- Variable load on power station

The function of a power station is to deliver 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 with load demanded by the users. The power station must produce power as and when demanded to meet the requirements of the consumers. On one hand, the power engineer would like that the alternators in the power station should run at their rated capacity for maximum efficiency**.**

Some of the important effects of variable load on a power station are :

(i) Need of additional equipment.
(ii) Increase in production cost.

- **Load Curves:**

The curve below showing the variation of load on the power station with respect to time is known as a **load curve**.

There are different types of load curve:

1- Daily load curve: The load on a power station is never constant; it varies from time to time. These load variations during the whole day (i.e., 24 hours) are recorded hourly and are plotted against time on the graph.

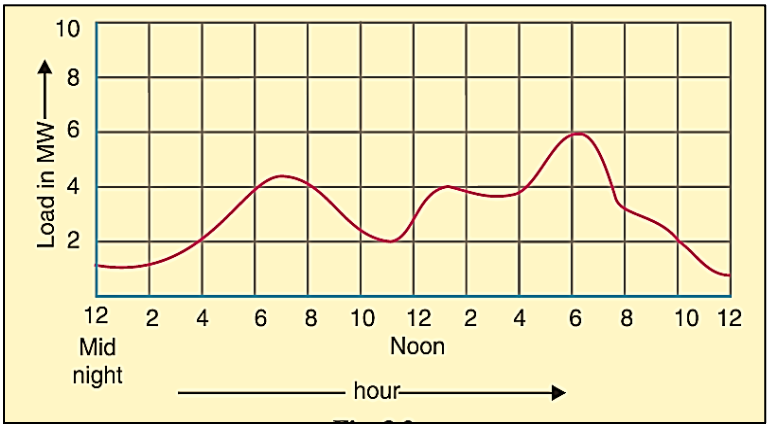


Fig. 3-1

2- Monthly load curve: The monthly load curve can be obtained from the daily load curves of that month plotted on the graph. The monthly load curve is generally used to fix the rates of energy.

3- Yearly load curve: 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.

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

1- The daily load curve shows the variations of load on the power station during different hours of the day.

2- The area under the daily load curve gives the number of units generated in the day.

3- The highest point represents the maximum demand on the station on that day.

4- The area under the daily load curve divided by the total number of hours gives **the average load** on the station in the day

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

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

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

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

6- The load curve helps in selecting the size and number of generating units.

7- 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 equipment's connected to supply system. 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.

Referring back to the load curve of Fig. 3.1, the maximum demand on the power station during the day is 6 MW and it occurs at 6 P.M. 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. It is very important as it helps in determining the installed capacity of the station, and 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 i.e.,

$$Demand\ Factor = \frac{Max.Demand}{Connected\ Load} \ldots\ldots \text{(usually less than 1)}$$

The knowledge of demand factor is usfel 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

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

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

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

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

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

If the plant is in operation for T hours then:

$$Load\ Factor = \frac{\text{Average load} \times \text{T}}{\text{Max.demand} \times \text{T}} = \frac{\text{Units generated in T hours}}{\text{Max.demand} \times \text{T hours}} \ldots\ldots..(\text{ less than 1})$$

Note: Higher load factor means lesser maximum demand. The station capacity is so selected that it must meet the maximum demand. Now, lower maximum demand means lower capacity of the plant which, therefore, reduces the cost of the plant.

(vi) ***Diversity factor***. The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor.

$$\text{Diversity factor} = \frac{\text{Sum of individual max.demands}}{\text{Max.demand on power station}} \ldots\ldots..(\text{ more than 1})$$

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 i.e.

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

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

T in hours, If T for one year then:

$$\text{Annual plant capacity factor} = \frac{\text{Annual } KWh\ output}{\text{Plant capacity} * 8760}$$

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. The plant will have no reserve capacity when plant capacity equal to max. Demand.

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

(vii) 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 i.e.

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

Suppose a plant having installed capacity of 20 MW produces annual output of $7{\cdot}35 \times 10^6$ kWh and remains in operation for 2190 hours in a year. Then,

$$\text{Plant use factor} = \frac{7 \cdot 35 \ \times \ 10^6}{(20 \times 10^6\ ) \times 2190} = 0.167 = 16.7\%$$

- ***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.

