1. Estimation of Water Power Potential

1.1. Water Power Potential

It is essential to assess the inherent power available from the discharge of a river and the head available at the site before any power plant is contemplated.

The gross head of any proposed scheme can be assessed by simple surveying techniques, where as hydrological data on rainfall and runoff are essential in order to assess the available water quantities. The following hydrological data are necessary:
a) the daily, weakly or monthly flow over a period of several years, to determine the plant capacity & estimated output.
b) low flows, to asses the primary, firm, or dependable power.

The potential or theoretical power in any river stretch with a difference in elevation H is computed from:

$$P_p = \gamma \cdot Q \cdot H$$

Which is a power that can be required for useful work by overcoming friction loss in watts.

where

H = head in m

Q = discharge of streams in m^3/s

P_p= Potential (theoretical) power of the stream in KW

$\gamma = \rho \cdot g \Rightarrow \gamma = \rho.g/1000 = 9.81$ KN/m^3

Actually, g varies between 9.768 m/s^2 at equator to 9.83 m/s^2 at the poles(according to latitude) and according to local condition i.e. altitude, varies between -0.2 to –0.4 cm/s^2 in average -0.31 cm/s^2 per 1000m above sea level, see *Mosonyi, E. (1987).* Generally an average value of 9.81m/s^2 is used.

The above equation neglects the difference in kinetic energy term. In low land rivers, with large magnitude of discharge and low head as in the runoff plants, neglecting the energy from this term may mean neglecting significant energy term.

From the above relationship:

$P_p = \gamma.Q.H$ (KW) = 9.81 Q.H (KW)

Since

1 hp = 736 Watts

P_p= 13.33 Q.H (hp)

The hydraulic power P is given by

$P = \eta.\ \gamma.Q.H = 9.81\ \eta.Q.H$ (KW)

Where η = is the total efficiency

If the river course is divided in to a number of n stretches, the total power can be described by:

$$P = \gamma \sum_{1}^{n} (Q \cdot H)$$

From the available stream flow data, one can obtain *flow duration curve of* the stream for a given site by plotting the discharge against the percentage duration of the time for which it is available. Similarly, *power duration curve* can be plotted since power is directly proportional to the discharge and available head.

