



POWER SYSTEMS-1

ELECTRICAL POWER GENERATION

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MODULE 1

Introduction to the Different Sources of Energy

1.1 Resources and Development of Power in India and Indian Energy Scenario.

In so far as electricity consumption is concerned, India has reached a level of about 600-kilowatt hour (kWh) per head per year.

India is targeting a growth rate of 9 – 10%, having already reached a level of almost 8%.

In the profile of energy sources in India, coal has a dominant position. Coal constitutes about 51% of India's primary energy resources followed by Oil (36%), Natural Gas (9%), Nuclear (2%) and Hydro (2%).

- More than 60% of Indian households depend on traditional sources of Energy for cooking & heating needs.
- At current rate of consumption & production, coal reserves in India would last for about 130 years.
- At current rate of consumption & production, oil in India would last only for about 20 to 25 years.
- In commercial energy consumption, coal constitutes 29%, Oil & gas 54% & electricity 17%.
- We are using only 20% of total hydro-power potential. (Estimated annual energy potential from hydro-electric sources is around 90000 MW while we are currently producing only 18000 MW.
- Out of total electricity production, 65.8% comes from thermal power plants, 26.3% from hydro electricity & only 3.1% from nuclear power. Non-conventional, renewable energy sources like solar, wind energy constitute nearly 4.9%. (As per NIC site on Ministry of Power).
- Public sector produces 558 billion kWh of electricity while private sector only 58 billion kWh.
- India is second largest exploiter of Wind Energy – 1000 MW (70% by private sector).
- There are 33 lakh bio-gas plants, 2 lakh solar cookers & 10000 street lighting systems using solar photo-voltaic technology.
- Out of total electricity consumption in India, 34% goes to Industry, 24% to agriculture, 21 % to domestic use, 12% to public lighting & 2% to railway traction. These figures do not include captive (i.e. private sector) power generation.
- Currently 5, 87,560 villages in India have electricity.

Economics of Power Generation & Variable Load on Power Station

1.2.1 Load Curve : The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a LOAD CURVE

A load curve is a chart used by engineers and power producers to show how much Electricity customers utilize during a given period of time. When looking at the graph, time usually is placed on the horizontal axis, and load is placed on the vertical axis. This data can be used to predict power trends, which allows an area to build and connect sufficient power generators for peak demand periods.

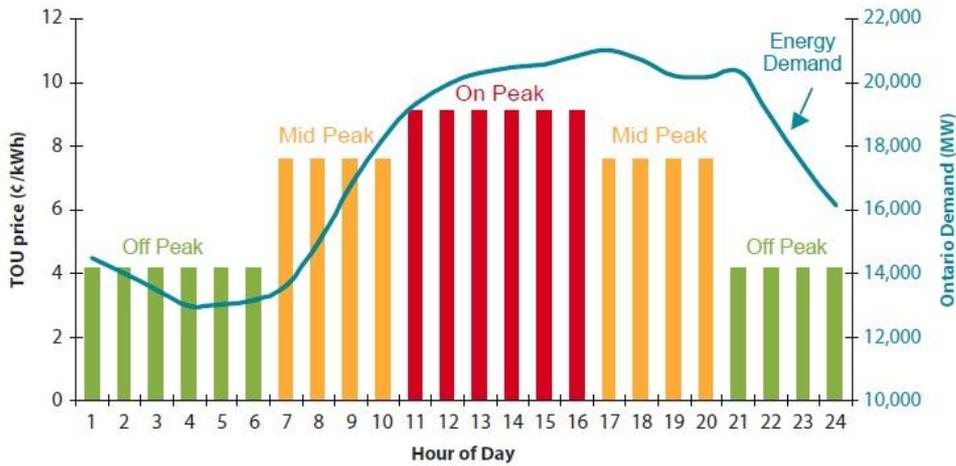


Fig 1.1 A Typical Load Curve Chart

1.2.2 Daily Load Curve: 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 half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as daily load curve as it shows the variations of load w.r.t. time during the day.



