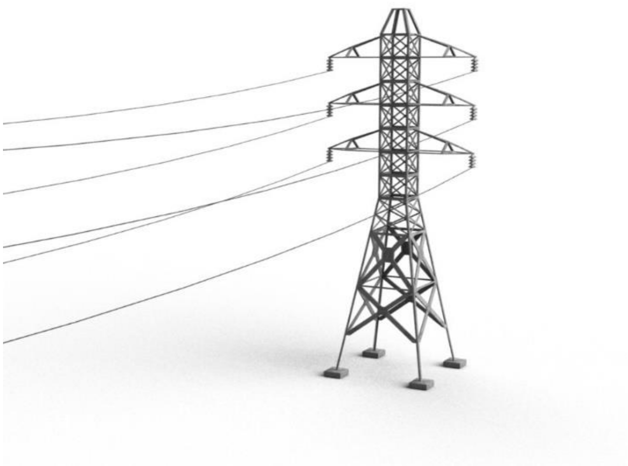
12

Economics of Power Generation



Course Contents

12.1 Load curves and Load duration curves

The curve showing variation of load or power consumption with time is known as load curve. If time is in hours, then it is called daily load curve. If the time in days, it is called monthly load curve and f time is in month it is called yearly load curve.

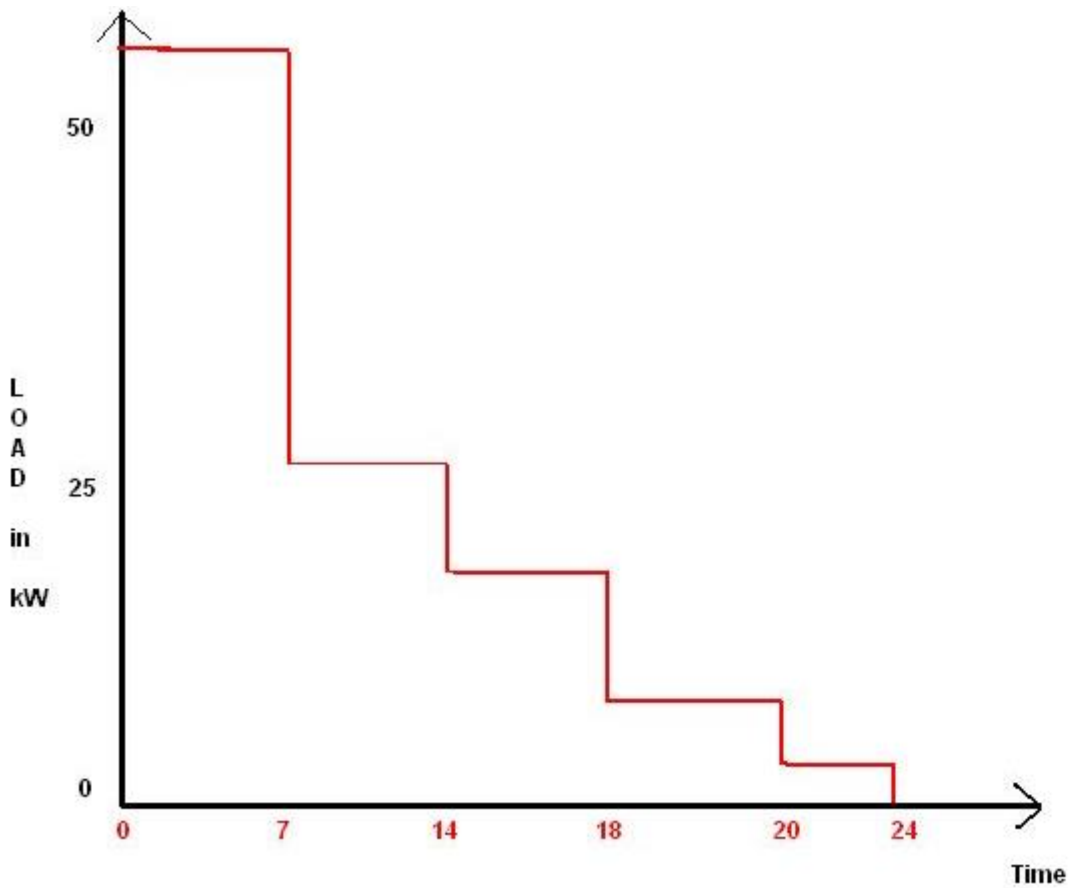


Figure 12.1 Load curve

Following information obtained from the load curve

- The area under the load curve gives the total energy consumption.
- Peak load and its duration can be known from load curve.
- The average load during day, month or year can be determined from load curve by dividing total energy consumption by time.

Load duration curve

A load duration curve is a rearrangement of daily load curve with load set up in descending order of magnitude. The area under the load curve and the area under load duration curve are equal.

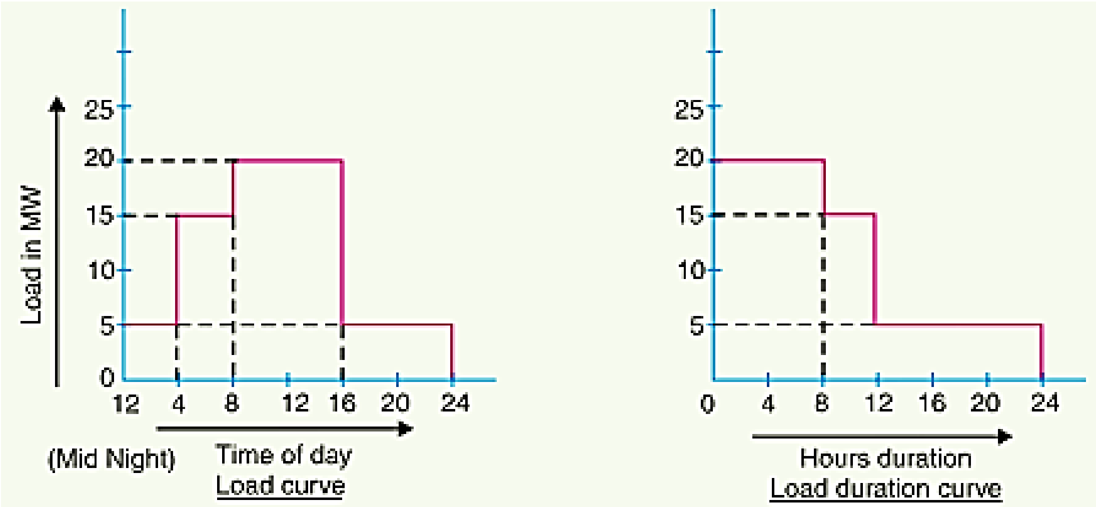


Figure 12.2 Load curve and Load duration curve

To get the load duration curve from chronological load curve, we cut the daily load curve into many vertical strips and then arrange them in descending order. The area under the load duration curve and corresponding load curve are equal and measure kWhr of energy for that period.

12.2 Different terms used in Economics of power generation

Connection load

It is defined as sum of the ratings of all the equipment installed in a given space which consumes the electrical energy ratings of all the equipments given in KW.

Maximum demand

It is defined as a maximum load which customers consume at a given time.

Demand factor

It is defined as the ratio of maximum demand to the connected load of a consumer.

Load curve

A diagram showing consumption of energy of a consumer in a given time/duration is termed as load curve.

Load curve can be prepared on daily basis, monthly basis or even a yearly basis.

Average load

It is defined as the ratio of energy consumed by the consumers in KWhr to the duration of consumption (i.e. 24 hours). It is also calculated by multiplication of load factor and peak load.

Load factor

It is defined as the ratio of average load to the maximum load consume by the consumer.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum load}}$$

Diversity factor

It is the ratio of sum of individual maximum demand of the load to the maximum demand of entire group of loads.

