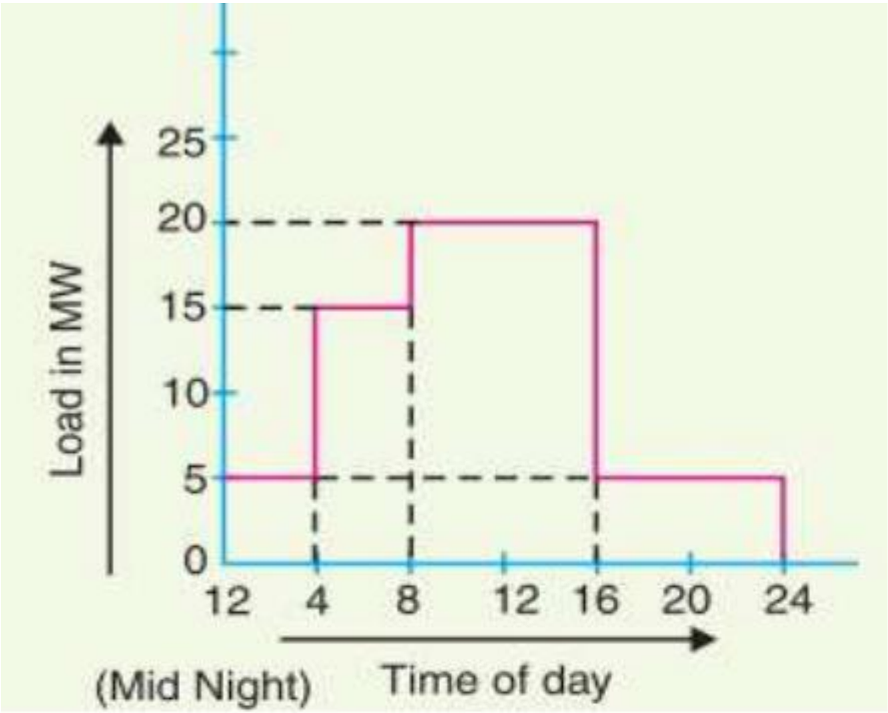
LOAD CURVE (or CHRONOGICAL LOAD CURVE):

- The curve showing the variation of load on the power station with respect to time is known as a load curve.
  - Daily load curve
  - Monthly load curve
  - Yearly load curve

DAILY LOAD CURVE

- ✓ The load on a power station is never constant and it varies from time to time.
- ✓ The load variations during the whole day are recorded half-hourly or hourly and are plotted against time on the graph.
- ✓ The curve thus obtained is known as daily load curve.



IMPORTANCE OF DAILY LOAD CURVE

- The daily load curve shows the variations of load on the power station during different hours of the day.
- The area under the daily load curve gives the number of units generated in a day.
- Units generated/day = Area (in kWh) under daily load curve.
- The highest point on the daily load curve represents the maximum demand on the station on that day.
- The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

  Average load = Area (in kWh) under daily load curve/24 hours
- The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor

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

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

Daily Load Curve

- The load curve helps in selecting the size and number of generating units.
- The load curve helps in preparing the operation schedule of the station .

IMPORTANCE OF MONTHLY AND YEARLY LOAD CURVE

- The monthly load curve can be obtained from the daily load curves of that month.
- In this the average values of power over a month at different times of the day are calculated and then plotted on the graph.
- If we consider the load on power station at mid-night during the various days of the month, it may vary slightly, then the average will give the load at mid night on the monthly curve.
- The monthly load curve is generally used to fix the rates of energy.
- 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.

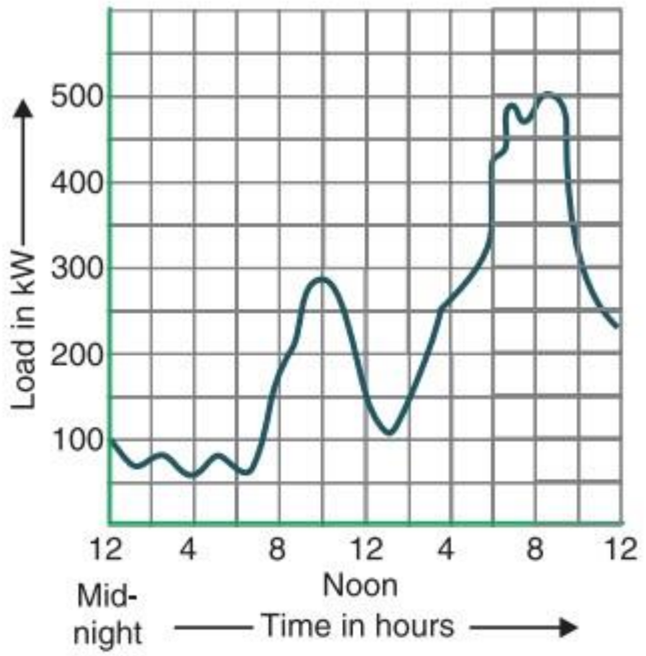
Load Curves and Selection of Generating Units

The load on a power station is not constant; it varies from time to time. Obviously, a single generating unit (i.e., alternator) will not be an economical solution to meet this varying load. The reason for this is that one unit will have a very low efficiency during periods of light loads at the power station. Therefore, a power station usually contains a variety of generating units with different capacities.

