UNIT-5

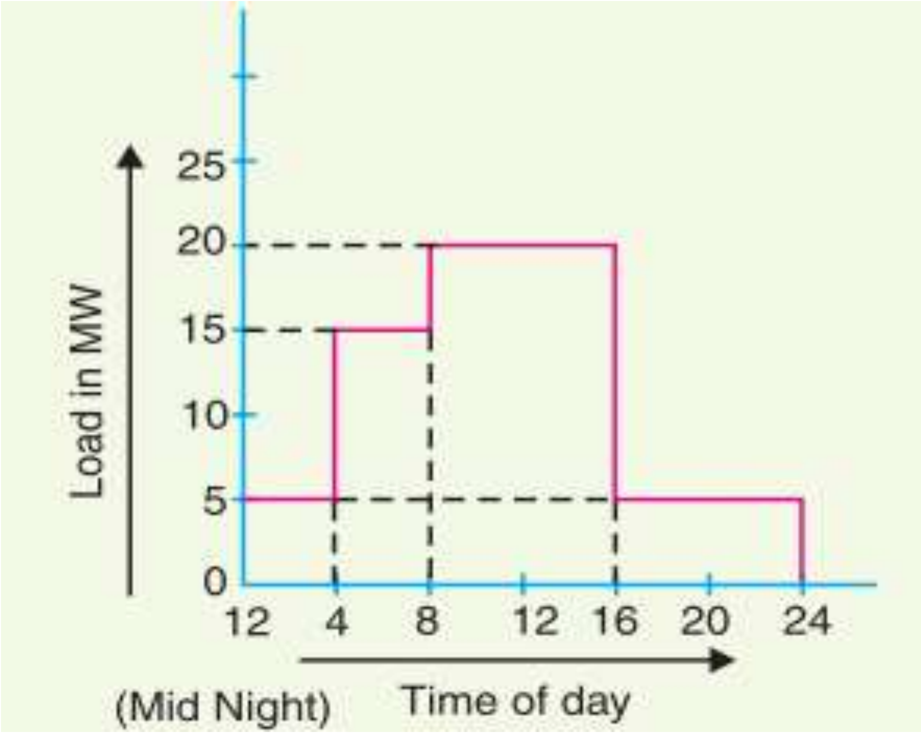
ECONOMIC ASPECTS OF POWER GENERATION AND TARIFF METHODS

VARIABLE LOAD ON POWER STATION

- The load on the power system varies from time to time due to uncertain demands of the consumers is known as variable load.
- **EFFECTS OF VARIABLE LOAD ON A POWER STATION:**
- Need of additional equipment: Ex., Air, Coal and Water.
- Increase in production cost: Ex., No. of units with different capacity.
- **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
    - **LOAD DURATION CURVE**
    - **INTEGRATED LOAD DURATION 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.

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

- The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor
- **Load factor** = $\frac{\textbf{Average load}}{\textbf{Max. demand}} = \frac{\textbf{Average load} \times 24}{\textbf{Max. demand} \times 24} =$