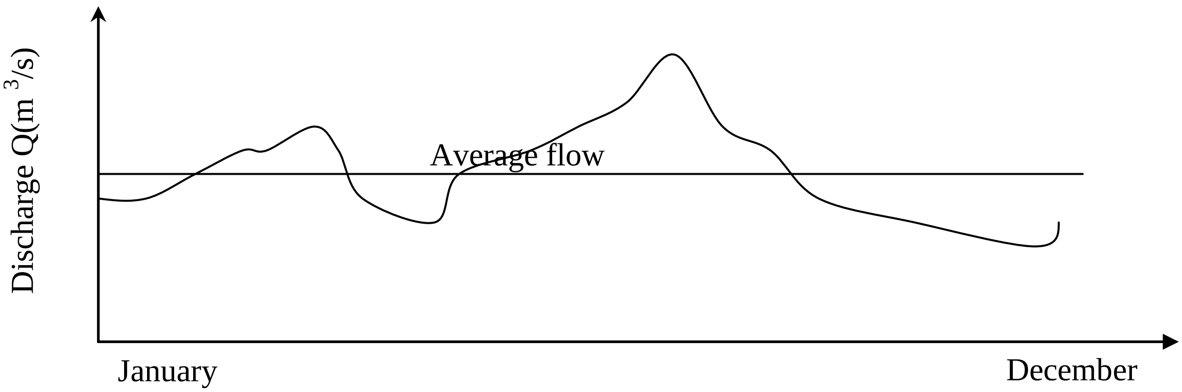

Fig.1.1: Stream flow hydrograph

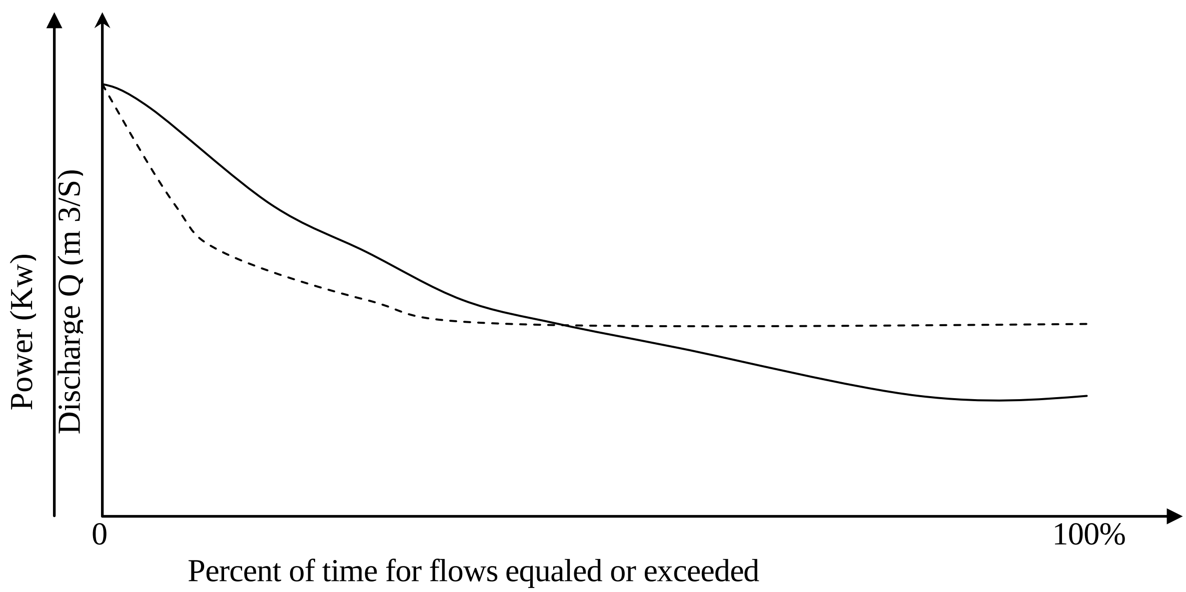

Figure 1.2 Flow\Power duration curve (Power scale multiplying factor = 9.81 η.H)

Potential power resources can be characterized by values according to the discharge taken as a basis of computation. The conventional discharges are Q_{100}, Q_{95}, Q_{50}, Q_m. Thus we have,

i) *Minimum potential power* designated P_{p100}, computed from the minimum flow that is available for 100% of the time (365 days or 8760 hrs.)
ii) *Small potential power* computed from the flow available for 95% of the time.This represented by $P_{p\,95}$
iii) *Median potential power* is computed from the flow available for 50% of time. This is represented by $P_{p\,50}$.
iv) *Mean potential power* is computed from the average of mean yearly flows for a period of 10 to 30 years. This is designated as P_{pm} and is also known as *gross power potential*.

Technically Available Power

Evaluation of technically available power from the available power is significance. According to Mossony the losses subtracted from the P_p values represents an upper limit of utilization.

Losses = Conveyance loss + plant losses

(entrance, rack, generator, turbine)

According to F.I. Nestruck

Conveyance efficiency = 70%

Overall plant efficiency = 80%

Total multiplying factor = 0.56 to be used with average potential power $P_{p\,50}$.

Therefore, technically available power $P_a = 0.56\ P_{p\,50}$. The multiplying factor depends up on the type of development. i.e. run-of-river plant, high head plant, etc.

Nestruck also suggested that a coefficient of 2.5 to be used for estimating the potential average water power from the 95% potential water power i.e. $P_{p\,50} = 2.5\ P_{p\,95}$.

Waterpower is also characterized by annual values of potential energy in a river i.e. by quantities of work expressed in Kilowatt hors & named as E_{95}, E_{50}, E_m, etc.