The size and number of the generating units are chosen according to the station's annual load curve. It is imperative to select the number and size of the units so that they fit correctly with the station load curve. When this underlying principle is adhered to, it is possible to operate the generating units at or near their maximum efficiency.

How Generating Units are Selected?

The principle of selection of number and sizes of generating units with the help of load curve is illustrated here. The annual load curve of a station is shown in the figure.

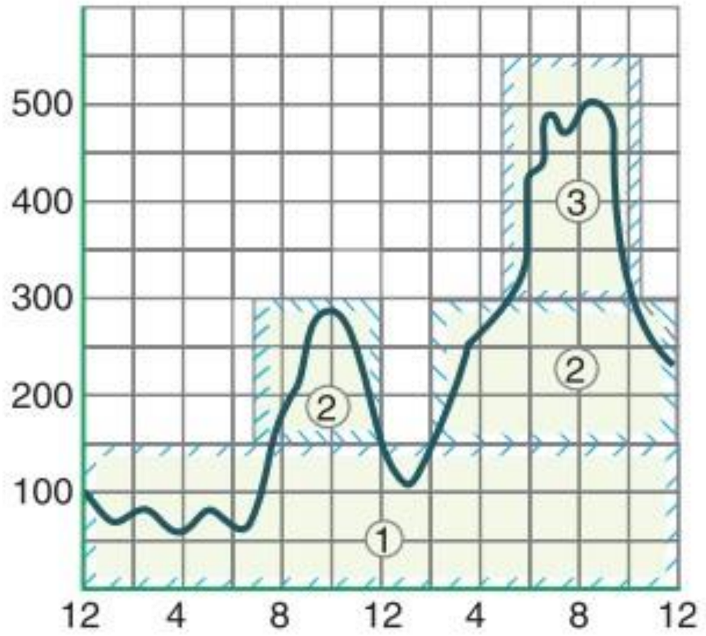


It is clear from the curve that the load on the station has wide variations. The minimum load being around 50 kW and the maximum load approaching 500 kW. The use of a single unit to meet such a varying load will be highly uneconomical.

The total plant capacity is divided into several generating units of varying sizes according to the load curve. This is illustrated in the figure where the plant capacity is divided into three units numbered 1, 2 and 3.

Colored cyan is the capacity of the unit as it is being used. The three units employed have different capacities and are used according to the station's demand.

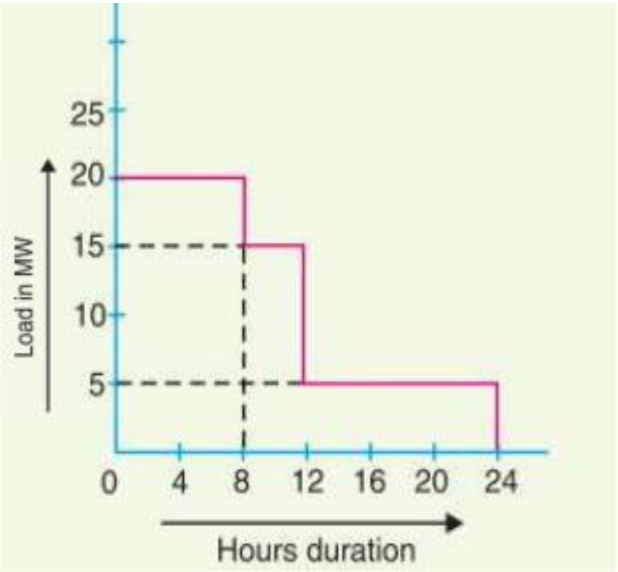
Time	Units in Operation
From 12 midnight to 7 A.M.	Only unit no.1 is put in operation.
From 7 A.M. to 12.00 noon	Unit no. 2 is started, so units 1,2 operate
From 12.00 noon to 2 P.M.	Unit no. 2 is stopped and only unit 1operates.
From 2 P.M. to 5 P.M.	Unit no. 2 is again started. units 1 and 2 operated
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.