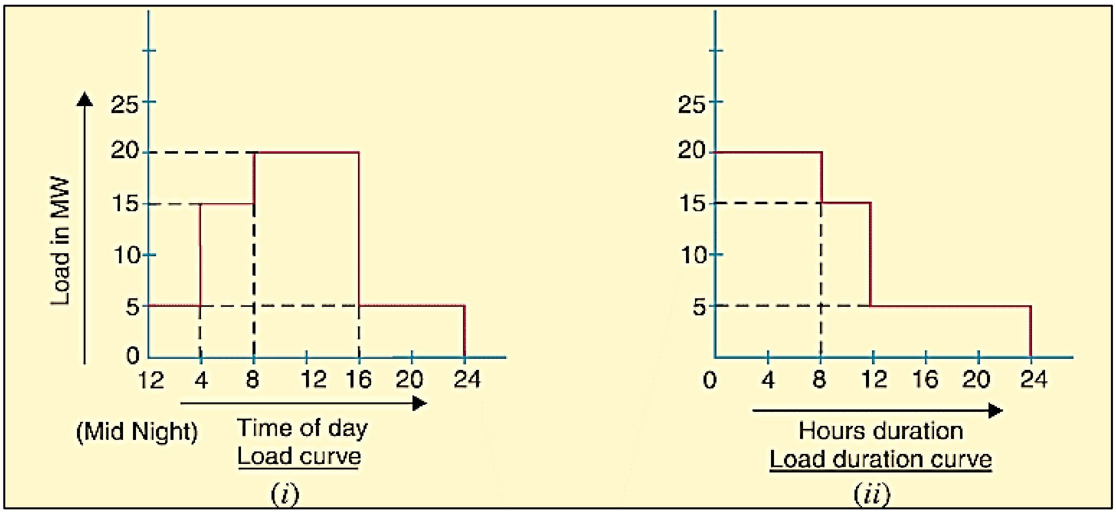


Fig. 3-2

Example 3.4. 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.

(i) $\text{Load factor} = \dfrac{\text{Average demand}}{\text{Maximum demand}}$

or $0{\cdot}60 = \dfrac{\text{Average demand}}{25}$

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

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

$\therefore$ $\text{Plant capacity} = \dfrac{\text{Average demand}}{\text{Plant capacity factor}} = \dfrac{15}{0\cdot 5} = 30 \text{ MW}$

$\therefore$ Reserve capacity of plant = Plant capacity – maximum demand
$= 30 - 25 = 5\text{ MW}$

(ii) Daily energy produced = Average demand × 24
$= 15 \times 24 = 360\text{ MWh}$

(iii) Maximum energy that could be produced

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

$$= \frac{360}{0 \cdot 72} = 500\text{ MWh/day}$$

Base Load and Peak Load on Power Station:

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. 3.13, it is clear that 20 MW of load has to be supplied by the station throughout 24 hours. Therefore, 20 MW is the base load of the station.

(ii) **Peak load.** The various peak demands of load over and above the base load of the station is known as peak load.

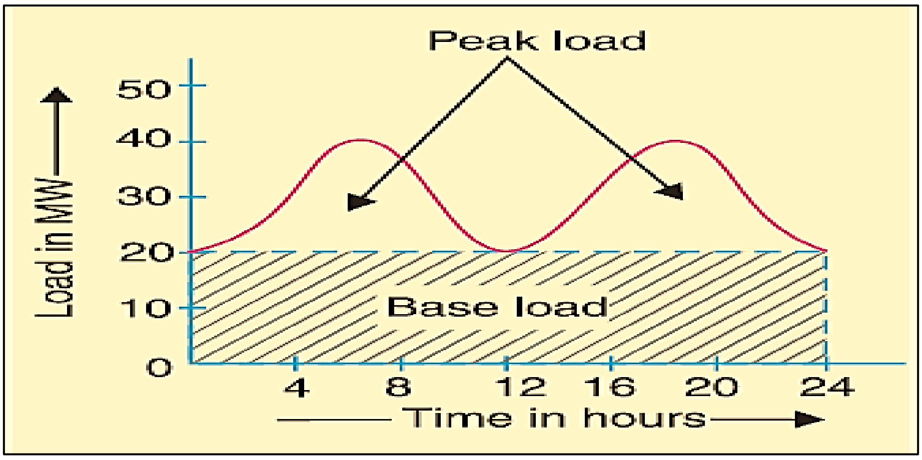


Fig. 3-3

- Method of Meeting the 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.

