UNIT –IV

Economic Aspects of power generation: Load curve - load duration and integrated load duration curve - number and size of generator units- Connected load - Maximum demand - Load Factor - Demand Factor- Diversity Factor - Plant use factor - Plant Capacity Factor - Utilization Factor- Power Factor - causes of low power factor - Numerical problems.

Cost of Electrical Energy: Cost of generation and their division into fixed, semi fixed and running costs. Tariff - Objectives of tariff - flat rate - block rate - two part - three part and power factor tariff methods - Numerical problems.

Economics of Power Generation

The art of determining the per unit (i.e., one kWh)cost of production of electrical energy is known as economics of power generation. The economics of power generation has assumed a greater importance. A consumer will use electric power only if it is supplied at reasonable rate. Therefore, power engineers have to find convenient methods to produce electric power as cheap as possible

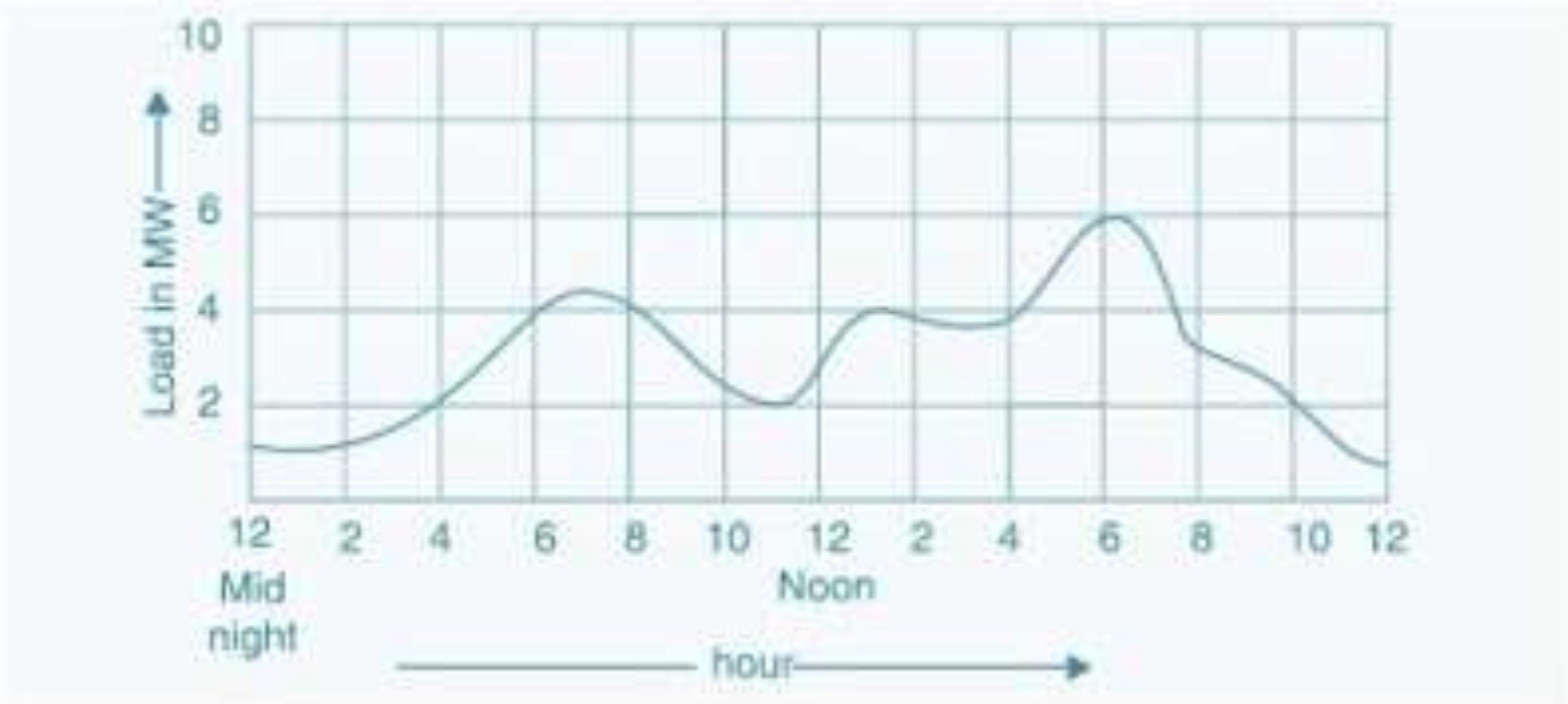
The load at which power system has to supply is never constant, because of variable demands at different times of a day. The minimum capacity of a generating station must be such as to meet the maximum load demand

At the same time ,it is essential for the power system to maintain reliability and continuity of power supply at all times

For deciding the rating of generating plants, the following terms can be used

Load Curve

Load curve is the variation of load with time on a Power Station. As the load on a Power Station never remain constant ,it varies time to time, these variations in load is plotted on half hourly or hourly basis for the whole day. The curve thus obtained is known as Daily Load Curve. Therefore, by having a look at the Load Curve, we can check the peak load on a Power Station and its variation. From the figure below, it is quite clear that the peak load (6 MW) on a particular Power Station is at 6 P.M.



The monthly load curve can be plotted using the daily load curve for a particular month. For this purpose the average load for the whole month is calculated and the value thus obtained is plotted against time to get the Monthly Load Curve.
Monthly Load Curve is used to fix the rate of energy.

In the same manner Yearly Load Curve can be obtained using the 12 monthly load curves.
The Yearly Load Curve is used for calculation the Annual Load Factor.

Importance of Load Curve:

- From the daily load curve we can have the knowledge of load at different times of a day.
- The area under the daily load curve gives the total units of electric energy generated.

    Units Generated / day = Area under the daily Load Curve in kW

- The peak point on the daily load curve gives the highest demand on the Power Station for that day.
- The average load per day on the Power Station can be calculated using the daily load curve.

    Average load = Area under the daily Load Curve (kWh)/ 24 hrs.

- Load curve helps in deciding the size and number of Generating Units.