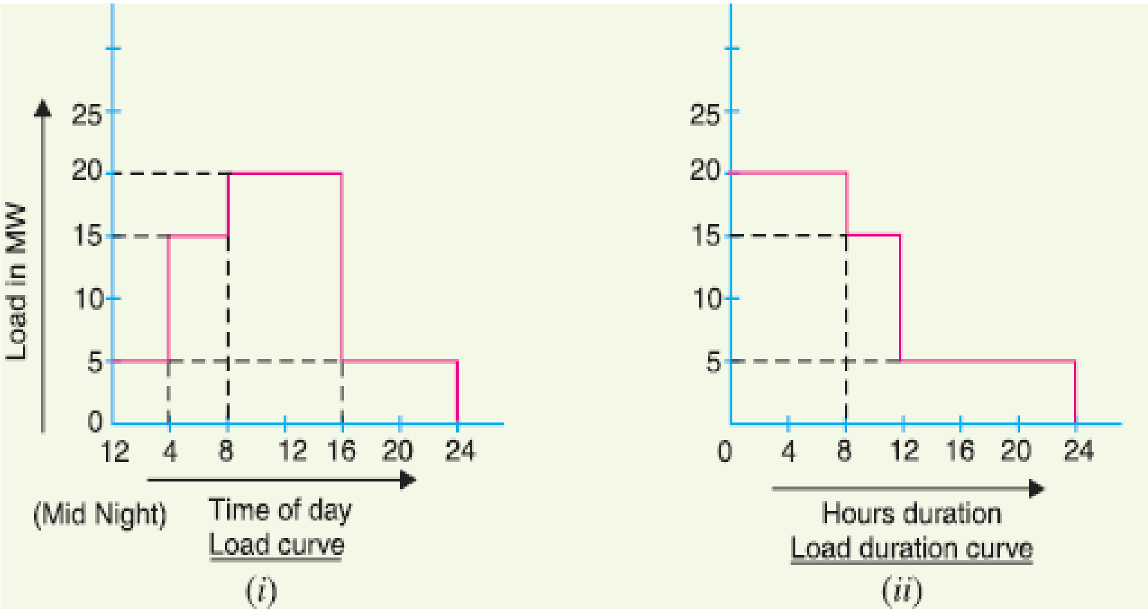
Generating Units from Load Curve

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.
- The load duration curve is obtained from the same data as the load curve but the ordinates are arranged in the order of descending magnitudes.
- Hence the area under the load duration curve and the area under the load curve are equal.
- The load duration curve can be extended to include any period of time.



In other words, the maximum load is represented to the left and decreasing loads are represented to the right in the descending order



The following points may be noted about load duration curve :

(i) The load duration curve gives the data in a more presentable form. In other words, it readily shows the number of hours during which the given load has prevailed.

(ii) The area under the load duration curve is equal to that of the corresponding load curve. Obviously, area under daily load duration curve (in kWh) will give the units generated on that day.

(iii) The load duration curve can be extended to include any period of time. By laying out the abscissa from 0 hour to 8760 hours, the variation and distribution of demand for an entire year can be summarised in one curve. The curve thus obtained is called the *annual load duration curve.*

IMPORTANT TERMS AND FACTORS

- Connected load: It is the sum of continuous ratings of all the equipments connected to supply system.
- Maximum demand: It is the greatest demand of load on the power station during a given period.
- Demand factor: It is the ratio of maximum demand on the power station to its connected load.

  Demand factor = Maximum demand/connected load

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.

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

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

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

LOAD FACTOR

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

$$Load\ factor = \frac{Average\ load}{Maximum\ demand} = \frac{Units\ generated\ in\ T\ hours}{Maximum\ demand\ \times T\ hours}$$

- 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.
- Higher load factor means lesser maximum demand.
- Lower maximum demand means lower capacity of the plant which, therefore, reduces the cost of the plant.
- **Load factor** is always less than 1 because average load is smaller than the maximum demand. The load factor plays a vital role in determining the cost of energy. Some important advantages of high load factor are listed below :

(*i*) *Reduces cost per unit generated* : A high load factor reduces the overall cost per unit generated. The higher the load factor, the lower is the generation cost. It is because higher load factor means that for a given maximum demand, the number of units generated is more. This reduces the cost of generation.

(*ii*) *Reduces variable load problems* : A high load factor reduces the variable load problems on the power station. A higher load factor means comparatively less variations in the load demands at various times. This avoids the frequent use of regulating devices installed to meet the variable load on the station

DIVERSITY FACTOR

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

$$Diversity\ factor = \frac{Sum\ of\ \ individual\ maximum\ demands}{Maximum\ demand\ on\ power\ station} = \frac{1}{Coincidence\ factor}$$

- 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.
- Greater diversity factor means lesser maximum demand, this in turn means that lesser plant capacity is required.
- Thus, the capital investment on the plant is reduced.

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.,

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

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

$$\text{Annual plant capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity} \times 8760}$$

- 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.

  Reserve capacity = Plant capacity − Max. demand
- It is interesting to note that difference between load factor and plant capacity factor is an indication of reserve capacity.
- If the maximum demand on the plant is equal to the plant capacity, then load factor and plant capacity factor will have the same value. In such a case, the plant will have no reserve capacity.

