UNIT 7 PLANT ECONOMY

Structure

7.1 INTRODUCTION

In all fields of industry economics plays an important role. In power plant engineering economics of power system use certain well established techniques for choosing the most suitable system. The power plant design must be made on the basis of most economical condition and not on the most efficient condition as the profit is the main basis in the design of the plant and its effectiveness is measured financially. *The main purpose of design and operation of the plant is to bring the cost of energy produced to minimum*. Among many factors, the efficiency of the plant is one of the factors that determines the energy cost. In majority of cases, unfortunately, the most thermally efficient plant is not economic one.

Objectives

After the studying of this unit, you should be able to

- know the costs associated with power generation,
- describe the fixed and operational costs,
- explain the economics of plant selection, and
- explain the economics of plant operation.

7.2 TERMS AND DEFINITIONS

Connected Load

The connected load on any system, or part of a system, *is the combined continuous rating of all the receiving apparatus on consumers' premises, which is connected to the system, or part of the system, under consideration*.

Demand

The demand of an installation or system *is the load that is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time*. Demand is expressed in kilowatts (kW), kilovolt-amperes (kVA), amperes (A), or other suitable units.

Maximum Demand or Peak Load

The maximum demand of an installation or system *is the greatest of all the demands that have occurred during a given period*. It is determined by measurement, according to specifications, over a prescribed interval of time.

Demand Factor

The demand factor of any system, or part of a system, is *the ratio of maximum demand of the system, a part of the system, to the total connected load of the system, or of the part of the system, under consideration*. Expressing the definition mathematically,

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}} \qquad \text{. . . (7.1)}$$

Land Factor

The load factor is *the ratio of the average power to the maximum demand*. In each case, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load factor. The proper interval and period are usually *dependent upon local conditions and upon the purpose for which the load factor is to be used*. Expressing the definition mathematically,

$$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum demand}} \qquad \text{. . . (7.2)}$$

Diversity Factor

The diversity factor of any system, or part of a system, *is the ratio of the maximum power demands of the subdivisions of the system, or part of a system, to the maximum demand of the whole system, or part of the system, under consideration, measured at the point of supply*. Expressing the definition mathematically,

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand of entire group}} \qquad \text{. . . (7.3)}$$

Utilisation Factor

The utilisation factor is defined as *the ratio of the maximum generator demand to the generator capacity*.

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,

$$\text{Plant capacity factor} = \frac{E}{C \times t} \qquad \text{. . . (7.4)}$$

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.

Plant Use Factor

It is defined as *the ratio of energy produced in a given time to the maximum possible energy that could have been produced during the actual number of hours the plant was in operation*. Expressing the definition mathematically,

$$\text{Plant use factor} = \frac{E}{C \times t'} \qquad \ldots (7.5)$$

where, t' = Actual number of hours the plant has been in operation.

Types of Loads

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.

Commercial Load

It includes lighting for shops, advertisements and electrical appliances used in shops and restaurants, etc.

Industrial Load

It consists of load demand of various industries.

Municipal Load

It consists of street lighting, power required for water supply and drainage purposes.

Irrigation Load

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

Traction Load

It includes terms, cars, trolley, buses and railways.

Load Curve

A load curve (or load graph) *is a graphic record showing the power demands for every instant during a certain time interval*. Such a record may cover 1 hour, in which case it would be *an hourly load graph*; 24 hours, in which case it would be a *daily load graph*; a month in which case it would be a *monthly load graph*; or a year (7860 hours), in which case it would be a *yearly load graph*. The following points are worth noting :

(i) The area under the load curve represents the energy generated in the period considered.

(ii) The area under the curve divided by the total number of hours gives the average load on the power station.

(iii) The peak load indicated by the load curve/graph represents the maximum demand of the power station.

Significance of Load Curves

- Load curves give full information about the incoming and help to decide the installed capacity of the power station and to decide the economical sizes of various generating units.

- These curves also help to estimate the generating cost and to decide the operating schedule of the power station, i.e. the sequence in which different units should be run.