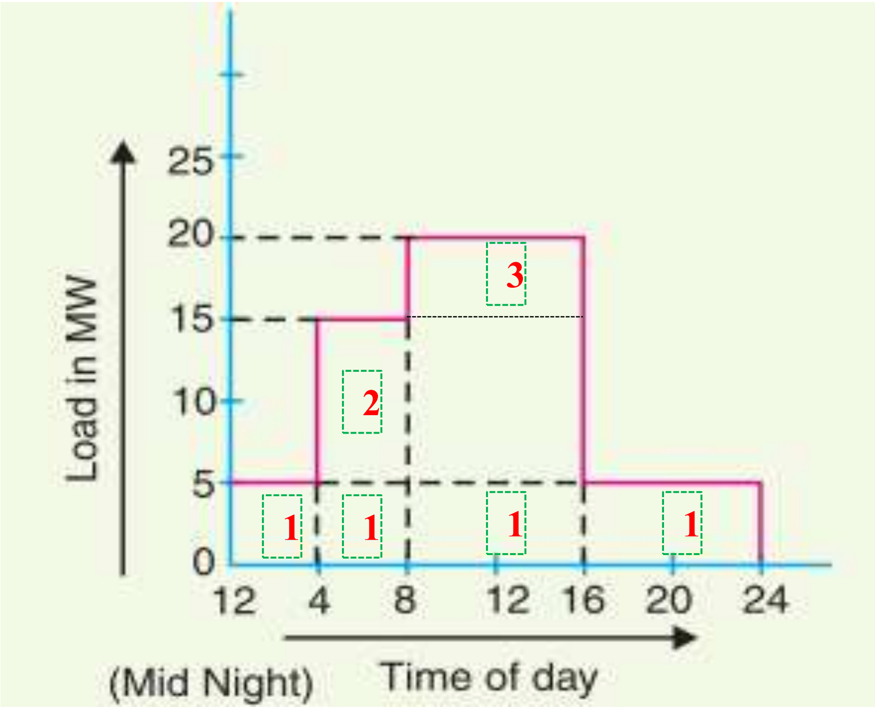
  $$\frac{\text{Area (in kWh) under daily load curve}}{\text{Total area of rectangle in which the load curve is contained}}$$

- 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**.

SELECTING THE SIZE AND NUMBER OF GENERATING UNITS

- The plant capacity is divided three units
- Unit-1=5MW, unit-2= 10MW and unit-3= 5MW
- From 12midnight to 4am only unit-1 is on operation
- From 4am to 8am: two units-1&2 are in operation
- From 8am to 4pm: all units-1,2&3 are in operation
- From 4pm to 12midnight only unit-1 is on operation
- Thus by selecting the proper number and sizes of units, the generating units can be made to operate near maximum efficiency.
- This results in the overall reduction in the cost of production of electrical energy.



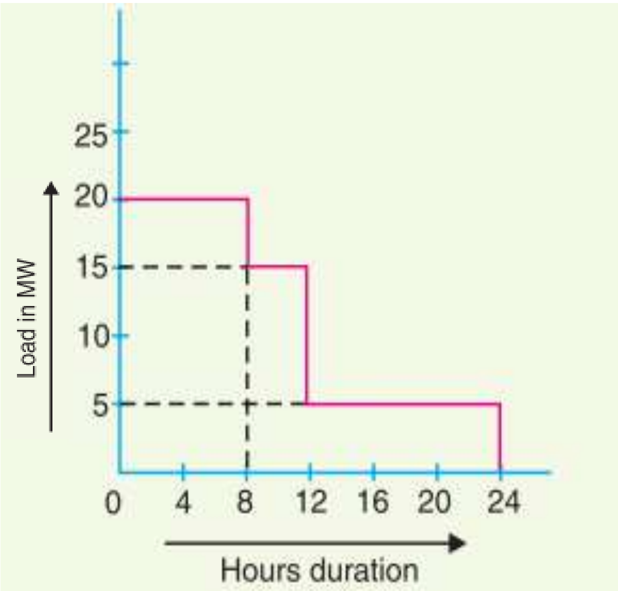
- **IMPORTANCE OF MONTHLY AND YEARLY LOAD CURVE**
- The monthly load curve can be obtained from the daily load curves of that month.
  - In this the average values of power over a month at different times of the day are calculated and then plotted on the graph.

- 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 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.