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 7·35 $* 10^6$ kWh and remains in operation for 2190 hours in a year. Then,

$$\text{Plant use factor} = \frac{7.35 \times 10^6}{\left(20 \times 10^3\right) \times 2190} = 0.167 = 16.7\%$$

Example: 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.*

Example: 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.

$$\text{i. Load factor} = \frac{\text{Average demand}}{\text{Maximum demand}}$$

$$0.6 = \frac{\text{Average demand}}{25}$$

$$\text{Average demand} = 25 \times 0.6 = 15MW$$

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

$$\text{Plant capacity} = \frac{\text{Average demand}}{\text{Plant capacity factor}} = \frac{15}{0.5} = 30MW$$

$$\text{Reserve capacity of plant} = \text{Plant capacity - maximum demand}$$

$$= 30 - 25 = 5MW$$

$$ii.\ \text{Daily energy produced} = \text{Average demand} \times 24$$

$$= 15 \times 24 = 360\text{MWh}$$

$$\text{iii. Maximum energy that could be produced} = \frac{\text{Actual energy produced in a day}}{\text{Plant use factor}}$$

$$= \frac{360}{0.72} = 500MWh / day$$

Selection of Generating Units

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.

Important Points in the Selection of Units

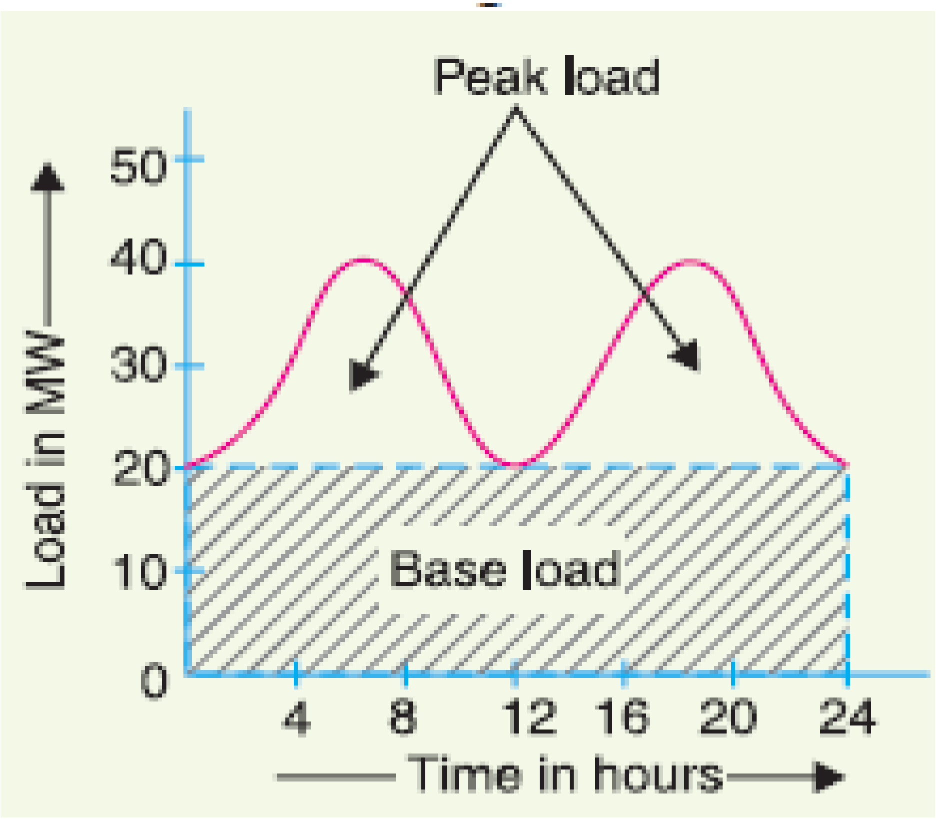
- The number and sizes of the units should be so selected that they approximately fit the annual load curve of the station.
- The units should be *preferably* of different capacities to meet the load requirements. Although use of identical units (*i.e.,* having same capacity) ensures saving* in cost, 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 meet 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.

Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature. Fig. shows the typical load curve of a power station. It is clear that load on the power station varies from time to time. However, 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