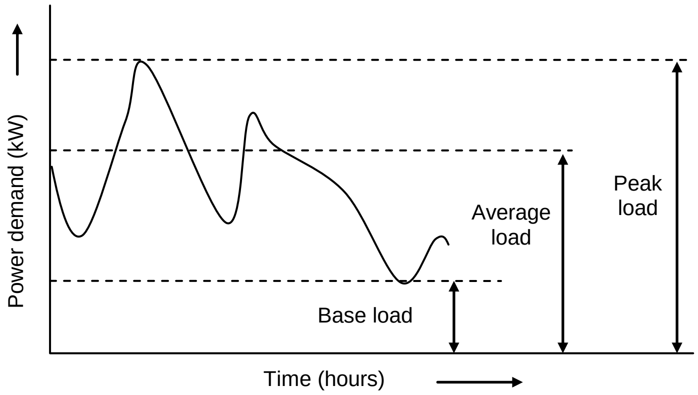

Figure 7.1 : Load Curve

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 7.2 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 7.3. Similarly, other loads of the load curve are plotted in *descending order* in the same figure. This is called *load duration curve* (Figure 7.3).

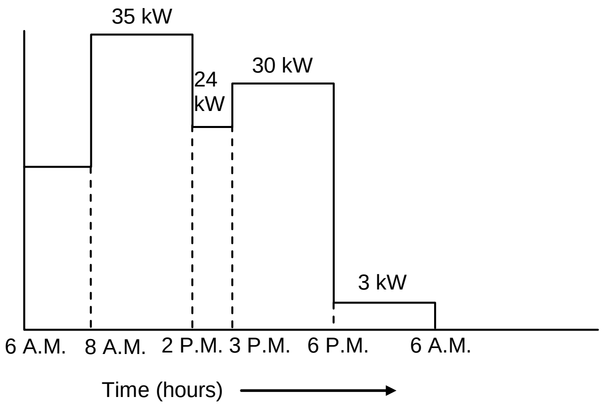

Figure 7.2 : Typical Daily Load Curve

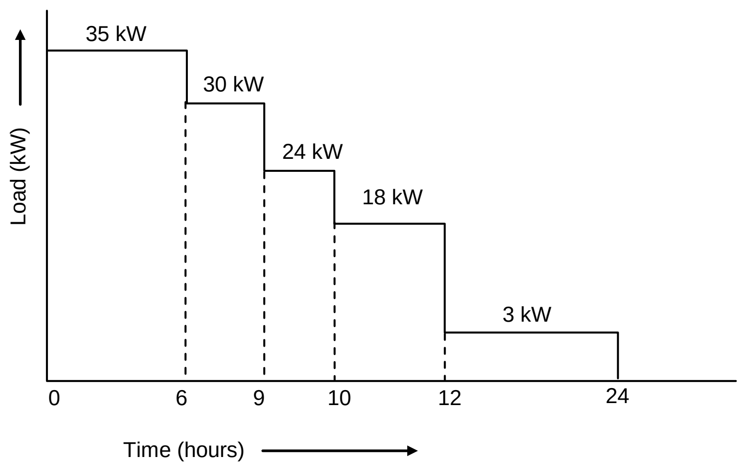

Figure 7.3 : Load Duration Curve

The following points are worth noting :

(a) The area under the load duration curve and the corresponding chronological load curve is equal and represents total energy delivered by the generating station.

(b) Load duration curve gives a clear analysis of generating power economically. Proper selection of base load power plants and peak load power plants becomes easier.

Dump Power

This term is used in hydroplants and it shows the *power in excess of the load requirements* and it is made available by *surplus water*.

Firm Power

It is the power which *should always be available even under emergency conditions*.

Prime Power

It is the power which may be mechanical, hydraulic or thermal that is *always available for conversion into electric power*.

Cold Reserve

It is that *reverse generating capacity which is not in operation but can be made available for service*.

Hot Reserve

It is that *reserve generating capacity which is in operation but not in service*.

Spinning Reserve

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

7.3 FIXED COST

Initial Cost of the Plant

Initial cost of the plant, which includes :

(a) Land cost

(b) Building cost

(c) Equipment cost

(d) Installation cost

(e) Overhead charges

Rate of Interest

It is the difference between the money obtained and the money returned and may be charged as simple interest or compound interest.

Depreciation Cost

It takes into account the deterioration of the component over a period of time.

7.4 METHODS OF DEPRECIATION

There are several methods for calculating depreciation, generally based on either the passage of time or the level of activity (or use) of the asset.