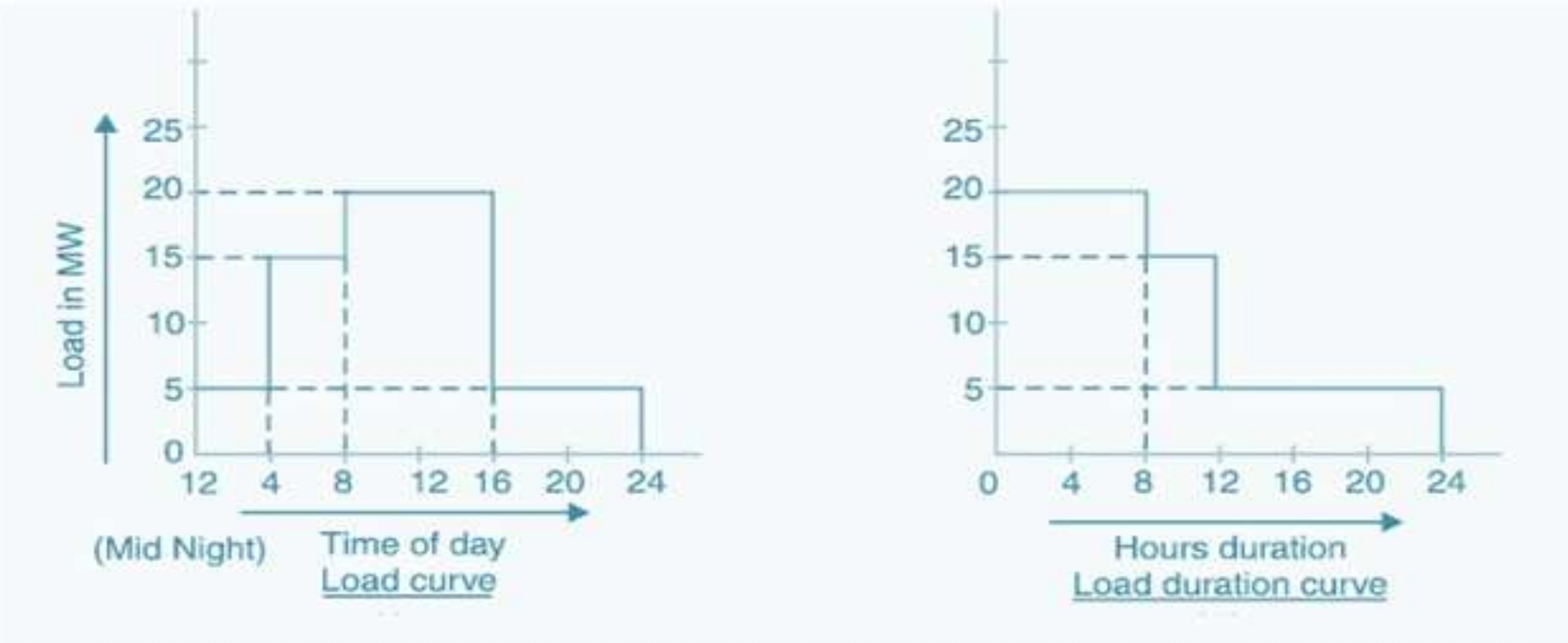
- Load curve helps in the preparing the operation schedule of the generating units.

Load Duration Curve

Load Duration Curve is the plot of Load versus time duration for which that load was persisting

The load duration curve is defined as the curve between the load and time in which the ordinates of the load are plotted in the order of decreasing magnitude, i.e., with the greatest load at the left, lesser loads towards the rights and the lowest loads at the time extreme right. The load duration curve is shown in the figure below.

Load Duration Curve is obtained from the Daily Load Curve as shown in figure below.



From the above Load Duration Curve, it is clear that 20 MW of Load is persisting for a period of 8 hours, 15 MW of Load for 4 hours and 5 MW of load existing for 12 hrs

The area under the load duration curve is equal to the daily load curve and gives the number of units generated for a given day. The load duration curve can be extended for any period of time i.e. it can be drawn for a month or for year too.

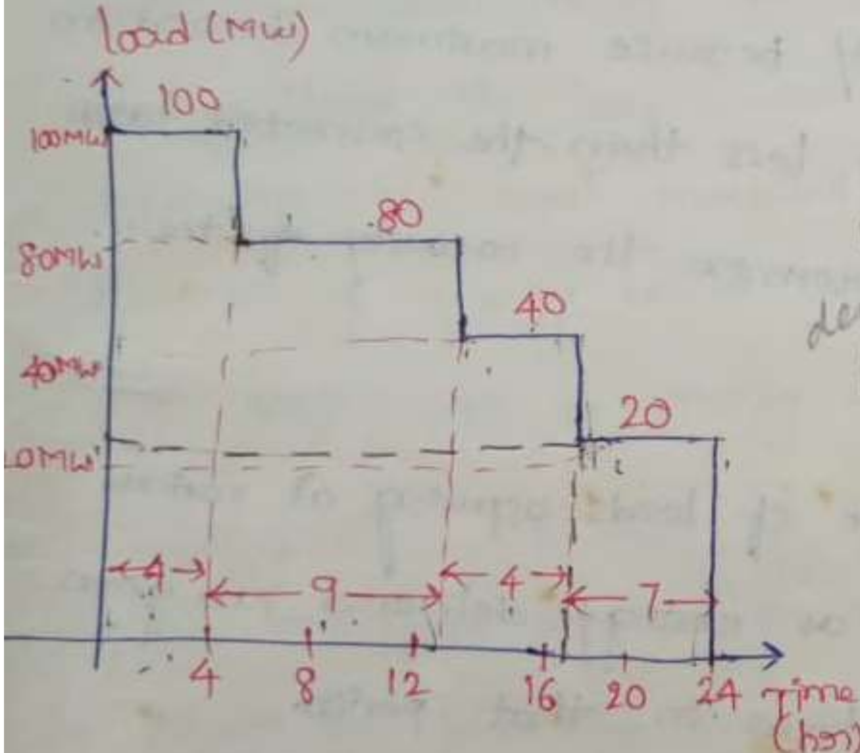
Procedure for Plotting the Load Duration Curve