Plant capacity factor

Capacity factor shows how close a plant runs to its full rating.

$$Plant\ capacity\ factor = \frac{E}{C \times t}$$

Where,

E= Actual energy generated in KWhr in given period

C= Capacity of the plant in KW

t= Total number of hours in the given period

Plant use factor

It is defined as the ratio of energy produced in a given time to maximum possible energy that could have been produced during the actual number of hours the plant was in operation. High value of plant use factor indicates that the plant is used more efficiently.

$$Plant\ use\ factor = \frac{E}{C \times t1}$$

Where,

E= Actual energy generated in KWhr in given period

C= Capacity of the plant in KW

t_1= Actual number of hours the plant is in operation.

12.3 Cost of Power Plant

The cost of electrical energy generated in power plant consists of fixed cost and running cost.

1. <u>Fixed Cost</u>

The fixed cost is the capital invested in the installation of complete plant. This includes the cost of land, buildings, equipments, transmission, and distribution lines, cost of planning and designing of the plant substations and many others. It further includes the interest on the invested capital, insurance, maintenance cost, and depreciation cost.

- **Land Building and Equipment Cost:-**

The cost of land, building, does not change much with different types of plants but the cost of equipment changes considerably. The cost of the equipment or the plant investment cost is usually expressed on the basis of kW capacity installed. The capital cost per kW installed capacity does not change much for thermal plant but it changes a lot in case of hydro-plants. Because the cost of hydro-plant depends upon the foundation available, type of dam and spillways used available head and quality of water. The capital cost of hydro-plant may vary from Rs.18000/kW to Rs.30000/kW. The capital cost of thermal plant is about Rs.10000/kW on the basis of 1970.

- **Interest:-**

The interest on the capital investment must be considered because otherwise if the same capital is invested in some other profitable business could have equal the interest considered. A suitable rate of interest must be considered on capital investment.

- **Depreciation Cost:-**

It is the amount to get aside per year from the income of the plant to meet the depreciation caused due to wear and tear of equipments. The capital investment for the plant installation must be recovered by the time the life span of the plant is over, so that it can be replaced by a new plant. Some amount from the income is set aside per year as depreciation cost of the plant which accumulates till the plant is in operation. The amount collected by the way of depreciation by the time the plant retires is equal to the capital invested in the installation of the plant. Different methods are used for finding out the depreciation cost of the power plant. Few of them which are commonly used are listed below:

a) Straight Line Method
b) Sinking Fund Method
c) Diminishing Value Method

Let us consider,

P = Initial investment to install the plant.
S = Salvage value at the end of the plant life.
n = Life of plant in years.
r = annual rate of compound interest on the invested capital.
A = the amount set aside per year for the accumulation of the depreciable investment at the end of n^{th} year.

a) <u>Straight Line Method</u>

According to this method, annual/amount to be set aside is calculated using the following formula:

$$A = \frac{P - S}{n}$$

In this method, the amount set aside per year as depreciation fund does not depend on the interest it may draw. The interest earned by the depreciation amount is taken as income. This method is commonly used because of its simplicity.

b) Sinking Fund Method

In this method, the amount set aside per year consists of annual installments and the interest earned on all the installments. This method is based on the conception that the annual uniform deduction from income for depreciation will accumulate to the capital value of the plant at the end of life of the plant or equipment. 'A' is the amount set aside at the end of year for 'n' years, then

Amount set aside at the end of first year = A
Amount at the end of second year = A + interest on A
= A + A*r
= A (1+r)

Amount at the end of third year = A (1+r) + interest on A (1+r)
= A (1+r) + A (1+r)*r
= $A (1+r)^2$

Amount at the end of n^{th} year = $A (1 + r)^{n-1}$

Total amount accumulated in n years
= Sum of the amounts accumulated in n years

$P-S = A + A (1+r) + A (1+r)^2 + \ldots\ldots + A (1+r)^{n-1}$
$= A [1+ (1+r) + (1+r)^2 + \ldots\ldots + (1+r)^{n-1}]$ ……………………….(i)

Multiplying the above equation by (1+r), we get

$y (1+r) = A [(1+r) + (1+r)^2 + (1+r)^3 + \ldots\ldots + (1+r)^n]$ …………………(ii)

Subtracting equation (i) from equation (ii), we get

$(P-S)r = [(1+r)^n - 1] A$
$P-S = [\{(1+r)^n - 1\}/r] A$

So finally,

$$A = \left[\frac{r}{(1+r)^n - 1}\right](P - S)$$

c) Diminishing value method

In this method, the amount set aside per year decreases as the life of the plant increases. This can be explained by the following example.
Say the equipment cost is Rs.20000/-.