1.2.3 Monthly Load Curve: The monthly load curve can be obtained from the daily load curves of that month. For this purpose, average values of power over a month at different times of the day are calculated and then plotted on the graph.

1.2.4 Yearly load curve: -- Load variations captured during the Year, this is derived from monthly load curves of a particular year.

1.2.5 Information obtained from load curves:

- Area under load curve = Units generated
- Highest point of the curve = maximum demand
- $(\text{Area under curve}) \div (\text{by total hours}) = \text{Average load}$
- Helps to select size & number of generating units.
- Helps to create operating schedule of the power plant.

1.2.6 Load Duration Curve

A load duration curve represents re-arrangements of all the load elements of chronological load curve in order of descending magnitude. This curve is derived from the chronological load curve.

Figure 1.3 shows a typical daily load curve for a power station. It may be observed that the maximum load on power station is 35 kW from 8 AM to 2 PM. This is plotted in Figure 1.4. Similarly; other loads of the load curve are plotted in descending order in the same figure. This is called load duration curve

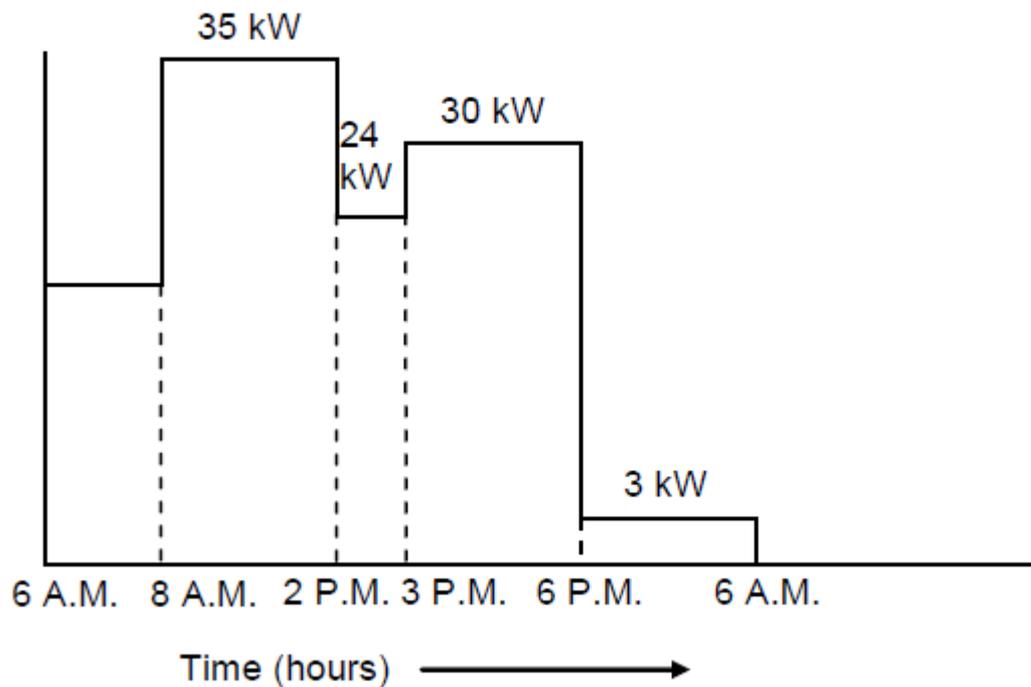


Fig 1.3 Typical Daily Load Curve

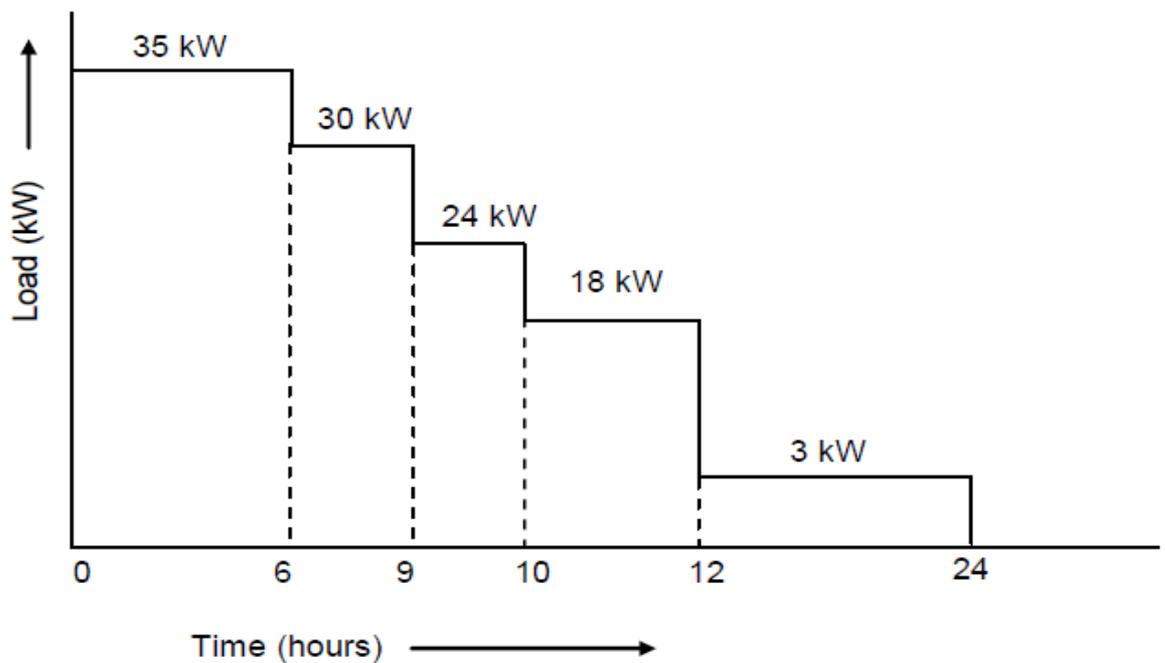


Fig 1.4 Load Duration Curve

1.3.1 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.

1.3.2 Diversity factor. : The ratio of the sum of individual maximum demands to the maximum demand on power station is known as **diversity factor** i.e.,

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

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 the greater the diversity factor, the lesser is the cost of generation of power.

1.3.3 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.

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

1.3.4 Plant Capacity Factor: It is defined as the ratio of actual energy produced in kilowatt hours (kWh) to the maximum possible energy that could have been produced during the same period. Expressing the definition mathematically,

$$\text{Plant capacity factor} = E / C * t$$

where, E = Energy produced (kWh) in a given period,

