**Interconnected Grid System:**

 The connection of several generating stations in parallel is known as interconnected grid system. Some of the advantages of interconnected system are listed below :

**1) 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.

**2) 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 interconnected with other modern plants. Therefore, interconnected system gives a direct key to the use of obsolete plants.

**3) Ensures economical operation :**

The interconnected system makes the operation of concerned power stations quite economical. It is because sharing of load among the stations is arranged in such a way that more efficient stations work continuously throughouts the year at a high load factor and the less efficient plants work for peak load hours only.

**4) Increases diversity factor :**

 The load curves of different interconnected stations are generally different. The result is that the maximum demand on the system is much reduced as compared to the sum of individual maximum demands on different stations. In other words, the diversity factor of the system is improved, thereby increasing the effective capacity of the system.

**5) Reduces plant reserve capacity :**

 Every power station is required to have a standby unit for emergencies. However, when several power stations are connected in parallel, the reserve capacity of the system is much reduced. This increases the efficiency of the system.

**6) Increases reliability of supply :**

The interconnected system increases the reliability of supply. If a major breakdown occurs in one station, continuity of supply can be maintained by other healthy stations.

**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 :

1. The number and sizes of the units should be so selected that they approximately fit the annual load curve of the station
2. 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.
3. The capacity of the plant should be made 15% to 20% more than the maximum demand to meet the future load requirements.
4. There should be a spare generating unit so that repairs and overhauling of the working units can be carried out.
5. 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.

**Power plant economics:**

A power station is required to deliver power to a large number of consumers to meet their requirements. While designing and building a power station, efforts should be made to achieve overall economy so that the per unit cost of production is as low as possible.

The following terms much used in the economics of power generation-

**(i) 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.

**(ii) 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.

**Cost of Electrical Energy:**

 The total cost of electrical energy generated can be divided into three parts, namely ;

 **(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.

 **(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.

**(iii) Running or operating 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.

**Methods of Determining Depreciation:**

There is reduction in the value of the equipment and other property of the plant every year due to depreciation. Therefore, a suitable amount (known as depreciation charge) must be set aside annually so that by the time the life span of the plant is over, the collected amount equals the cost of replacement of the plant. The following are the commonly used methods for determining the annual depreciation charge.

**(i) Straight line method-**

In this method, a constant depreciation charge is made every year on the basis of total depreciation and the useful life of the property. Obviously, annual depreciation charge will be equal to the total depreciation divided by the useful life of the property. Thus, if the initial cost of equipment is Rs 1,00,000 and its scrap value is Rs 10,000 after a useful life of 20 years, then,

Annual depreciation charge = Total depreciation/ Useful life = (100 000-10 000) /20 = Rs 4,500

**(ii) Diminishing value method-**

In this method, depreciation charge is made every year at a fixed rate on the diminished value of the equipment. In other words, depreciation charge is first applied to the initial cost of equipment and then to its diminished value. As an example, suppose the initial cost of equipment is Rs 10,000 and its scrap value after the useful life is zero. If the annual rate of depreciation is 10%, then depreciation charge for the first year will be 0·1 × 10,000 = Rs 1,000. The value of the equipment is diminished by Rs 1,000 and becomes Rs 9,000. For the second year, the depreciation charge will be made on the diminished value (i.e. Rs 9,000) and becomes 0·1 × 9,000 = Rs 900. The value of the equipment now becomes 9000 − 900 = Rs 8100. For the third year, the depreciation charge will be 0·1 × 8100 = Rs 810 and so on.

**(iii) 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 installments plus the interest accumulations equal to the cost of replacement of equipment after its useful life.

**Load Curves**

The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a load curve. The 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. Below figure shows a typical daily load curve of a power station. It is clear that load on the power station is varying, being maximum at 6 P.M. in this case. 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. 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.

 

**Importance**-

The daily load curves have attained a great importance in generation as they supply the following information-

**(i)** The daily load curve shows the variations of load on the power station during different hours of the day.

**(ii)**The area under the daily load curve gives the number of units generated in the day.

 Units generated**/**day = Area (in kWh) under daily load curve.

**(iii)**The highest point on the daily load curve represents the maximum demand on the station on that day.

**(iv)**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

 **(v)**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 = Average load**/**Max. demand = Average load x 24**/** Max. demand x 24

 = Area (in kWh) under daily load curve**/**(Total area of rectangle in which the load curve is contained)

**(vi)** The load curve helps in selecting the size and number of generating units.

**(vii)** The load curve helps in preparing the operation schedule of the station.

**Important Terms and Factors**

 The variable load problem has introduced the following terms and factors in power plant engineering:

**(i) Connected load-**

It is the sum of continuous ratings of all the equipments connected to supply system.

**(ii) Maximum demand-**

It is the greatest demand of load on the power station during a given period.

**(iii) Demand factor**

It is the ratio of maximum demand on the power station to its connected load.