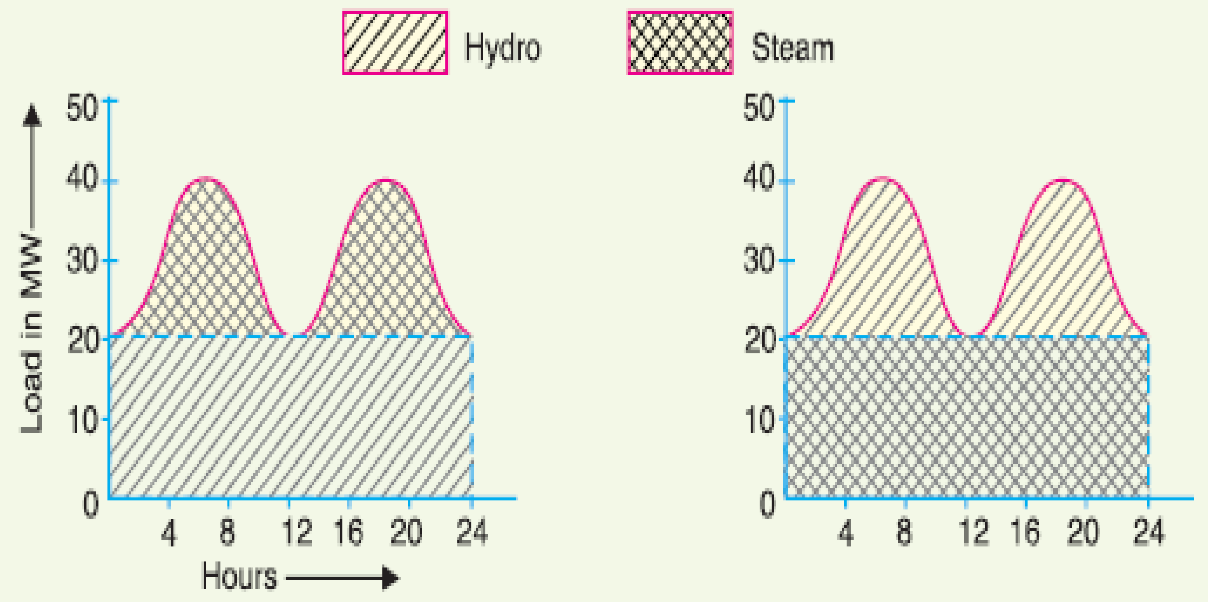
(i) Base load. The unvarying load which occurs almost the whole day on the station is known as base load. Referring to the load curve of Fig., it is clear that 20 MW of load has to be supplied by the station at all times of day and night i.e. throughout 24 hours. Therefore, 20 MW is the base load of the station. As base load on the station is almost of constant nature, therefore, it can be suitably supplied without facing the problems of variable load.

(ii) Peak load. The various peak demands of load over and above the base load of the station is known as peak load. Referring to the load curve of Fig., it is clear that there are peak demands of load excluding base load. These peak demands of the station generally form a small part of the total load and may occur throughout the day.

Properties of Base Load and Peak Load Plants

Characteristic	Characteristic	Characteristic
Purpose	Provides consistent, reliable power 24/7.	Provides power during periods of high demand or peak hours.
Type of Power	Constant and continuous power generation.	Power generation varies with demand fluctuations.
Efficiency	High efficiency as it operates at a constant load.	Lower efficiency due to frequent start-ups and shutdowns.
Fuel Source	Typically uses inexpensive and abundant fuel (e.g., coal, nuclear, hydro).	Often uses more expensive fuels (e.g., natural gas, oil).
Operational Costs	Lower operational costs due to continuous operation.	Higher operational costs due to ramping up and down.
Capital Cost	High capital investment due to large, complex plants.	Lower capital investment as these plants are usually smaller or more flexible.
Response Time	Slow response time to load changes.	Quick response time to changes in demand.
Examples	Nuclear, coal, hydro, geothermal plants.	Natural gas, peaking oil plants, gas turbines

- The total load on a power station consists of two parts *viz*., base load and peak 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.*
- For example, both hydro-electric and steam power stations are quite efficient and can be used as base load as well as peak load station to meet a particular load
- requirement.



Load division on Hydro-steam system.

(*i*) High Flow day (*ii*) Low Flow day

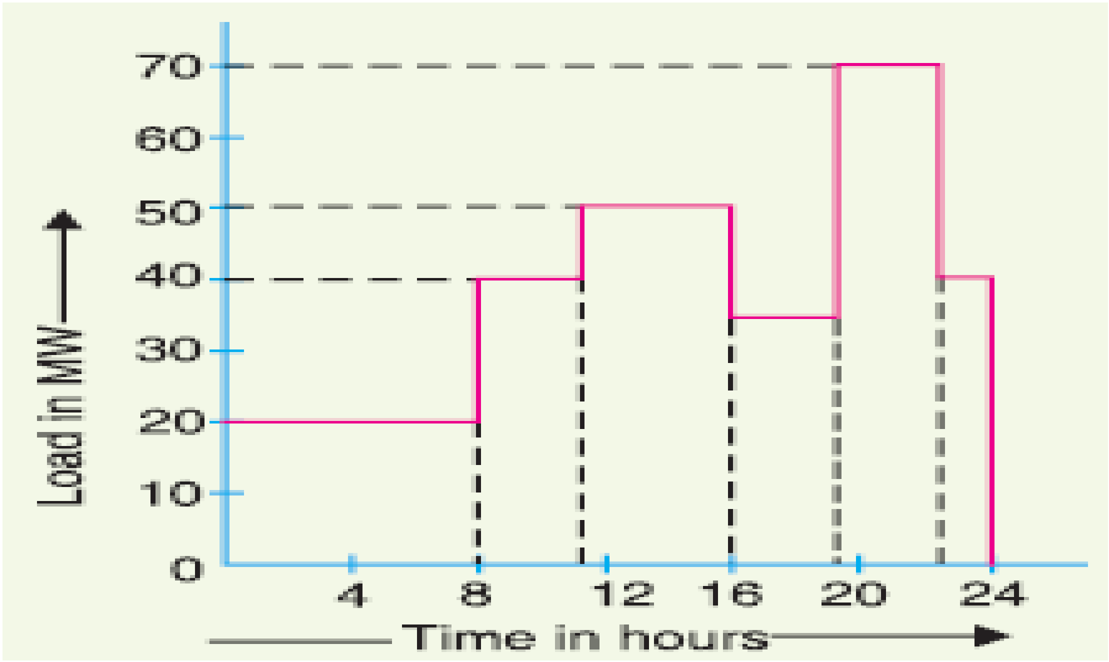
The interconnection of steam and hydro plants is a beautiful illustration to meet the load. When water is available in sufficient quantity as in summer and rainy season, the hydroelectric plant is used to carry the base load and the steam plant supplies the peak load as shown in Fig (*i*).