C = Capacity of the plant in kW, and

t = Total number of hours in the given period.

Types of load on Power Station

1.4 Types of Loads

1.4.1 Residential Load

This type of load includes domestic lights, power needed for domestic appliances such as radios, television, water heaters, refrigerators, electric cookers and small motors for pumping water. Most of the residential load occurs only for some hours during the day (i.e., 24 hours) e.g., lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%).

1.4.2 Commercial Load

It includes lighting for shops, advertisements and electrical appliances used in shops and restaurants, etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of air conditioners and space heaters.

1.4.3 Industrial Load

It consists of load demand of various industries. Small scale industry requires load upto 25 kW, medium scale industry between 25kW and 100 kW and large-scale industry requires load above 500 kW. Industrial loads are generally not weather dependent.

1.4.4 Municipal Load

It consists of street lighting, power required for water supply and drainage purposes. Street lighting load is practically constant throughout the hours of the night. For water supply, water is pumped to overhead tanks by pumps driven by electric motors. Pumping is carried out during the off-peak period, usually occurring during the night. This helps to improve the load factor of the power system.

1.4.5 Irrigation Load

This type of load includes electrical power needed for pumps driven by electric motors to supply water to fields.

1.4.6 Traction Load

It includes trams, cars, trolley, buses and railways. During the morning hour, it reaches peak value because people have to go to their work place. After morning hours, the load starts decreasing and again rises during evening since the people start coming to their homes.

1.5 Load Curves and Selection of Generating Units

The load on a power station is seldom constant; it varies from time to time. Obviously, a single generating unit (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. Once this underlying principle is adhered to, it becomes possible to operate the generating units at or near the point of maximum efficiency.