The amount set aside is 10% of the initial cost at the beginning of the year and 10% of the remaining cost with every successive year.

Therefore,

The amount set aside during first year = 20000 – (10/100)*20000
= 18000 balance
The amount set aside during second year = 18000 – (10/100)*18000
= 18000-1800
= 16200 balance

The next installment during third year = 16200 – (10/100)*16200
= 14580 balance
This method requires heavy installment in the early years when the maintenance charges are minimum and it goes on decreasing as the time passes but the maintenance charges increases. This is the main disadvantage of this method.

- **Insurance**

It becomes necessary many times to insure the costly equipments especially for the fire issues. A fixed sum is set aside per year as insurance charges. The annual premium may be 2-3% but the annual installment is quite heavy as the capital cost of the plant is considerably high.

- **Management Cost**

This includes the salaries of the people working in the plant. This must be paid whether the plant is working or not. Therefore, this is included in fixed charges of the plant.

2. <u>Running cost</u>

The operating cost of the electrical power generation includes the cost of fuel, cost of lubricating oil, grease, cooling water, and number of consumable articles required. The wages required for supplying the above material are also included in the operating cost of the power plant.

- **Fuel Cost**

The fuel cost is proportional to the amount of energy generated. The rate of fuel consumption per unit of energy generated also varies according to the load on power plant. The consumption of fuel per unit of energy generated is minimum at full load on power plant because the prime mover works at maximum efficiency at full load conditions.

- **Oil, Grease and Water Cost**

The cost of these materials is also proportional to the amount of energy generated. This cost increases with an increase in life of power plant as the efficiency of the power plant decreases with the age.

12.4 Performance & Operating Characteristics Of Power Plant

The performance of generating power plant is compared by their average efficiencies over a period of time. The average efficiencies of power plant is the ratio of useful energy output to the total energy input during the period considered. This measure of performance varies with uncontrolled conditions such as cooling-water temperature. Shape of load curve &quality of fuel. Therefore, it is not a satisfactory standard of comparison unless all plant performances are corrected to the same controlling conditions.

Plant performance can be precisely represented by the input-output curve from the tests conducted on individual power plant. The input-output can be represented as:

$$\mathbf{I= a+bL+cL^2+dL^3}$$

Where I is input expressed in millions of kJ per hour in case of thermal plants & in case of hydro plants & L is the output or load either in MW or kW, a, b, c & dare constants.

The input-output curve for a power plant is shown in Fig (A). At zero load (L=0), the positive intercept for I measures the amount of energy required to keep the plant in running condition. Any additional input over no-load input produces a certain output which is always less than input.

The efficiency of the power plant is defined as the ratio of output to input.

$$\text{Efficiency} = L/I$$

$$\text{Efficiency} = L/(a+bL+cL^2+dL^3)$$

The heat rate curve & the incremental rate curve may be derived from the basic input-output curve. The heat rate is defined as the input per unit output.

$$\text{HR (heat rate)} = I/L$$

$$= (a+bL+cL^2+dL^3)/L$$

$$\text{HR (heat rate)} = (a/L) + b + cL + dL^2$$

The relation between efficiency & heat Rate is given by

$$\text{Efficiency} = 1/HR$$

The incremental rate is defined as the ratio of additional Input (dI) required increasing additional output.