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 as shown in Fig. (*ii*).

Examples: The load curve of the power station can be drawn to some suitable scale as shown in Fig.

Time in hours	*6—8*	*8—11*	*11—16*	*16—19*	*19—22*	*22—24*	*24—6*
Load in MW	*20*	*40*	*50*	*35*	*70*	*40*	*20*

Draw the load curve and select suitable generator units from the 10,000, 20,000, 25,000, 30,000 kVA. Prepare the operation schedule for the machines selected and determine the load factor from the curve



Units generated per day = Area (in kWh) under the load curve = 10^3 [20 ∗ 8 + 40 ∗3 + 50 ∗5 + 35 ∗ 3 + 70 ∗3 + 40 ·∗2]

= 10^3 [160 + 120 + 250 + 105 + 210 + 80] kWh = 925 · 10^3 kWh

Average load = 925 * 10^3 /24 = 38541·7 kW

Load factor = (38541 7/70 *10^3)*100 = **55·06%**

Selection of number and sizes of units : Assuming power factor of the machines to be 0·8, the output of the generating units available will be 8, 16, 20 and 24 MW. There can be several possibilities. However, while selecting the size and number of units, it has to be borne in mind that

(i) one set of highest capacity should be kept as standby unit

(ii) the units should meet the maximum demand (70 MW in this case) on the station

(*iii*) there should be overall economy.

Keeping in view the above facts, *4 sets of 24 MW each may be chosen.*

Three sets will meet the maximum demand of 70 MW and one unit will serve as a standby unit.

Operational schedule. Referring to the load curve shown in Fig., the operational schedule will be as under :

(*i*) Set No. 1 will run for 24 hours.

(*ii*) Set No. 2 will run from 8.00 hours to midnight.

(*iii*) Set No. 3 will run from 11.00 hours to 16 hours and again from 19 hours to 22 hours.

Types of Reserve in Power Generation

1. **Spinning Reserve**
    1. **Definition**: Power that is immediately available from generating units that are online and operating but not fully loaded.
    2. **Purpose**: To quickly respond to sudden increases in demand or generation loss.

2. **Non-Spinning Reserve**
    1. **Definition**: Reserve that comes from generation units that are offline or from stored energy resources (e.g., batteries).
    2. **Purpose**: Provides backup power when there's a sudden drop in supply, but takes a little longer to bring online compared to spinning reserve.

3. **Replacement Reserve**
    1. **Definition**: A reserve to replace lost generation capacity over a longer time horizon.
    2. **Purpose**: Helps restore power generation after an unexpected outage of a unit or plant.

4. **Regulation Reserve**
   1. **Definition**: Reserves used to balance minor imbalances between supply and demand in real-time.
   2. **Purpose**: Ensures the grid frequency remains stable by adjusting power output to match small, continuous fluctuations.
5. **Black Start Reserve**
   1. **Definition**: Special reserve capacity used to restart the grid after a complete blackout.
   2. **Purpose**: Ensures critical power plants or systems can be brought online to start the grid recovery process.
6. **Contingency Reserve**
   1. **Definition**: Reserve set aside to address unexpected large-scale failures (e.g., loss of a major generating unit).
   2. **Purpose**: To maintain grid reliability in the event of a significant disturbance.

Types of Reserves in Economics of Power Generation

1.Operational Reserves

1. **Definition**: The capacity set aside to ensure reliable operation of the power system.
2. **Economic Role**: Balances supply and demand fluctuations, ensuring the grid remains stable even with unexpected generation losses or changes in demand.
3. **Example**: Spinning and non-spinning reserves.

2.Reserve Margin

1. **Definition**: The difference between the system's total capacity and its peak demand, typically expressed as a percentage.
2. **Economic Role**: Represents the excess capacity available to meet future demand growth and prevent blackouts.
3. **Example**: A reserve margin of 15% means that the power grid has 15% more capacity than needed to meet the peak demand.

3.Capacity Reserve

1. **Definition**: The difference between a power system's actual available capacity and its expected demand at any given time.
2. **Economic Role**: Ensures that there is enough backup capacity to meet unexpected spikes in demand or generation outages.
3. **Example**: Power plants kept in standby mode or those with quick ramp-up times.