The maximum potential energy of a river section is thus:

$E_{max.} = 8760\ P_m$ KWh

The upper value of *net power* capable of being developed technically is computed from the *potential waterpower by introducing reduction factors to account for losses in conveyance & in energy conversion.*

The EEC puts the factor to be about 0.75 to 0.80. Thus

$\mathbf{P_{m\,net} = (7.4\ to\ 8.0)\ Q_m\ H}$ **(KW)** for $\gamma = 10$

Where Q_m is arithmetic mean discharge.

Therefore, $\mathbf{E_{m\,net} = 8760\ P_{m\,net}}$ **(KWh)**

1.2. Firm and Secondary Power/ Electrical Load on Hydro-turbines

The power *demand* is defined as the total load, which consumers choose, at any instant of time, to connect to the supplying power system.

Load curve

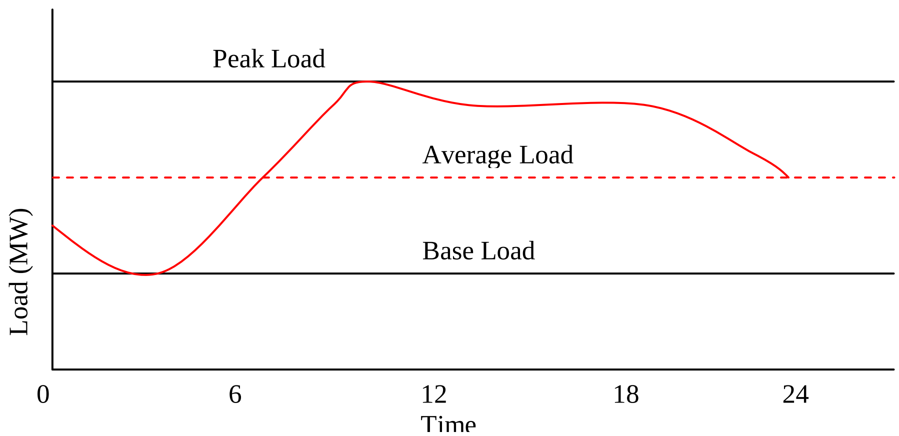

Figure 1.3: Definition Sketch of Load Curve

Maximum demand determines the size of the plant and its cost.

Highest instantaneous value of demand is, strictly speaking, the *peak load or peak demand.* Generally, however, peak load is defined as that carried at intensity greater than 4/3 times the average load intensity.

Base Load is the total load continuously exceeded, where as the **average load** is the area under the curve divided by the time.

Load factor is the ratio of average load to the peak load and is expressed as a daily, weakly, monthly or yearly value. The area under a load curve is energy (KWh) and it can be plotted to obtain energy consumption curve. Thus the load factor can also be defined as:

$$\text{Load Factor} = \frac{\text{energy consumed (say during 24 hrs)}}{\text{(max. demand) * 24 hrs.}}$$

Max. load - determines plant capacity

Load factor - gives an idea of degree of utilization of capacity. Thus an annual load factor of say 0.4 indicates that the machines are producing only 40% of their yearly maximum production capacity.

Capacity factor: also called plant use factor or plant factor

$$\text{Capacity factor} = \frac{\text{Average output of plant for a given period of}}{\text{Full plant capacity}}$$

$$= \frac{\text{Energy actually produced}}{\text{Energy that a plant is capable of producing at full capacity.}}$$

e.g.- If a plant with capacity of 100 MW produces 6,000,000 KWh operating for 100 hrs, its capacity factor will be

$$\text{C.F.} = \frac{6{,}000{,}000}{100{,}000*100} = 0.6 \text{ or } 60\%$$

The capacity factor for hydroelectric plant is generally b/n 0.25 & 0.75.

:. If the peak load = plant capacity, then capacity factor = load factor. If the plant is not used to its full capacity, then load factor ≠ capacity factor.