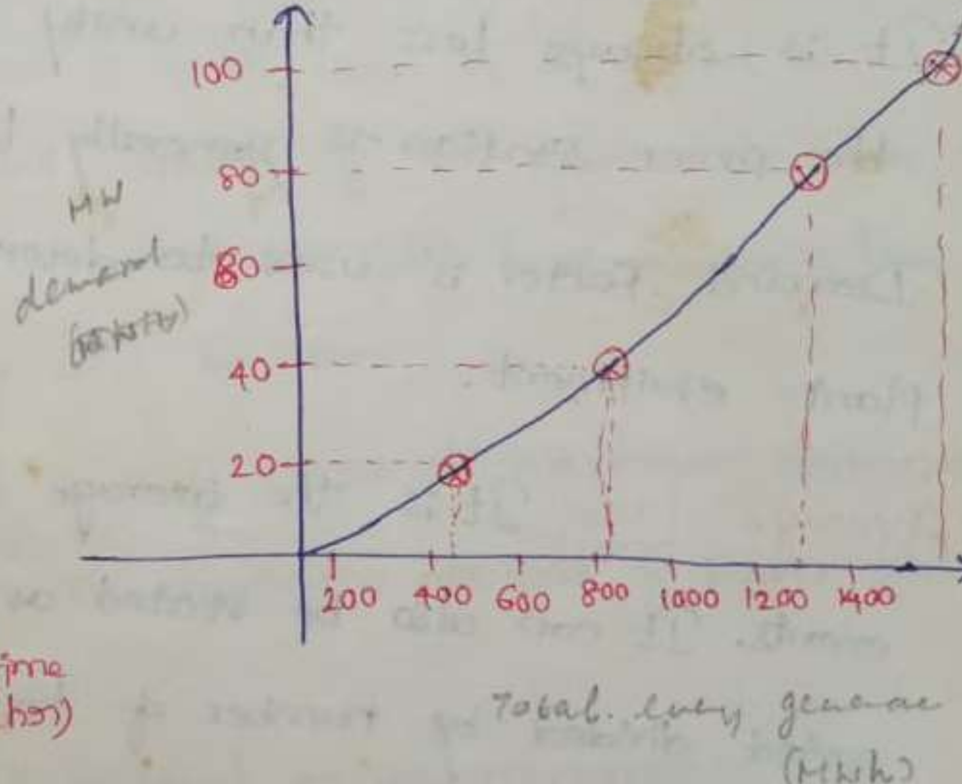
- From the data available from the load curve determines the maximum load and the duration for which it occurs.
- Now take the next load and the total time during which this and the previous load occurs.
- Plots the loads against the time during which it occurs.

Load integrated curve

Integrated load curve is drawn between load demand (Kw/Mw) to the total energy generated.
This curve can be obtained from load duration curve.
This curve gives the total number of units generated .

The figure shows the Integrated Load Duration Curve, its X-axis represents units generated in kWh & Y-axis represents Demand of load in kW.
Such type of curve can be drawn with the help of Load Duration Curve.





1 unit = 1kwh

Load (MW)	20	40	80	100
Energy generated MWH	20×24 = 480	480+(20×17) = 820	820+(40×13) = 1340	1340+(20×4) = 1420

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 five100-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

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 is the maximum demand

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

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

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.

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.

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

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

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

Load factor: The ratio of average load to the maximum demand during a given period is known as load factor

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

If the plant is in operation for T hours,

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

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

The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year. Load factor is always less than 1 because average load is smaller than the maximum demand.

The load factor plays key role in determining the overall cost per unit generated. Higher the load factor of the power station, lesser will be the cost per unit generated.

Diversity factor: The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor

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

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

Obviously, diversity factor will always be greater than 1. The greater the diversity factor, the lesser is the cost of generation of power.

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

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

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

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

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

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

Units Generated per Annum:

It is required to find the units generated (kwh) per annum from maximum demand and load factor.

Units generated/annum = Average load (in kW) × Hours in a year

Load factor =Average load / Max. demand

∴ Average load = Max. demand × L.F

Units generated/annum=Max. demand (in kW) × L.F. × 8760

1) The maximum demand on a power station is 100 KW. If the annual load factor is 40% , calculate the total energy generated in a year.

Solution.

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

$= (100 \times 10^3) \times (0{\cdot}4) \times (24 \times 365)$ kWh

$= 3504 \times 105$ kWh

2). *A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being $61{\cdot}5 \times 10^6$ per annum. Calculate (i) the demand factor and (ii) load factor.*

Solution.

(*i) Demand factor = Max. demand /* Connected load

$= 20/43 = 0{\cdot}465$

(*ii) Average demand = Units generated per annum /* Hours in a year

$= 61{\cdot}5\times10^6 / 8760$

$= 7020$ kW

∴ Load factor = Average demand/Max. demand

$=7020 / 20 \times10^3 = 0{\cdot}351$ or $35{\cdot}1\%$

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

Solution.

Energy supplied for each working day = (100 × 2) + (50 × 6) = 500 MWh

Station operates for = 365 − 45 = 320 days in a year

∴ Energy supplied/year = 500 × 320 = 160,000 MWh

$$\text{Annual load factor} = \frac{\text{MWh supplied per annum}}{\text{Max. demand in MW} \times \text{Working hours}} \times 100$$

$$= \frac{160{,}000}{(100) \times 320 \times 24} \times 100 = 20.8\%$$

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

Solution.

Load factor = Average demand/Max. demand

0·60 = Average demand / 25

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

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

Plant capacity = Average demand / Plant capacity factor

=15 / 0.5 =30MW

∴ Reserve capacity of plant = Plant capacity − maximum demand

= 30 − 25 = 5 MW

(*ii) Daily energy produced = Average demand × 24*

= 15 × 24 = 360 MWh

(*iii) Maximum energy that could be produced*

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

= 360/0.72

=500 MWh/day

5) *A diesel station supplies the following loads to various consumers :*

Industrial consumer = 1500 kW ; Commercial establishment = 750 kW

Domestic power = 100 kW; Domestic light = 450 kW

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

Solution.