7.4.1 Straight-line Depreciation

Straight-line depreciation is the simplest and most-often-used technique, in which the company estimates the salvage value of the asset at the end of the period during which it will be used to generate revenues (useful life) and will expense a portion of original cost in equal increments over that period. The salvage value is an estimate of the value of the asset at the time it will be sold or disposed of; it may be zero or even negative. Salvage value is also known as scrap value or residual value.

$$\text{Annual Depreciation Expense} = \frac{\text{Cost of Fixed Assed} - \text{Residual Value}}{\text{Useful Life of Asset (Years)}}$$

7.4.2 Sinking Fund Method

The sinking fund technique of calculating depreciation sets the depreciation expense as a particular amount of an annuity**.** The depreciation is calculated so that at the end of the useful life of the annuity, the amount of the annuity equals the acquisition cost. The sinking fund method calculates more depreciation closer to the end of the useful life of the asset, and isn't used very often.

7.4.3 Declining Balance/Reducing Balance

This way of calculating depreciation falls under the accelerated depreciation category. This means that it sets depreciation expenses as higher earlier on, more realistically reflecting the current resale value of an asset.

The way that declining-balance depreciation is calculated is by taking the net book value from the previous year, and multiplying it by a factor (usually 2) which has been divided by the useful life of the asset.

7.4.4 Activity Depreciation

This way of calculating depreciation bases the depreciation expense on the activity of an asset, like a machine. Multiplying the rate by the actual activity level of the asset will give depreciation expense for the year.

7.4.5 Sum of Years Digits

This way of calculating depreciation is given by the following formula :

$$\text{Sum} = \frac{N\ (N+1)}{2}$$

$$D(t) = \frac{(N - t + 1) \times (B = S)}{\text{Sum}}$$

where, N = Depreciable life,

B = Cost basis,

S = Salvage value, and

$D\ (t)$ = Depreciation charge for year t.

Taxes and Insurance.

7.5 OPERATIONAL COST

The elements that make up the operating expenditure of a power plant include the following costs :

(a) Cost of fuels.

(b) Labour cost.

(c) Cost of maintenance and repairs.

(d) Cost of stores (other than fuel).

(e) Supervision.

(f) Taxes.

7.5.1 Cost of Fuels

In a thermal station fuel is the heaviest item of operating cost. The selection of the fuel and the maximum economy in it use are, therefore, very important considerations in thermal plant design. It is desirable to achieve the highest thermal efficiency for the plant so that fuel charges are reduced. *The cost of fuel includes not only its price at the site of purchase but its transportation and handling costs also*. In the hydroplants the absence of fuel factor in cost is responsible for lowering the operating cost. *Plant heat rate can be improved by the use of better quality of fuel or by employing better thermodynamic conditions in the plant design*.

The cost of fuel varies with the following :

(a) Unit price of the fuel.

(b) Amount of energy produced.

(c) Efficiency of the plant.

7.5.2 Labour Cost

For plant operation labour cost is another item of operating cost. Maximum labour is needed in a thermal power plant using coal as a fuel. A hydraulic power plant or a diesel power plant of equal capacity require a lesser number of persons. In case of automatic power station the cost of labour is reduced to a great extent. However, labour cost cannot be completely eliminated even with fully automatic station as they will still require some manpower for periodic inspection, etc.

7.5.3 Cost of Maintenance and Repairs

In order to avoid plant breakdowns *maintenance* is necessary. *Maintenance* includes *periodic cleaning, greasing, adjustments and overhauling of equipment*. The material used for maintenance is also charged under this head. Sometimes an arbitrary percentage is assumed as maintenance cost. A good plan of maintenance would keep the sets in dependable condition and avoid the necessity of too many stand-by plants.

Repairs are necessitated when the plant breaks down or stops due to faults developing in the mechanism. The repairs may be minor, major or periodic overhauls and are charged to the depreciation fund of the equipment. This item of cost is higher for thermal plants than for hydro-plants due to complex nature of principal equipment and auxiliaries in the former.

7.5.4 Cost of Stores (Other Than Fuel)

The items of consumable stores other than fuel include such articles as lubricating oil and greases, cotton waste, small tools, chemicals, paints and such other things. The incidence of this cost is also higher in thermal stations than in hydro-electric power stations.