IR (incremental rate) = dI/dL

$$\therefore dI = IR \times dL$$

$$\int_{I1}^{I2} dI = \int_{L1}^{L2} IR \, . \, dL$$

$$\therefore I2 - I1 = \int_{L1}^{L2} IR \, . \, dL$$

$$IR = \frac{dI}{dL}$$

$$= \frac{d(\text{ a} + \text{bL} + \text{cL2} + \text{dL3})}{dL}$$

$$= b + 2cL + 3dL^2$$

Above equation is known as the incremental rate equation. The incremental load curve can be considered a straight line for relatively small increase in output. This is not true for large increment of load because of the measured curvature of the incremental rate curve.

At minimum heat rate, the slope of the heat rate curve must be zero

∴d/dL (HR) = d/dL (I/L)

As HR = I/L,

∴ $(LdI – IdL)/L^2 = 0$

∴ (dI/dL)= (I/L)

∴ IR= HR when HR is minimum.

This indicates that the heat rate of continuous input-output curve is minimum when it equals the incremental rate.

12.5 Tariff for electric energy

The rates of energy sold to the consumers depend on the type of consumers as domestic, commercial, and industrial. The rates depend upon the total energy consumed and the load factor of the consumer.

Whatever may be the type of consumer, all forms of energy rates must cover the following items,

1) Recovery of capital cost invested for the generating power plant.
2) Recovery of the running costs as operation cost, maintenance cost, metering the equipment cost, billing cost and many others.
3) Satisfactory profit on the invested capital as the power plant is considered a profitable business for the government.

Although the determination of each cost item is simple but the allocation of these items among the various classes of consumers is rather difficult and requires considerable engineering judgement.

General rate form

The general type of tariff can be represented by the following equation.

Z= ax + by + c

Where,

Z= Total amount of bill for the period considered

x= Maximum demand in KW

y= Energy consumed in KWh during the period considered

a=Rate per KW of max demand

b= Energy rate per KWh

c= Constant amount charged to the consumer during each billing period. This charge is independent of demand or total energy because a consumer that remains connected to the line incurs expenses even if he does not use energy.

(1) Flat demand rate

This type of charging depends only on the connected load and fixed number of hours of use per month or year. This rate expresses the charge per unit of demand (KW) of the consumer. This system eliminates the use of metering equipments and manpower required for the same.

This can be expressed as,

$$Z = ax$$

Under this system of charging the consumer cam theoretically use any amount of energy up to that consumed by all the connected load at 100% use factor continuously at full load.

The unit energy cost decreases progressively with an increased energy usage since the total cost remains constant

(2) Straight line meter rate

In this type of tariff, the charge is based on amount of energy consumed and the charge per unit is constant. It is expressed as

$$Z = by$$

The main drawback of this tariff is that a customer who does not use energy will not pay any amount.

(3) Block meter rate method

The straight line meter rate charges the same unit price for all magnitudes of energy consumption. The increased generation spreads the item of fixed charge over a greater number of units of energy and therefore the price of energy should decrease with an increase of consumption. To overcome this difficulty, the block meter rate is used. In this method the charging energy is done as stated below:

$$Z1 = b1y1 + b2y2 + b3y3 + \_\ \_\ \_\ \_$$

Where $b3 < b2 < b1$ and $y1+y2+y3+\_\ \_\ \_ = y$ (total energy consumption)

In gross meter rate system, the rate of unit charge decreases with increasing consumption of energy. The level y1, y2, y3 and so on is decided by the management to recover the capital cost of the plant.

(4) Hopkinson demand rate or Two part Tariff

This method of charging was proposed by Dr. John Hopkinson in 1892. This method charges consumer according to record the maximum demand and the energy consumption. This can be expressed as,

$$z=ax + by$$

This method required two meters to record the maximum demand and the energy consumption of the consumer. This method is generally used for industrial customers.

(5) Doherty rate or Three part Tariff

This rate of charging was suggested by Henry L. Doherty at the beginning of the twentieth century. According to this method of charge, the customer has to pay some fixed amount in addition to the charges for maximum demand and energy consumed. The fixed amount to be charged depends upon the occasional increase in prices and wage charges of the workers and so on. This is expressed as,

$$X = ax + by + c$$

The Doherty rate is sometimes modified by specifying the minimum demand and minimum energy consumption that must be paid for they are less than the minimum values specified.