(*i*) $$\text{Diversity factor} = \frac{1500 + 750 + 100 + 450}{2500} = \mathbf{1{\cdot}12}$$

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

$$\therefore \quad \text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{513{\cdot}7}{2500} = 0{\cdot}205 = \mathbf{20{\cdot}5\%}$$

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

Solution.

$$\begin{aligned}
\text{Energy generated/annum} &= \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year} \\
&= (15000) \times (0{\cdot}5) \times (8760) \text{ kWh} \\
&= 65{\cdot}7 \times 10^6 \text{ kWh}
\end{aligned}$$

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

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

$$\begin{aligned}
\text{Reserve capacity} &= \text{Plant capacity} - \text{Max. demand} \\
&= 18{,}750 - 15000 = \mathbf{3750 \text{ kW}}
\end{aligned}$$

7)

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*

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

Solution

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

∴ Max. demand on supply system = 13,500/1·35 = **10,000 kW**

Each type of load has its own diversity factor among its consumers.

max. demands of different domestic consumers = Max. domestic demand × diversity factor

= 1500 × 1·2 = 1800 kW

∴ Connected domestic load = 18000·8 = **2250 kW**

Connected commercial load = 2000 × 1·10·9 = **2444 kW**

Connected industrial load = 10,000 × 1·251= **12,500 kW**

8)

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*

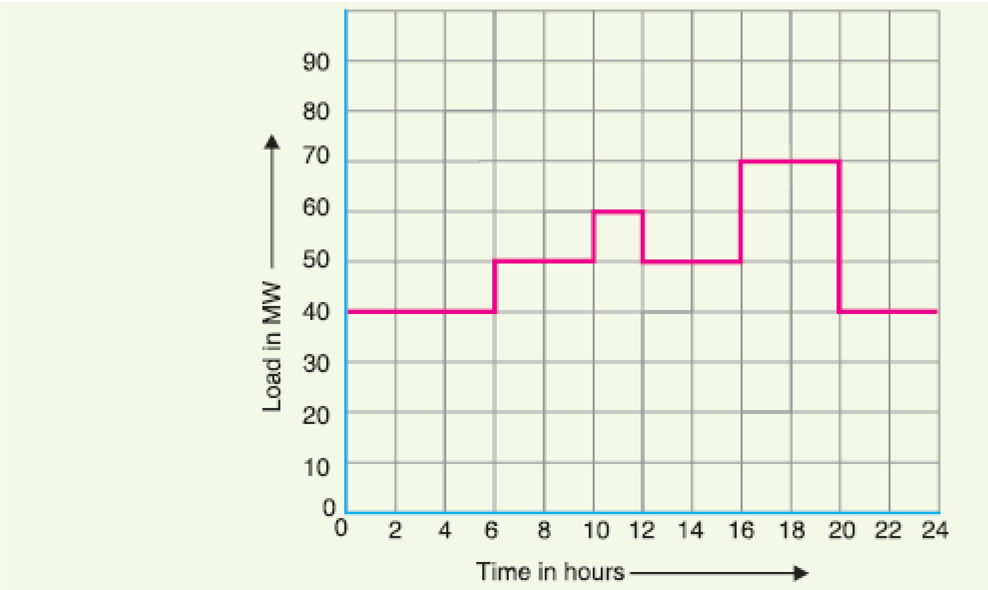
Draw the load curve and find (i) maximum demand (ii) units generated per day (iii) average load and (iv) load factor.

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

(*i) It is clear from the load curve that maximum demand on the power station is 70 MW and*

occurs during the period 16—20 hours.

∴ Maximum demand = **70 MW**



Units generated/day = Area under the load curve

$$= [40 \times 6 + 50 \times 4 + 60 \times 2 + 50 \times 4 + 70 \times 4 + 40 \times 4]$$

$$= [240 + 200 + 120 + 200 + 280 + 160] \text{ MWh}$$

$$= 1200 \text{ MWh}$$

$$\textit{Average load} = \frac{\textit{Units generated / day}}{24 \text{ hours}}$$

$$= 1200/24$$

$$= 50 \text{ MW}$$

$$\textit{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{50}{70}$$

$$= 0{\cdot}714 = 71{\cdot}4\%$$

9)

A power station has to meet the following demand :

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

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

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

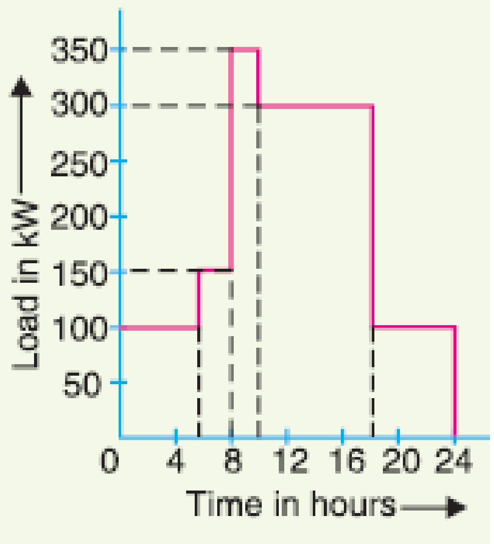
Group D : 100 kW between 10 A.M. and 6 P.M. and then between 6 P.M. and 6 A.M.