Thus in the above example if the max. load was 75 MW instead of 100 MW then

$$L.F. = \frac{6,000,000}{75,000*100} = 0.8 \text{ or } 80\% \text{ against } 60\% \text{ C.F.}$$

$$\text{Utilization factor} = \frac{\text{Quantity of water actually used for power production}}{\text{Quantity of water that is available in the river}}$$

For assumed constant head

$$\text{Utilization factor} = \frac{\text{Power utilized}}{\text{Power available}}$$

For hydroelectric plants, this factor varies from 0.4 to 0.9 depending on plant capacity, load factor & storage.

Load Duration Curve

This is a curve of load vs percentage of time this load or higher occurs. It is usually plotted for long duration such as a year.

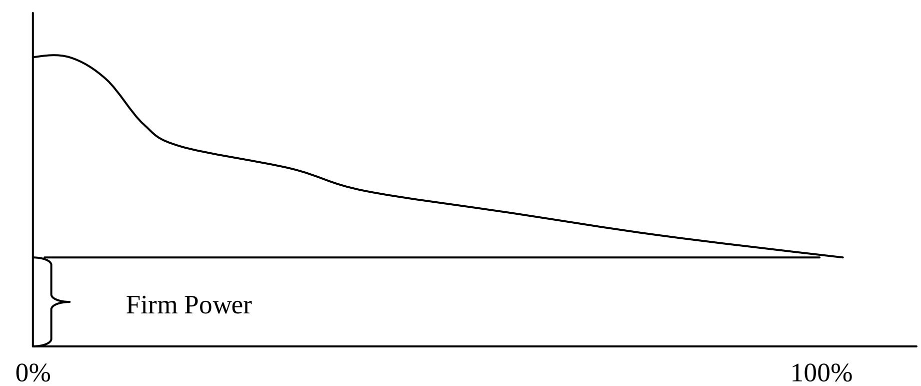

Figure 1.4: Definition Sketch of Firm Power

Area under load duration curve = total energy production during the period. Thus

$$\text{Annual load factor} = \frac{\text{Area under curve}}{\text{Area of rectangle corresponding to max. demand during the year}}$$

Firm Power: Also called primary power is the power which always ensured to a consumer at any hour of the day and is thus completely dependable power. Such a power corresponds to the minimum stream flow and is available for all times.

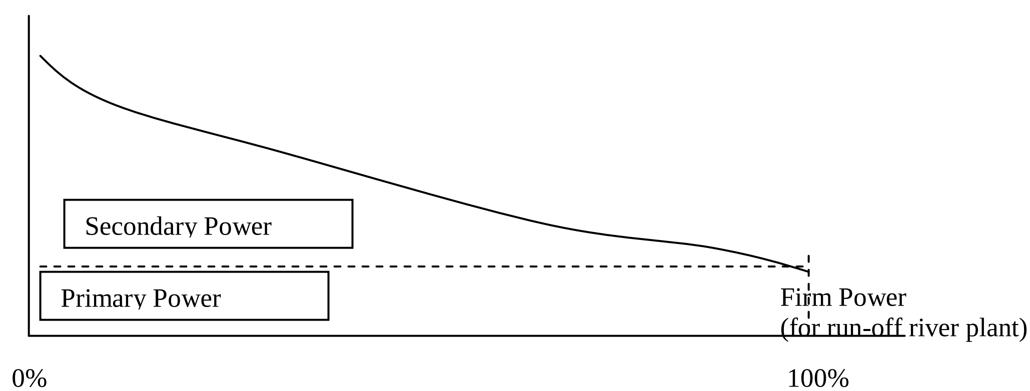

Figure 1.5: Definition Sketch of Firm/Primary and Secondary Power

Firm power can be increased by use of pondage (storage).