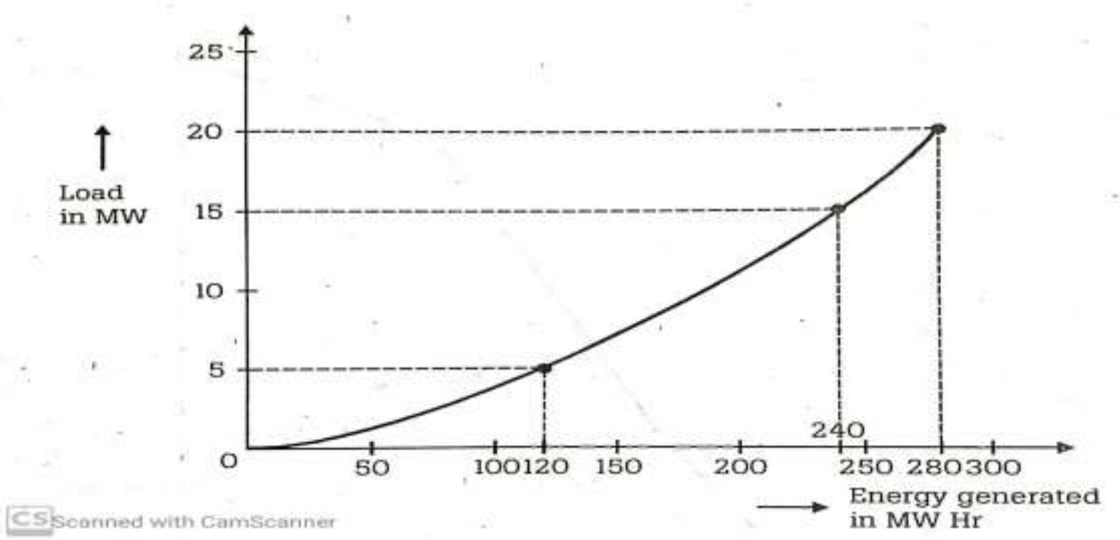


INTEGRATED LOAD DURATION CURVE (or ENERGY-LOAD CURVE)

- It is obtained from The load duration curve.

- Refer this table to make ILD curve
- It is drawn between the MW demand and the total energy generated up to the MW demand.
- Energy generated in MW demand = Load in MW x Time duration in hours.

Load in MW	**5**	**15**	**20**
Energy generated in Mwh	5x24hrs=120	120+10x12hrs=240	240+5x8hrs=280



Integrated 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.

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{connected load}}$$

- **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.

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

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

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

LOAD FACTOR

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

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

- 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.

DIVERSITY FACTOR

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

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

- 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.

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Maximum energy that could have been produced}} = \frac{\text{Average demand}}{\text{Plant capacity}}$$

- Thus if the considered period is one year, then 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 − Maximum demand**.

- It is interesting to note that **difference between load factor and plant capacity factor** is an indication of **reserve capacity**.

PLANT USE FACTOR AND UTILIZATION FACTOR

- **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

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

- **Utilization factor:**

- It is ratio of maximum demand to the rated capacity of plant.

Utilization factor = $\frac{\text{Maximum load}}{\text{Rated capacity}}$

- The value of **utilization factor can be more than unity** due to overloading of the plant.

- **Plant capacity factor = Load factor × Utilization factor**

RESERVES

- **Spinning reserve:** It is the generating capacity which is connected to the bus and ready to take load.

- **Cold reserve:** It is the reserve generating capacity which is available for service but not in operation.

- **Hot reserve:** It is the reserve generating capacity which is in operation but not in service.

- **Firm power:** It is power intended to be always available.

- **Reserve margin:** It is the difference between rated capacity minus actual loading on the generator.

TYPES OF LOADS

- **Domestic load:** Domestic load consists of lights, fans, refrigerators, heaters, television.
- **Commercial load:** Commercial load consists of lighting for shops, fans and electric appliances used in restaurants.
- **Industrial load:** Industrial load consists of load demand by industries.
- **Municipal load:** Municipal load consists of street lighting, power required for water supply and drainage purposes.
- **Irrigation load:** This type of load is the electric power needed for pumps driven by motors to supply water to fields.
- **Traction load:** This type of load includes tram cars, trolley buses, railways and this class of load has wide variation