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

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

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

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



Maximum demand = 350 kW

Sum of individual maximum demands of groups

= 200 + 100 + 50 + 100

= 450 kW

(*i) Diversity factor = Sum of individual max. demands /* Max. demand on station

= 450/350 = 1·286

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

= 100 × 6 + 150 × 2 + 350 × 2 + 300 × 8 + 100 × 6

= 4600 kWh

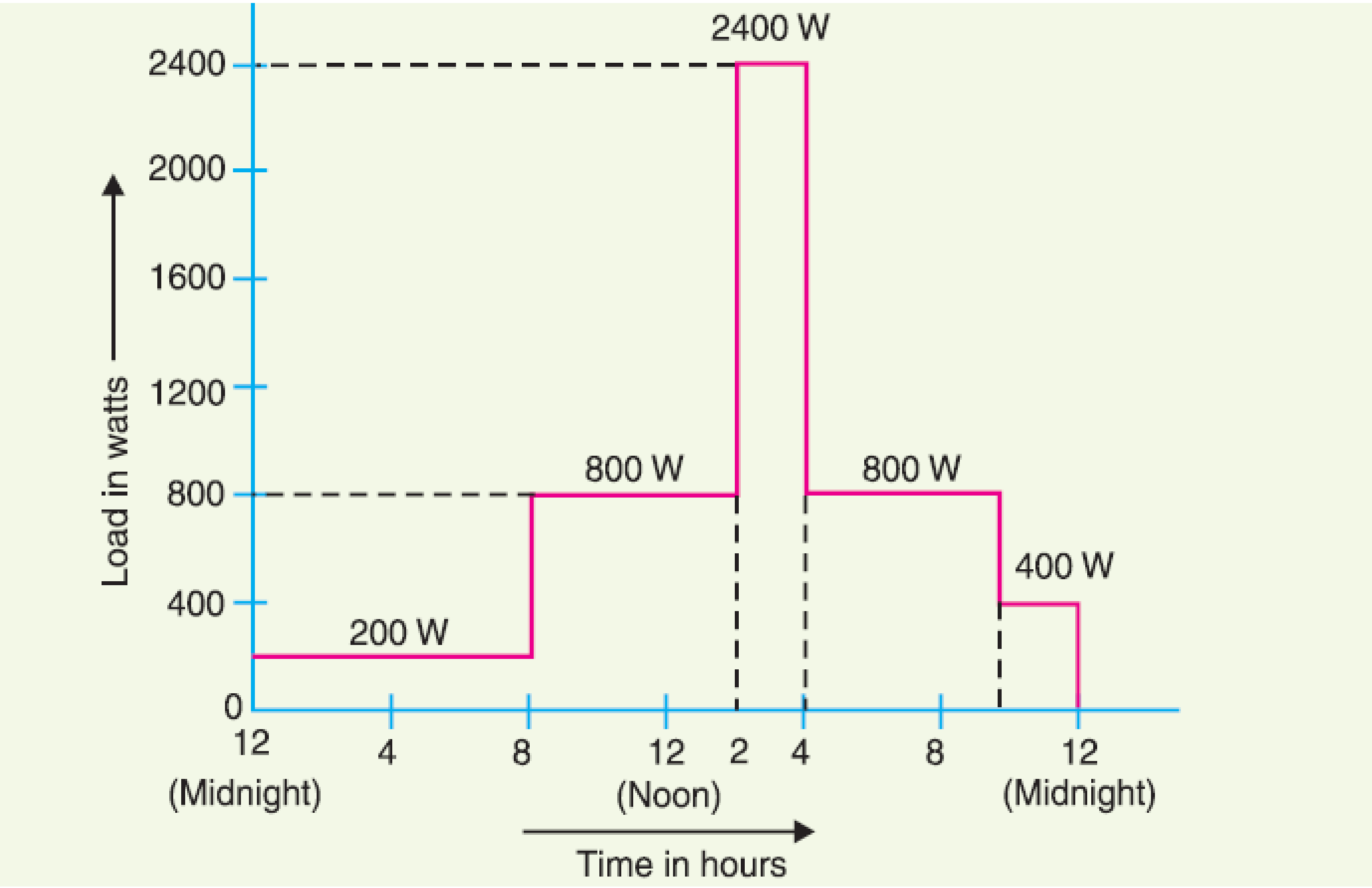
(*iii) Average load = 4600/24 = 191·7 kW*

∴ Load factor = 191.7/350 × 100 = 54·8%

10) *The daily demands of three consumers are given below :*

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

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



The Fig shows the load curve

(*i*) *Max. demand of consumer 1 = 800 W*
Max. demand of consumer 2 = 1000 W
Max. demand of consumer 3 = 1200 W

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

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

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

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

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

$$\therefore \quad \text{Diversity factor} = \frac{800 + 1000 + 1200}{2400} = \mathbf{1{\cdot}25}$$

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

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

11) *A power station has the following daily load cycle :*

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

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

Fig i) shows the daily load curve, whereas Fig. (*ii) shows the daily load* duraton curve.

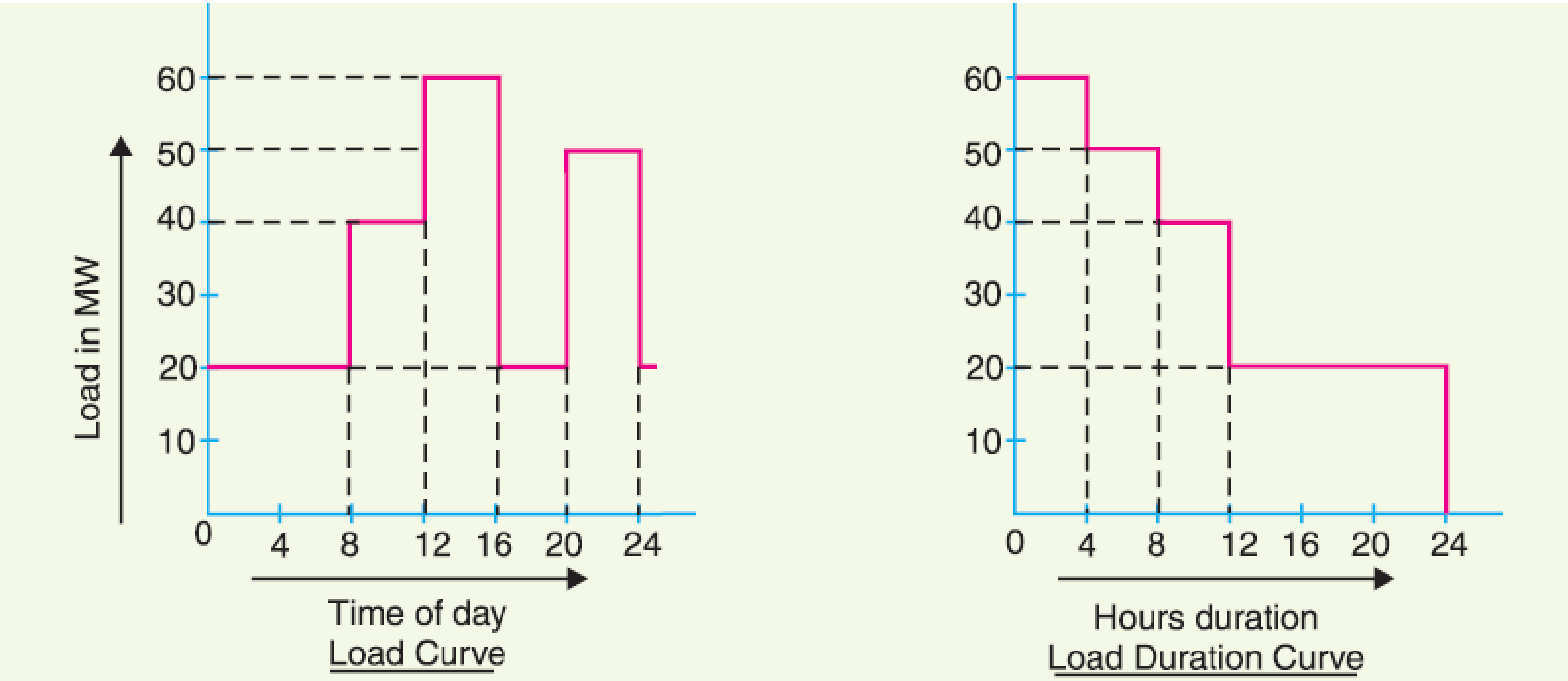


Fig i)