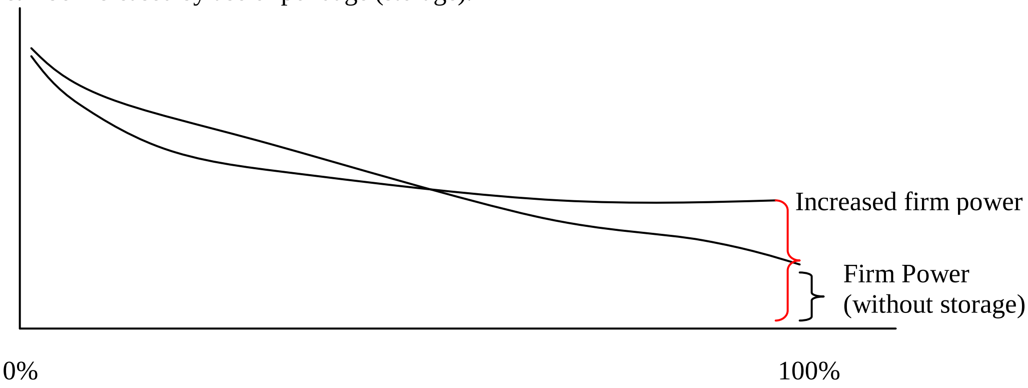

Figure 1.6: Increased Firm Power by Pondage

1.3. Load Predictions and Demand Assessment

1.3.1. Base Load - Peak Load

Power is needed for a variety of purposes, such as domestic, commercial, industrial, municipal, agricultural, public transport etc. The energy demand (local, regional, transregional) is subject to considerable temporal fluctuations. These variations could be from hour to hour within a day, from day to day within a week/month, from month to month within a year, etc.

These seasonal fluctuations depend on:
- Weather, season;
- Vacation times;
- Cyclical business activity.

Daily fluctuations are due to:
- Rhythm of work time and free time;
- Weather;
- Traffic.

A typical load curve, daily load curve is shown in Figure 3.7.

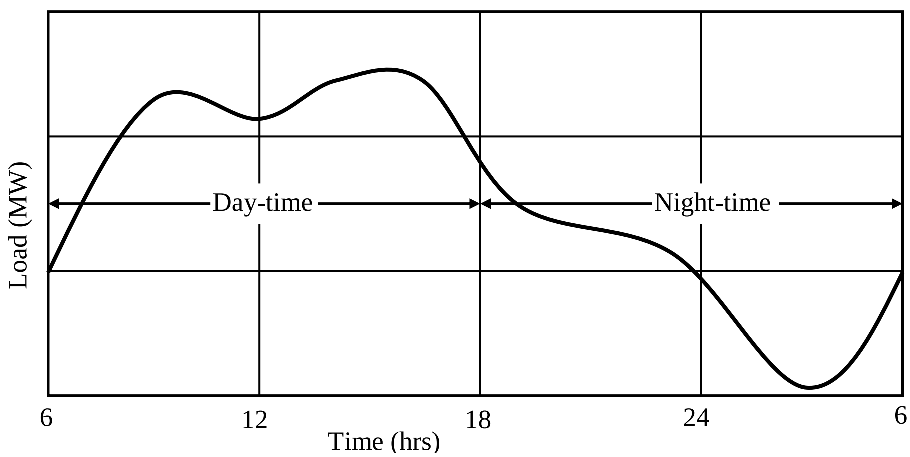

Fig. 1.7: Typical Daily Load Curve

At certain times the demand may reach the highest value, known as the peak-load. This maximum demand usually determines the size of a plant. Generally, the peak-load is defined as that part of the load carried at intensity greater than 4/3 times the mean load intensity.

To cover the fluctuating energy demand, the following types of power plants are interconnected to each others and work together:

- Base load power stations (coal, oil, nuclear and run-of-river scheme power stations);
- Average load power stations (temporary, gas and reservoir power stations);
- Peak load power stations (pumped storage and peak load hydro power stations).

Base load power stations having high utilization times, they produce electric energy on a very economical basis. The energy prime costs of peak load power stations are higher due to shorter utilization times; their emphasis lies on instant availability. These differences affect considerably the price of base load and peak load power.

1.3.2. Load Prediction

For the installation of a new power plant or for the expansion of the existing power plant, it is necessary to estimate the total amount of load that would be required to be met for various purposes. The economics of the installation or expansion of a power plant calls for the correct prediction or forecasting of the power demand.
Load forecasting may be done either for short-term (< 5 years), or medium-term (around 10 years), or long-term (> 20 years) periods. The short-term forecasting is usually done for operation planning of existing power plants, while the medium-term forecast is the basis for expansion program of power generation facilities. The long-term forecast helps in the formulation of the country’s perspective plan for power generation.