ECONOMICS OF POWER GENERATION

- The art of determining the per unit cost of production of electrical energy is known as economics of power generation.
- **The terms used in the economics of power generation:**

(i) Interest, and (ii) Depreciation

- **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 and the supply company has to pay the annual interest on this amount.
- Therefore, **while calculating the cost of production of electrical energy, the interest payable on the capital investment must be included.**

DEPRECIATION

- The **decrease in the value of the power plan**t equipment and building due to constant use is known as **depreciation**.
- Every power station has a **useful life** ranging from **fifty to sixty years**.
- Due to depreciation, the plant has to be replaced by the new one after its useful life.
- Therefore, suitable amount must be set aside every year so that by the time the plant retires, the collected amount by way of depreciation equals the cost of replacement.
- So, **while determining the cost of production, annual depreciation charges must be included.**
- **Methods of finding the annual depreciation charges:**

i) straight line method, ii) diminishing value method, and iii) sinking fund method

STRAIGHT LINE METHOD

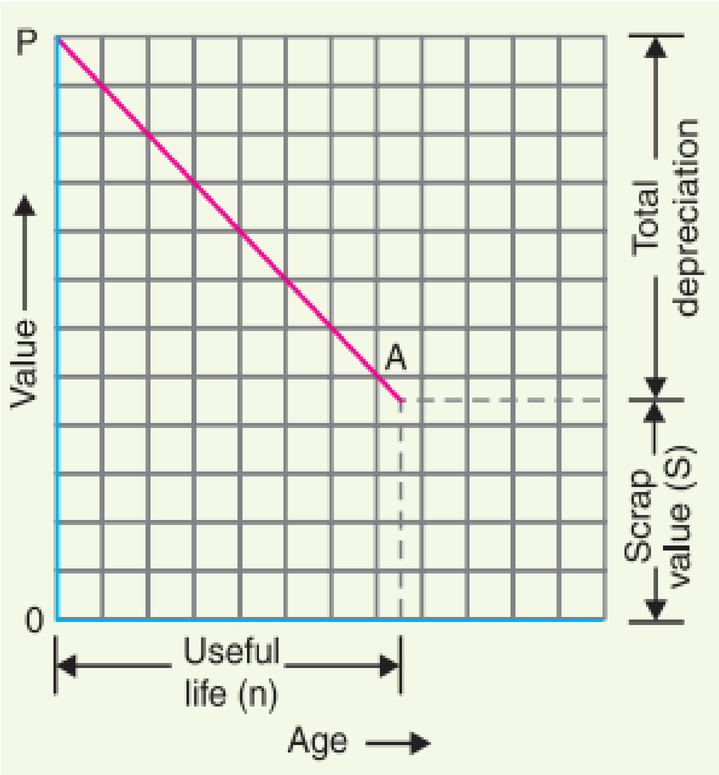
- In general, the annual depreciation charge on the straight line method expressed as :
- Let P= initial cost of equipment, S=scrap or salvage value after the useful life of plant, and n= useful life of equipment in years.
- **Annual depreciation charge (ADC) = $(P-S)/n$**
- **Value of equipment after 'm' years = P-[ADCxm]**
- This method is extremely simple.
- The depreciation curve (PA) follows a

straight line path, indicates constant ADC.

- **Disadvantages:**

- It does not account for the interest.

- Assumption of constant depreciation charge every year is not constant.