7.5.5 Supervisions

In this head the salary of supervising staff is included. A good supervision is reflected in lesser breakdowns and extended plant life. The supervising staff includes the station superintendent, chief engineer, chemist, engineers, supervisors, stores incharges, purchase officer and other establishment. Again, thermal stations, particularly coal fed, have a greater incidence of this cost than the hydro-electric power stations.

7.5.6 Taxes

The taxes under operating head includes the following :

(a) Income tax

(b) Sales tax

(c) Social security and employee's security, etc.

7.6 ECONOMICS IN PLANT SELECTION

After selection of type of drive (such as steam, gas diesel or water power) which depends on availability of cheap fuels or water resources, further selection of the design and size of the equipment is primarily based upon economic consideration and a *plant that gives the lowest unit cost of production is usually chosen*. In case of all types of equipment the working *efficiency is generally higher with larger sizes of plants and with high load factor operation*. *Also, the capital cost per unit installation reduces as the plant is increased in size*. However, *a bigger size of plant would require greater investment and possibilities of lower than optimum, load factor usually increase with larger size of the plant*.

Steam Power Plants

In case of steam power plants the choice of *steam conditions* such as throttle pressure and temperature, is an important factor affecting operating costs and is, therefore, very carefully made. *As throttle pressure and temperature are raised the capital cost increases but the cycle efficiency is increased*. The advantages of higher pressures and temperatures is generally not apparent below capacity of 10,000 kW unless fuel cost is very high.

Heat rates may be improved further through *reheating* and *regeneration*, but again the capital cost of additional equipment has to be *balanced against gain in operating cost*.

The use of heat reclaiming devices, such as air pre-heaters and economisers, has to be considered from the point of economy in the consumption of fuel.

Internal Combustion Engine Plants

In this case also the selection of I.C. engines also depends on thermodynamic considerations. *The efficiency of the engine improves with compression ratio but high pressures necessitate heavier construction of equipment which increases cost*.

The choice may also have to be made between *four-stroke* and *two-stroke* engines, the *former having higher thermal efficiency* and the *latter lower weight* and *cost*.

The cost of the *supercharger* may be justified if there *is a substantial gain in engine power which may balance the additional supercharger cost*.

Gas Turbine Power Plant

The cost of the gas turbine power plant increases as the simple plant is modified by inclusion of other equipment such as *intercooler, regenerator, re-heater,* etc. but the gain in thermal efficiency and thereby a reduction in operating cost may justify this additional expense in first cost.

Hydro-electric Power Plant

As compared with thermal stations an hydro-electric power plant has little operating cost and if sufficient water is available to cater to peak loads and special conditions for application of these plants justify, *power can be produced at a small cost*.

The *capital cost* per unit installed is *higher if the quantity of water is small*. Also, the unit cost of conveying water to the power house is greater if the quantity of water is small. The cost of storage per unit is also lower if the quantity of water stored is large.

An existing plant capacity may be *increased by storing additional water* through increasing the height of dam or by diverting water from other streams into the head reservoir. However, again it would be an economic study whether this additional cost of civil works would guarantee sufficient returns.

Some hydro-power plants may be made *automatic* or *remote controlled* to reduce the operating cost further, but the cost of automation has to be *balanced against the saving effected in the unit cost of generation*.

Interconnected Hydro-steam System

In such a system where *peak loads are taken up by steam units*, the capacity of water turbine may be kept somewhat higher than the water flow capacity at peak loads, and lesser than or equal to maximum flow of river. This would make it possible for the water turbine to generate adequate energy at low cost during sufficient water flow.

Some of the principal characteristics of hydro-electric, steam and diesel power plants are listed below :

Sl. No.	Characteristics	Hydro-plant	Steam Plant	Diesel Plant
1.	Planning and construction	Difficult and takes long time	Easier than hydro-plant	Easiest
2.	Civil works cost	Highest	Lower than hydro-plant	Lowest
3.	Running and maintenance cost (as a fraction of total generation cost)	$\frac{1}{10}$	$\frac{1}{7}$	$\frac{1}{6}$
4.	Overall generation cost	Lowest	Lower than for diesel plant	Highest
5.	Reliability	Good	Good	Excellent

Advantages of Interconnection

Major advantages of interconnecting various power stations are :

(a) Increased reliability of supply.