There are three basic load forecasting techniques:

- Trend analysis
- End-use analysis
- Econometric analysis

Each of the forecasting methods uses a different approach to determine electricity demand during a specific year in a particular place. Each forecasting method is distinctive in its handling of the four basic forecast ingredients: the mathematical expressions of the relationship between power demand and the factors which influence or affect it – *the functions*; the factors which actually influence the power demand (population, income, price, etc.) – *the independent variables*; power demand itself – *the dependent variables*; and how much power demand changes in response to population, income, price, etc., changes – *the elasticities*.

Trend Analysis:

Trend analysis extends past growth rates of power demand into the future. It focuses on past changes or movements in demand and uses them to predict future changes in the demand.

The advantage of trend analysis is that it is simple, quick and inexpensive to perform. It is useful when there is no enough data to use more sophisticated methods or when time and funding do not allow for a more elaborate approach.

The disadvantage of trend analysis is that it produces only one result – future power demand. It doesn’t help analyze why power demand behaves the way it does, and it provides no means to accurately measure how changes in energy prices or government policies, for instance, influence the demand.

End-Use Analysis:

The basic idea of end-use analysis is that the demand for power depends on what it is used for (the end-use). For instance, by studying historical data to find out how much power is used for individual electrical appliances in homes, then multiplying that number by the projected number of appliances in each home and multiplying again by the projected number of homes, an estimate of how much power will be needed to run all household appliances in a geographical area during any particular year in the future can be determined.

Using similar techniques for power used in business and industry, then adding up the totals for residential, commercial, and industrial sectors, a total forecast of power demand can be derived.

The advantage of end-use analysis is that it identifies exactly where power goes and how much is used for each purpose.

The disadvantage of the end-use analysis is that it assumes a constant relationship between power and end-use, for example, power used per appliance. But, in actual case, energy saving technology or energy prices will undoubtedly change with time, and the relationship will not remain constant. End-use analysis also requires extensive data.

Econometric Analysis:

Econometric analysis uses economics, mathematics, and statistics to forecast power demand. It is a combination of trend analysis and end-use analysis, but it does not make the trend analyst's assumption that future power demand can be projected based on past demand. Moreover, unlike end-use method, it can allow for variations in the relationship between power input and end-use.

Econometric analysis uses complex mathematical equations to show past relationships between demand and the factors which influence the demand. For instance, an equation can show how power demand in the past reacted to population growth, price changes, etc. For each influencing factor, the equation can show whether the factor caused an increase or decrease in a power demand. The equation is then tested and fine tuned to make sure that it is a reliable a representation as possible of the past relationships. Once this is done, projected values of demand-influencing factors (population, income, prices) are put in to the equation to make the forecast.

The advantage of econometric analysis is that it provides detailed information on future levels of power demand, why future power demand increases or decreases, and how power demand is affected by all the various factors. In addition, it is flexible and useful for analyzing load growth under different scenarios.

The disadvantage of econometric forecasting is the assumption that the changes in the power demand caused by changes in the factors influencing that demand remain the same in the forecast period as in the past. However, this constant elasticity assumption is hard to justify in reality.

Note:

- Load forecasts should be interpreted as rough indications of the reasonable range of possible outcomes of power growth, rather than precise computations of future power consumption.

- Often it is necessary to develop a range of load growth projections that reflect the uncertainty associated with many of the factors that influence load growth. Then, the mid-range forecast will be used as the basis for planning and the high and low growth scenarios will be utilized for sensitivity studies.