1.6 Important Points in the Selection of Units

While making the selection of number and sizes of the generating units, the following points should be kept in view:

- The number and sizes of the units should be so selected that they approximately fit the annual load curve of the station
- The units should be preferably of different capacities to meet the load requirements. All use of identical units (i.e., having same capacity) ensures saving in cost, they often do not meet the load requirement.
- The capacity of the plant should be made 15% to 20% more than the maximum demand to the future load requirements.
- There should be a spare generating unit so that repairs and overhauling of the working units can be carried out.
- The tendency to select a large number of units of smaller capacity in order to fit the load curve very accurately should be avoided. It is because the investment cost per kW of capacity increases as the size of the units decreases.

1.7 Interconnected Grid System

- The connection of several generating stations in parallel is known as interconnected grid system.
- Although interconnection of station involves extra cost, yet considering the benefits derived from such an arrangement, it is gaining much favour these days.
- Some of the advantages of interconnected system are listed below :
 - (i) **Exchange of peak loads:** An important advantage of interconnected system is that the peak load of the power station can be exchanged. If the load curve of a power station shows a peak demand that is greater than the rated capacity of the plant, then the excess load can be shared by other stations interconnected with it.
 - (ii) **Use of older plants:** The interconnected system makes it possible to use the older and less efficient plants to carry peak loads of short durations. Although such plants may be inadequate when used alone, yet they have sufficient capacity to carry short peaks of loads when with other modern plants. Therefore, interconnected system gives a direct key to the use of obsolete plants.

1.8 Tariff Methods

Before going into this session we first know what Tariff is all about. 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.

1.8.1 Objectives Of Tariff.

In this world useful things don't come free. Like other commodities, electrical energy is also sold. It is 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:

- Recovery of cost of producing electrical energy at the power station.
- Recovery of cost on the capital investment in transmission and distribution systems.
- Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.
- A suitable profit on the capital investment.

1.9 Desirable Characteristics of a Tariff

A Tariff must be defined with following desirable characteristics:

- **Proper Return:** The tariff should be such that it ensures the proper return from each consumer. That means the total revenue collected from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit (**COP + COT + PROFIT**). This will enable the electric supply company to ensure continuous and reliable service to the consumers and will help them to recover money for future extension
COP: Cost of Production of Electrical Energy.
COT: Cost of Transmission of Electrical Energy.
- **Fairness:** The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy. Similarly, a consumer whose load conditions do not deviate much from the ideal (i.e., non- variable) should be charged at a lower rate than the one whose load conditions change appreciably from the ideal.
- **Simplicity:** The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.
- **Reasonable Profit:** The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. Therefore, the investment is relatively safe due to non-competition in the market. This calls for the profit to restricted to 8% or so per annum.
- **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.

1.10 Types of Tariff

There are several types of tariff. But in INDIA, following are the commonly used types of tariff:

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

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

Disadvantages Of Simple Tariff Method

- There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed charges.
- The cost per unit delivered is high.
- It does not encourage the use of electricity. (Its sounds odd ,right !!. But that is the real thing. If electricity supplied is more than electricity demanded ,then it will cause decrease in **Load Factor** and further to huge losses .So to keep **Load Factor** high, electricity consumption in some areas are encouraged)

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

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

Disadvantages Of Flat Rate Tariff

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

3. 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.

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

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

Total charges = Rs. $(b \times KW + c \times KWh)$

Where, b = charge per KW of Maximum Demand.

c = charge per KWh of Energy Consumed.

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

Advantages

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

Disadvantages

- The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.
- There is always error in assessing the maximum demand of the consumer.

5. Maximum Demand Tariff. It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the ratable value. This type of tariff is mostly applied to big consumers.

However, it is not suitable for a small consumer (e.g., residential consumer) as a separate maximum demand meter is required.

6. 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:

- **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.

- **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.
- **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.

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

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

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

b = charge per kW of maximum demand,

c = charge per kWh of energy consumed.