understood by the consumers.
- It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed

Disadvantages

(i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy

(ii) There is always error in assessing the maximum demand of the consumer

Maximum demand tariff: It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rateable value. This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer (eg, residential consumer) as a separate maximum demand meter is required.

Power factor tariff: The tariff in which power factor of the consumer's load is taken into consideration is known as **power factor tariff.**

In an ac system, power factor plays an important role. A low power factor increases the rating of station equipment and line losses. Therefore, a consumer having low power factor must be penalized. The following are the important types of power factor tariff:

(i) k VA maximum demand tariff: It is a modified form of two-part tariff In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW. As kVA is inversely proportional to power factor, therefore, a consumer having low power factor has to contribute more towards the fixed charges. This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved power factor.

(ii) Sliding scale tariff: This is also know as average power factor tariff. In this case, an average power factor, say 0·8 lagging, is taken as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power

factor is above the reference, a discount is allowed to the consumer.

(iii) kW and kVAR tariff: In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately. A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

Three-part tariff: When the total charge to be made from the consumer is split into three parts viz, fixed charge, semi-fixed charge and running charge, it is known as a **three-part tariff**.

Total charge = Rs $(a + b \times kW + c \times kWh)$

Where, a= fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues,

b= charge per kW of maximum

demand, c= charge per kWh of energy

consumed.

It may be seen that by adding fixed charge or consumer’s charge (ie, a) to two-part tariff, it becomes three-part tariff. The principal objection of this type of tariff is that the charges are split into three components. This type of tariff is generally applied to big consumers.