Example 1:

Given: $Q=50\ m^3/s$ Find: Power, P
$H=5\ m$ Work, A for t=7,000h/year
$0_{tot}=0.8$

Example 2:

Given: Two stations sharing a common load

- one is base load station
- the other is stand by station

Base load station characteristics:

Installed capacity = 25 MW

Yearly output = $125*10^6$ KWh

Take a peak of 22.5 MW

Standby station characteristics

Installed capacity = 30 MW

Yearly output = $10.5*10^6$ KWh

Peak load taken by stand by station = 15 MW

Station works for 2500 hrs/year

Determine (1) Annual load factor for both

(2) Plant use factor for both

(3) Capacity factor for both

Example 3:

A run-off-river plant operates as a peak load plant with 20% weekly load factor, and all its capacity is firm capacity. What will be the minimum flow in the river so that the station may serve as a base load station given that:

Installed capacity of generator = 10,000 KW

Operating head = 15m

Plant efficiency = 80%

Estimate the daily load factor of the plant if the stream flow is $15m^3/s$.

Example 1:

Given: Q=50 m³/s   Find: Power, P
H=5 m   Work, A for t=7,000h/year
0_{tot}=0.8

Solution

Power, P

P = η. γ.Q.H

P=0.8*(1000kg/m³*9.81m/s²)*50.0m³/s*5m=1962 KW = 1.962 MW

Work, A, for a yearly operation of 7000 hrs

A=P*t

A=1962 KW*7000h = $13.7*10^6$ KWh
= 13.7 GWh

Example 2

Given: Two stations sharing a common load
- one is base load station
- the other is stand by station

Base load station characteristics:

Installed capacity = 25 MW

Yearly output = $125*10^6$ KWh

Take a peak of 22.5 MW

Standby station characteristics

Installed capacity = 30 MW

Yearly output = $10.5*10^6$ KWh

Peak load taken by stand by station = 15 MW

Station works for 2500 hrs/year

Determine (1) Annual load factor for both
(2) Plant use factor for both
(3) Capacity factor for both

Solution

Base load station

Total energy generated per year = $125*10^6$

Capacity of the station = $25*10^3$ KW

Maximum demand = 22,500 KW

i) Annual load factor = $\frac{\text{total units generated}}{\text{peak demand * 8760}} = \frac{125*10^6}{22500*8760}$

= 0.634 = 63.4%

ii) Plant use factor = $\frac{\text{max. demand}}{\text{station capacity}} = \frac{22,500}{2,500}$ = 0.9 = 90%

iii) Capacity factor = $\frac{\text{average demand}}{\text{capacity of the station}}$

average demand = $\frac{125*10^6 \text{ KWh}}{8760 \text{ h}}$ = 14269 KW

:. capacity factor = 14269/2500 = 0.57 = 57%

Standby station

i) annual load factor = $10.5*10^6$ / (15,000*2500) = 0.028 = 28%

ii) plant use factor = $15*10^3$ / 30000 = 0.5 = 50%

iii) average demand = 10.5* 10^6 / 2500 = 4200 KW

capacity factor = 4200/30000 = 0.14 =14%

Example 3

A run-off-river plant operates as a peak load plant with 20% weekly load factor, and all its capacity is firm capacity. What will be the minimum flow in the river so that the station may serve as a base load station given that:

Installed capacity of generator = 10,000 KW

Operating head = 15m

Plant efficiency = 80%

Estimate the daily load factor of the plant if the stream flow is $15m^3/s$.

<u>Solution :</u>

When the plant operates as a peak-load plant with 20% load factor, the total energy generated for one week will be

10,000*0.20*7*24 = 33.6 * 10^4 KWh

If Q is min. flow necessary for plant to run as abase load, the power P developed will be.

P = 9.81 n Q H KW

= 9.81*Q*15*0.8 = 117.6 Q KW

Total generated per week = 117.6 Q * 7 * 24 = $1.98*10^4$ * Q KWh.

:. Q = $\frac{33.6 * 10^4}{1.98 * 10^4}$ = 16.97 m^3/s min. flow in the river.

If the stream flow is $15m^3/s$, the power developed = 117.6 Q

Total generated in 24 hrs = 1764*24 = 42336 KWh

:. Daily load factor = $\frac{42336}{10000*24}$ = 0.1764 = 17.64%