4. **Strategic Reserve**
   1. **Definition**: A reserve of power generation or capacity that is kept as a strategic backup, often used during periods of high demand or when regular supply is insufficient.
   2. **Economic Role**: Used to avoid market price volatility and provide backup during supply shortages.
   3. **Example**: A country might maintain a strategic reserve of coal or natural gas plants for peak demand seasons.
5. **Reserve for Ancillary Services**
   1. **Definition**: Reserves that are needed to support the transmission of electric power from generation sources to load centers while maintaining the reliability of the grid.
   2. **Economic Role**: Provides services like frequency regulation, voltage control, and reactive power support.
   3. **Example**: Power plants that offer ancillary services like voltage support.
6. **Energy Reserve**
   1. **Definition**: A physical reserve, typically in the form of stored energy or fuel, available to generate power during peak demand.
   2. **Economic Role**: Ensures there is enough fuel or energy to meet demand during periods when renewable sources like wind or solar are unavailable.
   3. **Example**: Battery storage systems or backup fossil fuel plants

Life Cycle Cost (LCC)

The **Life Cycle Cost (LCC)** in the economics of power generation is a comprehensive evaluation of the total cost of a power generation system over its entire lifespan. It provides a detailed understanding of the financial implications of power projects and helps in comparing alternatives to determine the most cost-effective solution.

- Initial Cost (Acquisition Cost)
  - Purchase price
  - Design and engineering costs
  - Installation and commissioning costs
- Operating Cost
  - Energy consumption
  - Labor costs
  - Operational efficiency
- Maintenance and Repair Cost
  - Routine maintenance
  - Replacement of parts
  - Unexpected repairs

- Downtime Cost
  - Loss of productivity
  - Revenue loss due to equipment failure
- Environmental and Compliance Cost
  - Waste disposal
  - Environmental impact mitigation
  - Regulatory compliance costs
- Disposal or Decommissioning Cost
  - Dismantling and removal
  - Recycling or disposal fees
  - Site restoration

LCC Formula

$$LCC = C_{initial} + \sum (C_{operation} + C_{maintenance} + C_{downtime} + C_{disposal}) \times (1+r)^{-t}$$

Where:

- $C_{initial}$= Initial cost
- $C_{operation}$ = Operating cost
- $C_{maintenance}$ = Maintenance cost
- $C_{downtime}$= Downtime cost
- $C_{disposal}$= Disposal cost
- r= Discount rate
- t = Time period

Importance of LCC in Electrical Energy:

- . Helps in cost-effective decision-making
- Promotes sustainability by considering long-term costs
- Reduces unexpected expenses through better planning
- Enhances investment return by selecting efficient alternatives

LCC Across Power Generation Technologies

Technology	Capital Cost	O&M Cost	Fuel Cost	Decommissioning Cost	Lifespan
Coal	High	Moderate	High	High	40 years
Gas	Moderate	Low	Variable	Moderate	30 years
Nuclear	Very High	Low	Low	Very High	60 years
Solar	High	Low	None	Low	25 years
Wind	Moderate	Low	None	Low	20 years
Hydropower	Very High	Low	None	Low	70 years

Levelized Cost of Generation (LCOG) in Electrical Energy

Levelized Cost of Generation (LCOG) (often referred to as **Levelized Cost of Electricity (LCOE)**) represents the total cost of generating electricity over the lifetime of a power plant, normalized per unit of energy produced. It is a crucial metric used to compare different energy generation technologies on a consistent basis.

Formula for LCOG:

$LCOG = \sum(C_t + O_t + F_t) \backslash \sum(E_t)$

Where:

- C_t = Capital cost in year t
- O_t = Operating & Maintenance cost in year t
- F_t = Fuel cost in year t
- E_t = Energy generated in year t

Key Components of LCOG:

1. **Capital Cost (C_t)** – Includes the cost of land, equipment, construction, and installation.
2. **Operating & Maintenance Cost (O_t)** – Regular expenses for running and maintaining the power plant.
3. **Fuel Cost (F_t)** – Cost of fuel for thermal, nuclear, and biomass power plants.

Energy Source	LCOG (USD/MWh)
Coal	60 – 150
Natural Gas	40 – 100
Nuclear	70 – 140
Solar PV	30 – 60
Wind (Onshore)	25 – 50
Wind (Offshore)	50 – 120
Hydro	40 - 90

Importance of LCOG:

- Helps policymakers and investors compare different energy sources.
- Aids in decision-making for new power plant installations.
- Encourages cost-effective and sustainable energy solutions.

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 organisation and salaries of high officials is fixed since it has to be met whether the plant has high or low maximum demand or it generates less or more units. 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.

Interest. *The cost of use of money is known as* **interest.**

A power station is constructed by investing a huge capital. This money is generally borrowed from banks or other financial institutions and the supply company has to pay the annual interest on this amount. The rate of interest depends upon market position and other factors, and may vary from 4% to 8% per annum.

Depreciation.

The decrease in the value of the power plant equipment and building due to constant use is known as **depreciation.**

If the power station equipment were to last for ever, then interest on the capital investment would have been the only charge to be made. However, in actual practice, every power station has a useful life ranging from fifty to sixty years. From the time the power station is installed, its equipment steadily deteriorates due to wear and tear so that there is a gradual reduction in the value of the plant. This reduction in the value of plant every year is known as *annual depreciation.* Due to depreciation, the plant has to be replaced by the new one after its useful life.