Fig ii

Units generated/day = Area under daily load curve

$= [20 \times 8 + 40 \times 4 + 60 \times 4 + 20 \times 4 + 50 \times 4]$

= **840 MWh**

Units generated/day = Area under daily load duration curve

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

= **840 MWh**

Area under the two load curves is same

Power Factor:

The cosine of angle between voltage and current in an a.c. circuit is known as ***power factor.***

In an a.c. circuit, there is generally a phase difference (ϕ) between voltage and current. The term cos ϕ is called the power factor of the circuit.

If the circuit is inductive, the current lags behind the voltage and the power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and power factor is said to be leading.

The power factor of a circuit can be defined in one of the following three ways :

(*a*) Power factor $= \cos\phi =$ cosine of angle between V and I

(*b*) Power factor $= \dfrac{R}{Z} = \dfrac{\text{Resistance}}{\text{Impedance}}$

(*c*) Power factor $= \dfrac{VI\cos\phi}{VI} = \dfrac{\text{Active power}}{\text{Apparent Power}}$

$VI\cos\phi$ and represents the *active power* in watts or kW

$VI\sin\phi$ and represents the *reactive power* in VAR or kVAR

VI and represents the *apparent power* in VA or kVA

Disadvantages of Low Power Factor:

The power factor plays an importance role in a.c. circuits since power consumed depends upon this factor.

$$P = V_L I_L \cos\phi \qquad \text{(For single phase supply)}$$

$$I_L = \frac{P}{V_L \cos\phi} \qquad \text{...}(i)$$

$$P = \sqrt{3}\, V_L I_L \cos\phi \qquad \text{(For 3 phase supply)}$$

$$I_L = \frac{P}{\sqrt{3}\, V_L \cos\phi} \qquad \text{...}(ii)$$

It is clear from above that for fixed power and voltage, the load current is inversely proportional to the power factor. Lower the power factor, higher is the load current and *vice-versa*

A Lower power factor results in the following disadvantages :

(*i) Large kVA rating of equipment.*

(*ii) Greater conductor size*

iii) Large copper losses

iv) Poor voltage regulation

v) Reduced handling capacity of system

Causes of Low Power Factor

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system in lower than 0·8. The following are the causes of low power factor:

(*i*) Most of the a.c. motors are of induction type (1ϕ and 3ϕ induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0·2 to 0·3) and rises to 0·8 or 0·9 at full load.

(*ii*) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

(*iii*) The load on the power system is varying ; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetisation current. This results in the decreased power factor.

Number and size of generator units:

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

The selection of the number and sizes of the units is decided from the annual load curve of the station.

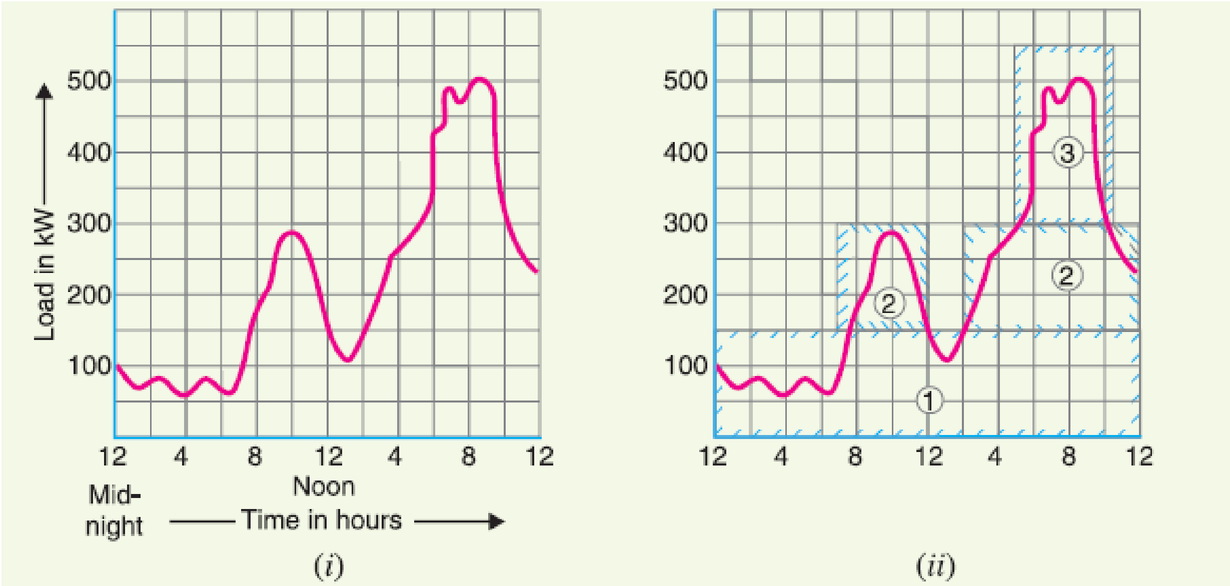
The number and size of the units are selected in such a way that they correctly fit the station load curve.

Example:

The principle of selection of number and sizes of generating units with the help of load curve is shown in Fig. i & ii

It is clear form the curve that load on the station has wide variations ; the minimum load being somewhat near 50 kW and maximum load reaching the value of 500 kW.

use of a single unit to meet this varying load will be highly uneconomical.



This is shown in Fig. (ii) where the plant capacity is divided into three units numbered as 1, 2 and 3.