(b) Reduction in total installed capacity.

(c) Economic operation.

(d) Operating savings.

(e) Low capital and maintenance costs.

(f) Peak loads of combined system can be carried at a *much lower cost* than what is possible with small individual system.

7.7 FACTORS AFFECTING ECONOMICS OF GENERATION AND DISTRIBUTION OF POWER

The economics of power plant operation is greatly influenced by :

(a) Load factor

(b) Demand factor

(c) Utilisation factor

Load Factor

In a *hydro-electric power station* with water available and a fixed staff for maximum output, the cost per unit generated at 100% *load factor* would be *half* the cost per unit at 50% load factor. In a *steam power station* the difference would not be so pronounced since fuel cost constitutes the major item in operating costs and does not vary in the same proportion as load factor. The cost at 100% load factor in case of this station may, therefore, be about $2/3^{rd}$ of the cost 50% load factor. For a *diesel station* the cost per unit generated at 100% load factor may be about $3/4^{th}$ of the same cost at 50% load factor. From the above discussion it follows that :

(a) Hydro-electric power station should be run at its maximum load continuously on all units.

(b) Steam power station should be run in such a way that all its running units are economically loaded.

(c) Diesel power station should be worked for fluctuating loads or as a stand by.

Demand Factor and Utilisation Factor

A higher efficient station, if worked at low utilisation factor, may produce power at high unit cost.

The time of maximum demand occurring in a system is also important. In an interconnected system, a study of the curves of all stations is necessary to plan most economical operations.

The endeavour should be to load the most efficient and cheapest power producing stations to the greatest extent possible. Such stations, called “base load stations” carry full load over 24 hours, i.e. for three shifts of 8 hours.

- The stations in the medium range of efficiency are operated only during the two shifts of 8 hours during 16 hours of average load.
- The older or less efficient stations are used as peak or standby stations only, and are operated rarely or for short periods of time.

Presently there is a tendency to use units of large capacities to reduce space costs and to handle larger loads. However, *the maximum economical benefit of large sets occurs only when these are run continuously at near full load. Running of large sets for long periods at lower than maximum continuous rating increase cost of unit generated*.

SAQ 1

(a) Describe the various costs associated with power plants.

(b) Explain the economics in plant selection.

(c) Describe the factors affecting economics of generation and distribution of power.

7.8 SUMMARY

In this unit, we have studied about the costs associated with the power generation. It also explains the various types of costs and its implications. Economics in plant selection also elaborated in this unit. Finally, the economics of power plant operations also described in detail.

7.9 KEY WORDS

Fixed Cost **:** Fixed costs are nothing but initial costs, which are fixed at all the time.

Depreciation **:** Depreciation accounts for the deterioration of the equipment and decrease in its value due to corrosion, weathering and wear and tear with use.

7.10 ANSWERS TO SAQs

Refer the preceding text for all the Answers to SAQs.

FURTHER READING

R. K. Rajput (2009), *A Text Book of Power Plant Engineering*, Laxmi Publications (P) Ltd.

R. K. Rajput (2009), *A Text Book of Internal Combustion Engines*, Laxmi Publications (P) Ltd.

R. K. Rajput (2009), *A Text Book of Thermal Engineering*, Laxmi Publications (P) Ltd.

POWER PLANT ENGINEERING

This course consists of 7 units.

The first unit deals with sources of energy fuels. It also explains the concepts of renewable energy resources.

In Unit 2, we will be discussing about the steam power plant, steam generator, steam turbine and cooling towers.

Unit 3 deals with atomic structure of matter, nuclear fission, nuclear fussion, nuclear reaction, nuclear power reactors, boiling water reactors, etc.

Unit 4 Diesel engine power plant, explains the elements of diesel power plant, basic functions of fuel injection system and different types of fuel injection schemes.

Unit 5 Gas turbine power plant, deals with concept of gas turbine engine, important parts and their functions. It also elaborate on different types of gas turbines.

Unit 6 Hydro power plants, enumerates the advantages of hydroelectric power plants. It also describes the hydro power plant.

In Unit 7 Plant economy, we will be discussing about the fixed costs, operating costs, and economics in plant selection. Finally, in this we will be learning about different types of power plants, the working principle of various power plants and its advantages and disadvantages.