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.

Expressions for Cost of Electrical Energy

The overall annual cost of electrical energy generated by a power station can be expressed in two forms *viz three part form* and *two part form*.

(*i*) Three part form. In this method, the overall annual cost of electrical energy generated is divided into three parts *viz* fixed cost, semi-fixed cost and running cost *i.e.*

Total annual cost of energy = Fixed cost + Semi-fixed cost + Running cost

= Constant + Proportional to max. demand + Proportional to kWh generated.

= Rs (a + b kW + c kWh)

where a = annual fixed cost independent of maximum demand and energy output.

b = constant which when multiplied by maximum kW demand on the station gives the annual semi-fixed cost.

c = a constant which when multiplied by kWh output per annum gives the annual running cost.

(*ii*) Two part form. It is sometimes convenient to give the annual cost of energy in two part form. In this case, the annual cost of energy is divided into two parts *viz.*, a fixed sum per kW of maximum demand *plus* a running charge per unit of energy. The expression for the annual cost of energy then becomes :

Total annual cost of energy = Rs. (A kW + B kWh)

where A = a constant which when multiplied by maximum kW demand on the station gives the annual cost of the first part.

B = a constant which when multiplied by the annual kWh generated gives the annual running cost.

It is interesting to see here that two-part form is a simplification of three-part form. A little reflection shows that constant "a" of the three part form has been merged in fixed sum per kW maximum demand (*i.e.* constant A) in the two-part form.

Tariff

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

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 *e.g.*, metering equipment, billing etc.

(*iv*) A suitable profit on the capital investment

Types of Tariff

There are several types of tariff. However, the 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

Disadvantages

(*i*) There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed* charges.

(*ii*) The cost per unit delivered is high.

(*iii*) It does not encourage the use of electricity.

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.

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. 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

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

Total charges = Rs (b ∗ kW + c ∗ 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

(*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

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 rateable 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 penalised.

The following are the important types of power factor tariff :

(*i*) *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 know 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.

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.*,

Total charge = Rs ($a + b$ ∗kW + c ∗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.

It may be seen that by adding fixed charge or consumer's charge (*i.e.*, a) to two-part tariff, it becomes three-part tariff. The principal objection of this type of tariff is that the charges are split into three components. This type of tariff is generally applied to big consumers.

Example: 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.

Example: *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.*

Units consumed/year = Max. demand ∗ L.F. ∗ Hours in a year

= (200) ∗(0·4) ∗ 8760 = 7,00,800 kWh

Annual charges = Annual M.D. charges + Annual energy charges

= Rs (100 ∗ 200 + 0·1 ∗ 7,00,800) = Rs 90,080

Overall cost/kWh = Rs 90 080/7 00 800

= Re 0·1285 = **12·85 paise**

Example . *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.*

Example . *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.

$$\text{Maximum demand} = \frac{220 \times 20 \times 1}{1000} = 4.4kw$$

(*i*) Units consumed in 500 hrs = 4.4 ∗ 500 = 2200 kWh

Charges for 2200 kWh = Rs 0.2 ∗2200 = Rs 440

Remaining units = 8760 – 2200 = 6560 kWh

Charges for 6560 kWh = Rs 0.1 ∗ 6560 = Rs 656

Total annual bill = Rs (440 + 656) = **Rs. 1096**

$$\text{ii. Equivalent flat rate} = \text{Rs}\frac{1096}{8760} = 0.125 = 12.5\,paisa$$

Example 5.3. *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 $0{\cdot}15x = 100$

$x = 100/0{\cdot}15 =$ **666·67 units**

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

Power Exchanges

- **What is a Power Exchange?**
  - A marketplace where electricity is traded transparently between buyers (utilities, industries) and sellers (power generators).
- **Purpose**:
  - To balance supply and demand efficiently.
  - Ensure competitive pricing and reliability.

Objectives of Power Exchanges

1. **Market Transparency**: Open bidding and price discovery.
2. **Efficiency**: Optimal utilization of generation and grid capacity.
3. **Competition**: Encourage participation from multiple players.
4. **Integration**: Incorporate renewable energy sources effectively.
5. **Reliability**: Maintain grid stability and meet real-time demand.

How Power Exchanges Work

1. **Participants**:
   1. **Buyers**: Distribution companies (DISCOMs), industries, traders.
   2. **Sellers**: Power generators, renewable energy producers.
2. **Trading Mechanism**:
   1. **Day-Ahead Market (DAM)**: Electricity trading for the next day based on hourly schedules.
   2. **Real-Time Market (RTM)**: Trading close to delivery time (15-minute intervals).
   3. **Term-Ahead Market (TAM)**: Contracts for intraday, daily, or weekly delivery.
3. **Bidding Process**:
   1. Participants submit bids for buying or selling power.
   2. Exchange matches bids and clears transactions based on market rules.
4. **Price Discovery**:
   1. Determined by supply-demand dynamics.