The three units employed have different capacities and are used according to the demand on the station. In this case, the operating schedule can be as under :

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

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

<u>Cost of Electrical Energy</u>: Cost of generation and their division into fixed, semi fixed and running costs. Tariff - Objectives of tariff - flat rate - block rate - two part - three part and power factor tariff methods - Numerical problems

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The electrical energy produced by a power station is delivered to a large number of consumers. The consumers are convinced to use electrical energy if it is sold at reasonable rates. So The tariff *i.e., the rate at which* electrical energy is sold naturally becomes very important aspect for an electric supply company

<u>Tariff::</u>

The rate at which electrical energy is supplied to a consumer is known as ***tariff.***

Tariff should include the total cost of producing and supplying electrical energy plus the profit. 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 while fixing the price, consideration has to be given to different types of consumers (*e.g., industrial,* domestic and commercial) . This makes fixing suitable rate 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*
(*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. 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.

(*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

(*iv) Reasonable profit :* *The profit element in the tariff should be reasonable.* The profit to be restricted to 8% or so per annum for an electric supply company.

(*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::

Flat rate tariff::

When different types of consumers are charged at different per unit rates, it is called flat rate tariff.

In this type of tariff, the consumers are grouped into different classes and each class of consumers are 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

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

i) fixed charges and ii) 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

i.e., Total charges = $(b \times kW + c \times kWh)$ Rs

where, *b = charge per kW of maximum demand*

c = charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand

Advantages

(*i) It is easily understood by the consumers.*

(*ii) 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*

Three-part tariff.:

When the total charge to be made from the consumer is split into three parts
i) fixed charge ii) semi-fixed charge iii) running charge

It is known as a three-part tariff.

i.e., 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 labor cost of collecting revenues,

b = charge per kW of maximum demand

c = charge per kWh of energy consumed

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 a.c. 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 :

1) 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 known 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.

1) *A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is Rs. 100 per kW of maximum demand plus 10 paise per kWh, find the overall cost per kWh.*

Solution::

$$\text{Units consumed/year} = \text{Max. demand} \times \text{L.F.} \times \text{Hours in a year}$$

$$= (200) \times (0{\cdot}4) \times 8760 = 7{,}00{,}800 \text{ kWh}$$

$$\text{Annual charges} = \text{Annual M.D. charges} + \text{Annual energy charges}$$

$$= \text{Rs } (100 \times 200 + 0{\cdot}1 \times 7{,}00{,}800)$$

$$= \text{Rs } 90{,}080$$

$$\therefore \quad \text{Overall cost/kWh} = \frac{90\ 080}{7\ 00\ 800}$$

$$= \text{Rs } 0{\cdot}1285 = 12{\cdot}85 \text{ paise}$$

2) *The maximum demand of a consumer is 20 A at 220 V and his total energy consumption is 8760 kWh. If the energy is charged at the rate of 20 paise per unit for 500 hours use of the maximum demand per annum plus 10 paise per unit for additional units, calculate : (i) annual bill (ii) equivalent flat rate.*

Solution.

Assume the load factor and power factor to be unity.

$$\therefore \quad \text{Maximum demand} = \frac{220 \times 20 \times 1}{1000} = 4 \cdot 4 \text{ kW}$$

(*i*) $$\text{Units consumed in 500 hrs} = 4{\cdot}4 \times 500 = 2200 \text{ kWh}$$

$$\text{Charges for 2200 kWh} = \text{Rs } 0{\cdot}2 \times 2200 = \text{Rs } 440$$

$$\text{Remaining units} = 8760 - 2200 = 6560 \text{ kWh}$$

$$\text{Charges for 6560 kWh} = \text{Rs } 0{\cdot}1 \times 6560 = \text{Rs } 656$$

$$\therefore \quad \text{Total annual bill} = \text{Rs } (440 + 656) = \textbf{Rs. 1096}$$

(*ii*) $$\text{Equivalent flat rate} = \text{Rs } \frac{1096}{8760} = \text{Re } 0 \cdot 125 = \textbf{12.5 paise}$$

3) *The following two tariffs are offered :*

(a) Rs 100 plus 15 paise per unit ;

(b) A flat rate of 30 paise per unit ;

At what consumption is first tariff economical ?

Solution.

Let x be the number of units at which charges due to both tariffs become equal. Then,

$$100 + 0{\cdot}15x = 0{\cdot}3x$$

or $$0{\cdot}15x = 100$$

$$\therefore \quad x = 100/0{\cdot}15 = \textbf{666·67 units}$$

Therefore, tariff (*a*) is economical if consumption is more than 666·67 units.

4) *A supply is offered on the basis of fixed charges of Rs 30 per annum plus 3 paise per unit or alternatively, at the rate of 6 paise per unit for the first 400 units per annum and 5 paise per unit for all the additional units. Find the number of units taken per annum for which the cost under the two tariffs becomes the same.*

Solution. Let x (> 400) be the number of units taken per annum for which the annual charges due to both tariffs become equal.

$$\text{Annual charges due to first tariff} = \text{Rs } (30 + 0{\cdot}03\,x)$$

$$\text{Annual charges due to second tariff} = \text{Rs } [(0{\cdot}06 \times 400) + (x - 400) \times 0{\cdot}05]$$

$$= \text{Rs } (4 + 0{\cdot}05\,x)$$

As the charges in both cases are equal,

$$\therefore \quad 30 + 0{\cdot}03\,x = 4 + 0{\cdot}05\,x$$

or

$$x = \frac{30 - 4}{0 \cdot 05 - 0 \cdot 03} = \mathbf{1300\ kWh}$$

5)

An electric supply company having a maximum load of 50 MW generates 18×10^7 units per annum and the supply consumers have an aggregate demand of 75 MW. The annual expenses including capital charges are :

For fuel	=	*Rs 90 lakhs*
Fixed charges concerning generation	=	*Rs 28 lakhs*
Fixed charges concerning transmission and distribution	=	*Rs 32 lakhs*

Assuming 90% of the fuel cost is essential to running charges and the loss in transmission and distribution as 15% of kWh generated, deduce a two part tariff to find the actual cost of supply to the consumers.

Solution.