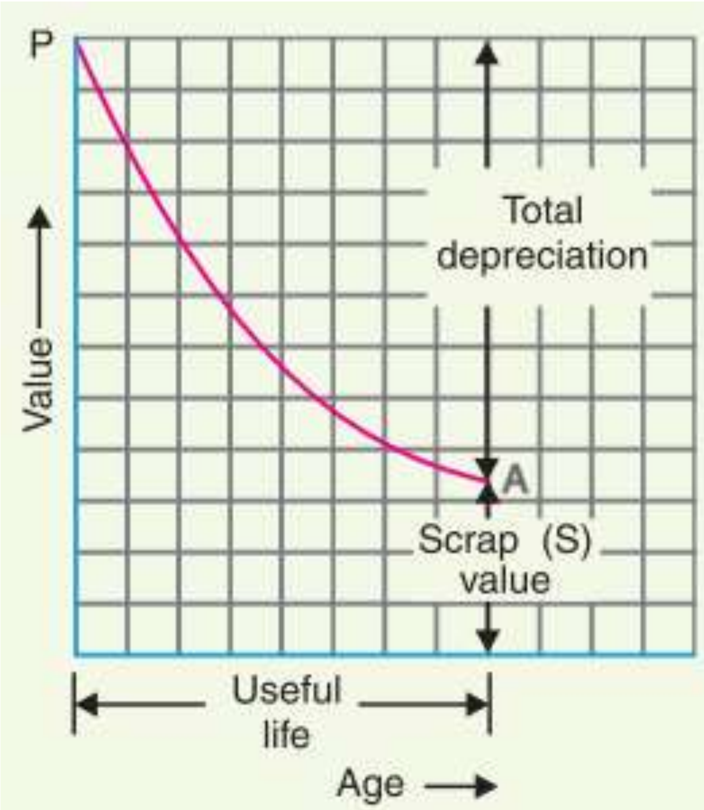


DIMINISHING VALUE METHOD

- In this method depreciation charge is first applied to the initial cost of equipment and then to its diminished value.

❖ **Mathematical Expression:**

- Let the annual depreciation is x, it is desired to find the value of x in terms of P, n and S.
- Value of equipment after one year = P − Px (depreciation for 1st year) = P (1 − x)
- Value of equipment after 2 years = Diminished value[P(1-x)] − Annual depreciation[P(1-x)x] = $P(1 - x)^2$
- **Therefore, Value of equipment after 'm' years = $P(1 - x)^m$**
- The value of equipment after 'n' years is equal to the scrap value S [$S = P(1 - x)^n$]
- **Therefore, annual unit depreciation, $x = 1 - (S/P)^{1/n}$**



- The depreciation curve follows the path PA.
- It is observed that the depreciation charges are heavy in the early years but decrease to a low value in the later years.

❖ **Disadvantages:**

- The depreciation charge is independent of the rate of interest, which it may draw during accumulation.
- low depreciation charges are made in the late years when the maintenance and repair charges are quite heavy.

SINKING FUND METHOD

- In this method a fixed depreciation charge is made every year and interest compounded on it annually.

- The constant depreciation charge is such that total of annual instalments plus the interest accumulations equal to the **cost of replacement (P − S)** of equipment after its useful life.

- **Mathematical Expression:**

- Let r = Annual rate of interest expressed as a decimal.
- Let us suppose that an amount of q is set aside as depreciation charge every year and interest compounded on it, at the end of n years the amount is q$(1+r)^n$
- Total fund after n years = **q [$(1+r)^{n-1}$ +$(1+r)^{n-2}$+…….+q(1+r)]** = **q** $\frac{(1+r)^n-1}{r}$ = P-S(cost of replacement)
- **Annual deposit in the sinking fund, q = (P-S) [$\frac{r}{(1+r)^n-1}$]**
- **Sinking fund at the end of 'm' years, F = q** $\frac{(1+r)^m-1}{r}$
- **Therefore, value of equipment (or plant) after 'm' years = P- F**

COST OF ELECTRICAL ENERGY

- The total cost of electrical energy generated can be divided into three parts.

(i) Fixed cost ; (ii) Semi-fixed cost; and (iii) Running or operating cost.

- **FIXED COST:**

- It is the cost which is independent of maximum demand and units generated.
- The fixed cost is due to the following:
  1. Interest on capital cost of land
  2. Annual cost of central organization
  3. Salaries of high officials

- **SEMI-FIXED COST:**

- It is the cost which depends upon maximum demand, but independent of units generated.