 Demand factor = Maximum demand **/** Connected load

**(iv) 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 = No. of units (kWh) generated in a day **/** 24 hours

Monthly average load = No. of units (kWh) generated in a month **/** Number of hours in a month

Yearly average load = No. of units (kWh) generated in a year **/** 8760 hours

**(v) Load factor-**

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

 Load factor = Average load **/** Max. demand

If the plant is in operation for T hours,

Load factor = Average load x T **/** Max. demand x T = Units generated in T hours **/** Max. demand x T hours

The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year. Load factor is always less than 1 because average load is smaller than the maximum demand. 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.

**(vi) Diversity factor-**

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

 Diversity factor = Sum of individual max. demands **/** Max. demand on power station

**(vii) 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.

 Plant capacity factor = Actual energy produced **/**  Max. energy that could have been produced

**(viii) 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.



**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 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.

**Tariff:**

The rate at which electrical energy is supplied to a consumer is known as tariff. Although tariff should include the total cost of producing and supplying electrical energy plus the profit.

**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. The consumption of electrical energy at the consumer’sterminals is recorded by means of an energy meter. This is the simplest of all tariffs and is readily understood by the consumers.

**2. Flat rate tariff.**

When different types of consumers are charged at different uniform per unitrates, 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.

**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.

**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, 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.

**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 notin 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 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, fixed charge, semi-fixed charge and running charge, it is known as a three-part tariff.

 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.

**PERFORMANCE CURVES OF POWER PLANT**

**Input-output curve**

This is the fundamental curve for a thermal plant and is a plot of the input in British thermal units (Btu) per hour versus the power output of the plant in MW as shown in Fig.4.1



**Heat rate curve**

The heat rate is the ratio of fuel input in Btu to energy output in KWh. It is the slope of the input – output curve at any point. The reciprocal of heat – rate is called fuel – efficiency. The heat rate curve is a plot of heat rate versus output in MW. A typical plot is shown in figure.



**Incremental fuel rate curve**

The incremental fuel rate is equal to a small change in input divided by the corresponding change in output.

Incremental fuel rate =ΔInput/ΔOutput

The unit is again Btu / KWh. A plot of incremental fuel rate versus the output is shown in figure.



**Incremental cost curve**

The incremental cost is the product of incremental fuel rate and fuel cost (Rs / Btu). The curve in shown in figure. The unit of the incremental fuel cost is Rs / MWh.



In general, the fuel cost Fi for a plant, is approximated as a quadratic function of the generated output PGi.

The incremental fuel cost is given by

 Fi = ai + biPGi + ciPGi2 Rs/h

The incremental fuel cost is given by

 dFi/dPGi = bi + 2 ciPGi  Rs/Mwh

The incremental fuel cost is a measure of how costly it will be produce an increment of power. The incremental production cost, is made up of incremental fuel cost plus the incremental cost of labour, water, maintenance etc. which can be taken to be some percentage of the incremental fuel cost, instead of resorting to a rigorous mathematical model. The cost curve can be approximated by a linear curve. While there is negligible operating cost for a hydel plant, there is a limitation on the power output possible. In any plant, all units normally operate between PGmin, the minimum loading limit, below which it is technically infeasible to operate a unit and PGmax, which is the maximum output limit.

**Economic load sharing**

The economic load dispatch means the real and reactive power of the generator vary within the certain limits and fulfils the load demand with less fuel cost. The sizes of the electric power system are increasing rapidly to meet the energy requirement. So the number of power plants is connected in parallel to supply the system load by an interconnection of the power system. In the grid system, it becomes necessary to operate the plant units more economically.

The economic scheduling of the generators aims to guarantee at all time the optimum combination of the generator connected to the system to supply the load demand.The economic load dispatch problem involves two separate steps. These are the online load dispatch and the unit commitment.

The unit commitment selects that unit which will anticipate load of the system over the required period at minimum cost. The online load dispatch distributes the load among the generating unit which is parallel to the system in such a manner as to reduce the total cost of supplying. It also fulfils the minute to the minute requirement of the system.

Basic Mathematical Formulation

Consider n generators in the same plant or close enough electrically so that the line losses may be neglected. Let C1, C2, …, Cn be the operating costs of individual units for the corresponding power outputs P1, P2,…., Pn respectively. If C is the total operating cost of the entire system and PR is the total power received by the plant bus and transferred to the load, then





The equation (1) and equation (2) can be minimised as





The above equation shows that if transmission losses are neglected, the total demand PR at any instant must be met by the total generation. The above equation is the equality constraint.

This a constrained minimising problem.  This problem can be solved by using  Lagrangian multiplier technique.



where f is the equality constraint equation given by



And λ is the Lagrange multiplier. Combination of equations (3) and (4) gives



Equation (5) can be solved for minimum by determining the partial derivate of the function C\* on variable Pi and equating it equal to zero.



Since Ci is a function of Pi only. The partial derivates become full derivates, that is,



Therefore, the condition for optimum operation is



Since the dci/ dpi is the increment cost generation for the generator. The above equation shows that the criterion for a most economical division of load between within a plant is that all the unit is must operate at the same incremental fuel cost. This is known as the principle of equal λ criterion or the equal incremental cost-loading principle for economic operation.