Annual fixed charges

$$\text{For generation} = \text{Rs } 28 \times 10^5$$

$$\text{For transmission and distribution} = \text{Rs } 32 \times 10^5$$

$$\text{For fuel (10\% only)} = \text{Rs } 0{\cdot}1 \times 90 \times 10^5 = \text{Rs } 9 \times 10^5$$

$$\text{Total annual fixed charge} = \text{Rs } (28 + 32 + 9) \times 10^5 = \text{Rs } 69 \times 10^5$$

This cost has to be spread over the aggregate maximum demand of all the consumers *i.e.*, 75 MW.

$$\therefore \quad \text{Cost per kW of maximum demand} = \text{Rs} \frac{69 \times 10^5}{75 \times 10^3} = \textbf{Rs. 92}$$

Annual running charges.

$$\text{Cost of fuel (90\%)} = \text{Rs } 0{\cdot}9 \times 90 \times 10^5 = \text{Rs } 81 \times 10^5$$

$$\text{Units delivered to consumers} = 85\% \text{ of units generated}$$

$$= 0{\cdot}85 \times 18 \times 10^7 = 15{\cdot}3 \times 10^7 \text{ kWh}$$

This cost is to be spread over the units delivered to the consumers.

$$\therefore \quad \text{Cost/kWh} = \text{Rs} \frac{81 \times 10^5}{15 \cdot 3 \times 10^7} = \text{Re } 0 \cdot 053 = \textbf{5.3 paise}$$

$\therefore$ Tariff is Rs 92 per kW of maximum demand plus 5·3 paise per kWh.

6) *A generating station has a maximum demand of 75 MW and a yearly load factor of 40%. Generating costs inclusive of station capital costs are Rs. 60 per annum per kW demand plus 4 paise per kWh transmitted. The annual capital charges for transmission system are Rs 20,00,000 and for distribution system Rs 15,00,000 ; the respective diversity factors being 1·2 and 1·25. The efficiency of transmission system is 90% and that of the distribution system inclusive of substation losses is 85%. Find the yearly cost per kW demand and cost per kWh supplied :*

(i) at the substation (ii) at the consumers premises.

Solution.

$$\text{Maximum demand} = 75 \text{ MW} = 75{,}000 \text{ kW}$$

$$\text{Annual load factor} = 40\% = 0{\cdot}4$$

(*i*) **Cost at substation.** The cost per kW of maximum demand is to be determined from the total annual fixed charges associated with the supply of energy at the substation. The cost per kWh shall be determined from the running charges.

(*a*) **Annual fixed charges**

$$\text{Generation cost} = \text{Rs } 60 \times 75 \times 10^3 = \text{Rs } 4{\cdot}5 \times 10^6$$

$$\text{Transmission cost} = \text{Rs } 2 \times 10^6$$

Total annual fixed charges at the substation

$$= \text{Rs } (4{\cdot}5 + 2) \times 10^6 = \text{Rs } 6{\cdot}5 \times 10^6$$

Aggregate of all maximum demands by the various substations

$$= \text{Max. demand on generating station} \times \text{Diversity factor}$$

$$= (75 \times 10^3) \times 1{\cdot}2 = 90 \times 10^3 \text{ kW}$$

The total annual fixed charges have to be spread over the aggregate maximum demands by various substations *i.e.*, 90×10^3 kW.

Annual cost per kW of maximum demand

$$= \text{Rs } \frac{6 \cdot 5 \times 10^6}{90 \times 10^3} = \textbf{Rs. 72.22}$$

(*b*) **Running Charges.** It is given that cost of 1 kWh transmitted to substation is 4 paise. As the transmission efficiency is 90%, therefore, for every kWh transmitted, 0·9 kWh reaches the sub-station.

$\therefore$ Cost/kWh at substation $= 4/0{\cdot}9 =$ **4·45 paise**

Hence at sub-station, the cost is **Rs 72·22** per annum per kW maximum demand plus **4·45 paise** per kWh.

(*ii*) **Cost at consumer's premises.** The total annual fixed charges at consumer's premises is the sum of annual fixed charges at substation (*i.e.* Rs $6{\cdot}5 \times 10^6$) and annual fixed charge for distribution (*i.e.*, Rs $1{\cdot}5 \times 10^6$).

$\therefore$ Total annual fixed charges at consumer's premises

$$= \text{Rs } (6{\cdot}5 + 1{\cdot}5) \times 10^6 = \text{Rs } 8 \times 10^6$$

Aggregate of maximum demands of all consumers

$$= \text{Max. demand on Substation} \times \text{Diversity factor}$$

$$= (90 \times 10^3) \times 1{\cdot}25 = 112{\cdot}5 \times 10^3 \text{ kW}$$

$\therefore$ Annual cost per kW of maximum demand

$$= \text{Rs } \frac{8 \times 10^6}{112 \cdot 5 \times 10^3} = \textbf{Rs. 71.11}$$

As the distribution efficiency is 85%, therefore, for each kWh delivered from substation, only 0·85 kWh reaches the consumer's premises.

$\therefore$ Cost per kWh at consumer's premises

$$= \frac{\text{Cost per kWh at substation}}{0 \cdot 85} = \frac{4 \cdot 45}{0 \cdot 85} = \textbf{5.23 paise}$$

Hence at consumer's premises, the cost is **Rs. 71·11** per annum per kW maximum demand plus **5·23 paise** per kWh.

Cost of Electrical Energy::

The total cost of electrical energy generated can be divided into three parts, namely ;

(*i*) Fixed cost ; (*ii*) Semi-fixed cost ; (*iii*) Running or operating cost.

(*i*) **Fixed cost.** *It is the cost which is independent of maximum demand and units generated.*

The fixed cost is due to the *annual cost of central organisation, interest on capital cost of land* and *salaries of high officials.*

The annual expenditure on the central organization and salaries of high officials is fixed

Further, the capital investment on the land is fixed and hence the amount of interest is also fixed.

ii) Semi-fixed cost.

It is the cost which depends upon maximum demand but is independent of units generated.

The semi-fixed cost is directly proportional to the maximum demand on power station and is on account of *annual interest and depreciation on capital investment of building and equipment, taxes, salaries of management and clerical staff. The maximum demand on the power station determines* its size and cost of installation. The greater the maximum demand on a power station, the greater is its size and cost of installation. Further, the taxes and clerical staff depend upon the size of the plant and hence upon maximum demand.

(iii) Running cost.

It is the cost which depends only upon the number of units generated.

The running cost is on account of *annual cost of fuel, lubricating oil, maintenance, repairs and salaries of operating staff. Since these charges depend upon the energy output, the running cost is* directly proportional to the number of units generated by the station. In other words, if the power station generates more units, it will have higher running cost and *vice-versa.*