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 hydroelectric plant is used to carry the base load and the steam plant supplies the peak load as shown in Fig above. 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 .

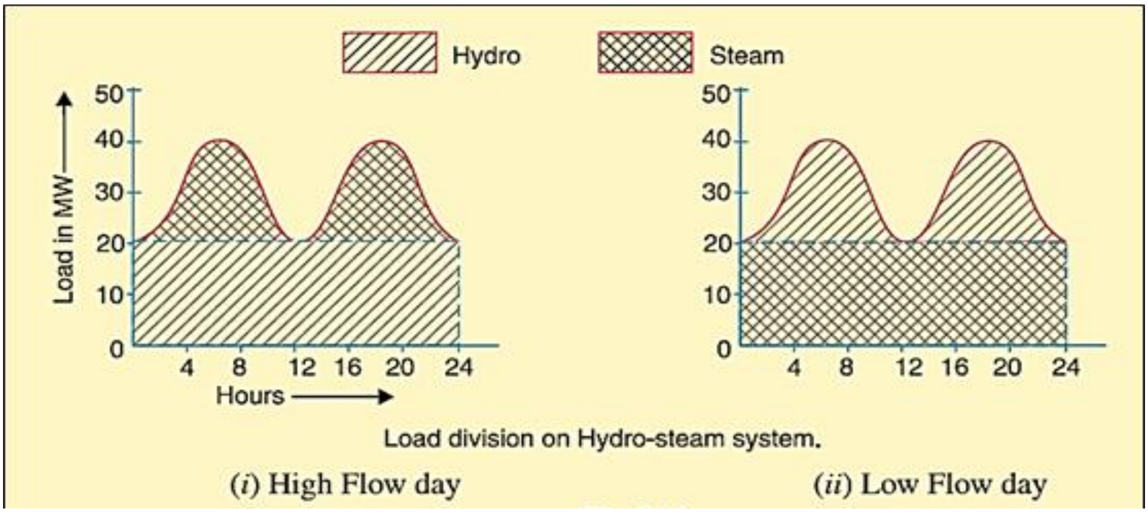


Fig. 3-4

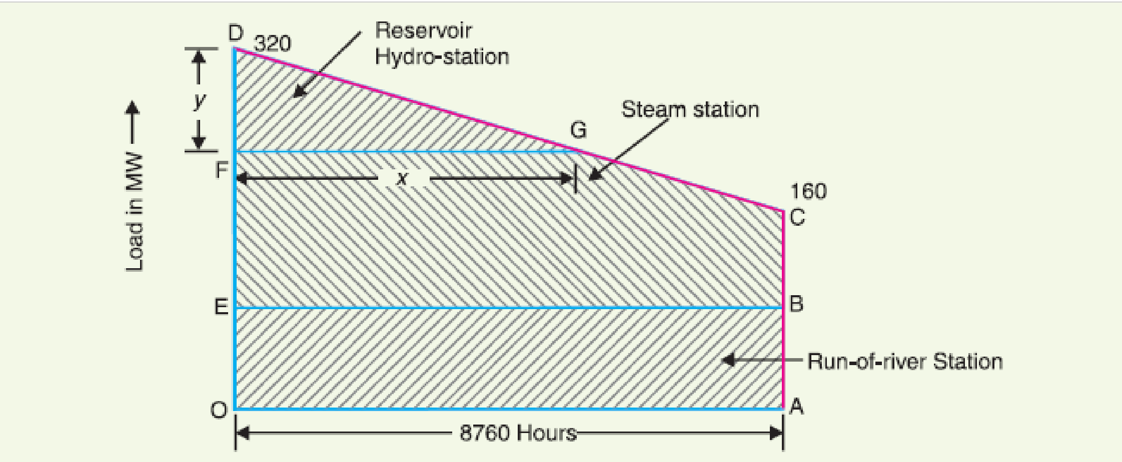
- **Interconnected Grid System:**

The connection of several generating stations in parallel is known as **interconnected grid system.** Some of the advantages of interconnected system are listed below:

(i) *Exchange of peak loads,*
(ii) *Use of older plants,*
(iii) *Ensures economical operation,*
(iv) *Increases diversity factor,*
(iv) *Reduces plant reserve capacity,*
(vi) *Increases reliability of supply.*

Example 3.22. *The annual load duration curve for a typical heavy load being served by a steam station, a run-of-river station and a reservoir hydro-electric station is as shown in Fig. 3.16.The ratio of number of units supplied by these stations is as follows :*
Steam : Run-of-river : Reservoir : : 7 : 4 : 1
The run-of-river station is capable of generating power continuously and works as a base load station. The reservoir station works as a peak load station. Determine (i) the maximum demand of each station and (ii) load factor of each station.

Solution. ODCA is the annual load duration curve for the system as shown in Fig. 3.16. The energy supplied by the reservoir plant is represented by area DFG ; steam station by area FGCBE and run-of-river by area OEBA. The maximum and minimum loads on the system are 320 MW and160 MW respectively.



$$\text{Units generated/annum} = \text{Area (in kWh) under annual load duration curve}$$

$$= 10^3\left[\frac{1}{2}(320+160)\times 8760\right]\text{kWh} = 2102\cdot 4\times 10^6\text{ kWh}$$

As the steam plant, run-of-river plant and hydro plant generate units in the ratio of 7 : 4 : 1, therefore, units generated by each plant are given by :

$$\text{Steam plant} = 2102{\cdot}4\times 10^6\times 7/12 = 1226{\cdot}4\times 10^6\text{ kWh}$$

$$\text{Run-of-river plant} = 2102{\cdot}4\times 10^6\times 4/12 = 700{\cdot}8\times 10^6\text{ kWh}$$

$$\text{Reservoir plant} = 2102{\cdot}4\times 10^6\times 1/12 = 175{\cdot}2\times 10^6\text{ kWh}$$

(*i*) Maximum demand on run-of-river plant

$$= \frac{\text{Area } OEBA}{OA} = \frac{700\cdot 8\times 10^6}{8760} = \mathbf{80{,}000\text{ kW}}$$

Suppose the maximum demand of reservoir plant is y MW and it operates for x hours (See Fig. 3.16).

$$\text{Then,}\quad \frac{y}{160} = \frac{x}{8760} \quad\text{or}\quad x = \frac{8760\,y}{160}$$

Units generated per annum by reservoir plant

$$= \text{Area (in kWh) } DFG$$

$$= 10^3\left(\frac{1}{2}xy\right) = 10^3\left(\frac{1}{2}\times\frac{8760\,y}{160}\,y\right)$$

$$= \frac{y^2}{32}\times 8{,}76{,}000$$

But the units generated by reservoir plant are $175{\cdot}2\times 10^6$ kWh.

$$\therefore\quad \frac{y^2}{32}\times 8{,}76{,}000 = 175{\cdot}2\times 10^6$$

$$y^2 = 6400 \quad \text{or} \quad y = \sqrt{6400} = 80 \text{ MW}$$

∴ Maximum demand on reservoir station is

$$FD = 80 \text{ MW}$$

Maximum demand on steam station is

$$EF = 320 - 80 - 80 = 160 \text{ MW}$$

(*ii*) L.F. of run of river plant $= 100^{*}\ \%$

$$\text{L.F. of reservoir plant} = \frac{\text{Units generated / annum}}{\text{Maximum demand} \times 8760} \times 100$$

$$= \frac{175 \cdot 2 \times 10^6}{(80 \times 10^3) \times 8760} \times 100 = 25\%$$

$$\text{L.F. of steam plant} = \frac{1226 \cdot 4 \times 10^6}{(160 \times 10^3) \times 8760} \times 100 = 87.5\%$$