- The semi-fixed cost is due to the following:

    i. Annual interest and depreciation on capital investment of building and equipment
    ii. Taxes, insurance of building and equipment
    iii. Salaries of management and clerical staff

- **RUNNING OR OPERATING COST:**

- It is the cost which depends only upon the number of energy units generated.

- The running cost is due to the following:

    i. Annual cost of fuel
    ii. Maintenance cost
    iii. Salaries of operating staff
    iv. Cost of lubricating oil, cooling water and other consumable materials.

EXPRESSIONS FOR COST OF ELECTRICAL ENERGY

- The overall annual cost of electrical energy generated by a power station can be expressed in two forms.

(i) Three part form,   and (ii) Two part form

- **THREE PART FORM:** In this method, the overall annual cost of electrical energy generated is divided into three parts, they are fixed cost, semi-fixed cost and running cost.

- 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 , b and c are the constants to the corresponding costs.

- **TWO PART FORM:** In this method, the overall annual cost of electrical energy generated is divided into two parts, a fixed sum per kW of maximum demand and a running charge per unit of energy.
  - Total annual cost of energy = Rs. (A kW + B kWh)
- Where, A is a constant which when multiplied by maximum kW demand on the station gives the annual cost of the first part.
- And B is a constant which when multiplied by the annual kWh generated gives the annual running cost.
- The two part form is a simplification of three part form.
- 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:**
  1. Recovery of cost of producing electrical energy at the power station.
  2. Recovery of cost on the capital investment in transmission and distribution systems.
  3. Recovery of cost of operation and maintenance of supply of electrical energy
  4. A suitable profit on the capital investment.
- **DESIRABLE CHARACTERISTICS OF A TARIFF:**

1. **Proper return:** The total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit.
2. **Fairness:** The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy.
3. **Simplicity:** The tariff should be simple so that an ordinary consumer can easily understand it.

4. **Reasonable profit:** The profit element in the tariff should be reasonable.
5. **Attractive:** The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy.

TYPES OF TARIFF

1. Simple tariff
2. Flat rate tariff
3. Block rate tariff
4. Two-part tariff
5. Maximum demand tariff
6. Power factor tariff
    i. kVA maximum demand tariff
    ii. Sliding scale tariff
    iii. kW and kVAR tariff
7. Three-part tariff

SIMPLE TARIFF

- **It is a fixed rate per unit of energy consumed.**
    - In this type of tariff, the price charged per unit is constant.
    - It means 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 consumers
- **Disadvantages:**

- 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 and it does not encourage the use of electricity.

FLAT RATE TARIFF

- **When different types of consumers are charged at different uniform per unit rates.**
    - In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate.
    - **Advantage:** It is more fair to different types of consumers and is quite simple in calculations.
- **Disadvantages:**
    - Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load, 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.
    - A big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

BLOCK RATE TARIFF

- **In this a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates:**
    - 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**.

TWO PART TARIFF

- **In this the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed.**
- In this the total charge to be made from the consumer is split into two components, they are, (i) Fixed charges, and (ii) 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.
- This type of tariff is mostly applicable to industrial consumers.
- **Advantages:**
  - It is easily understood by the consumers.
  - It recovers the fixed charges.
- **Disadvantages:**
  - The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not.
  - There is always error in assessing the maximum demand of the consumer.

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.

POWER FACTOR TARIFF

- **In this the power factor of the consumer's load is taken into consideration.**
- A low power factor increases the rating of station equipment and line losses.
- **kVA 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 but not in kW.
  - 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 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.

- **kW and kVA 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.

THREE PART TARIFF

- **In this the total charge to be made from the consumer is split into three parts, they are fixed charge, semi-fixed charge and running charge.**
  - Total charge = Rs, (a + b × kW + c × kWh).
    - Where, a = fixed charge made during each billing period.

      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.