ME8792-POWER PLANT ENGINEERING

UNIT V-ENERGY, ECONOMIC AND ENVIRONMENTAL ISSUES OF POWER PLANTS

5.2-LOAD DISTRIBUTION PARAMETERS, LOAD CURVE, COMPARISON OF SITE SELECTION CRITERIA, RELATIVE MERITS & DEMERITS, CAPITAL & OPERATING COST OF DIFFERENT POWER PLANTS.

LOAD DISTRIBUTION PARAMETERS

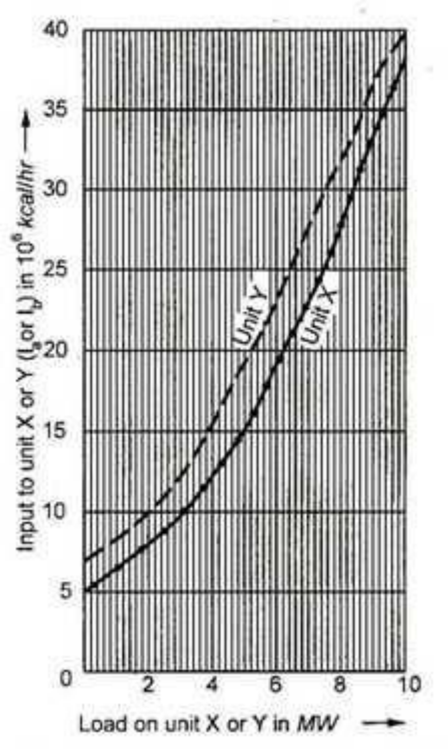
1. **Economics of load sharing between generators**

During design of power plants, prime importance is given to the economics of load sharing. Engineers are designing the power plant components such as boilers, heat turbines, heat exchangers, condensers, and generators etc for getting the highest thermal efficiency of the plant.

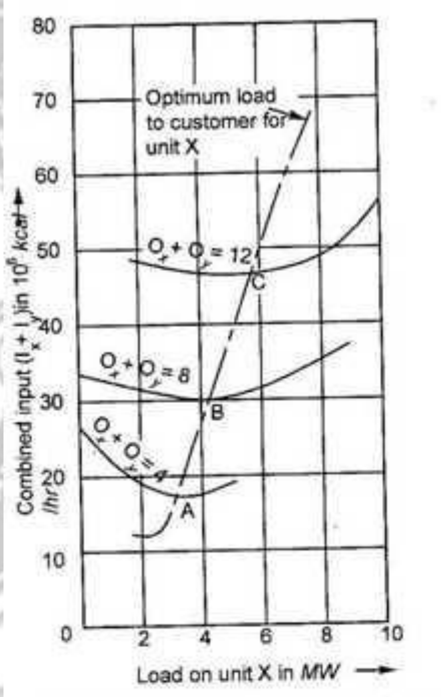
Various methods have been developed for economic operation of the power plant under varying load conditions. Transmission loss is also minimized by introducing the successful design of transmission lines.

The main problem for the electrical power engineers is the economic load sharing of the output of the generators. The proper sharing of load between two generators to give maximum overall efficiency is the major problem in load distribution among generators.

This input-output carries for two generators within a power plant which are operating in parallel and supply a common load is shown in fig below. From this fig, it is evident that the generator X is more efficient than Y throughout its load range as the output of X is more than the output of Y for the same input. Therefore, the engineers may think that they can load generator X first to its full capacity and then for generator Y for the remaining load. But it is not proper distribution as the overall efficiency of the system would not be highest with the distribution of loads as mentioned above.

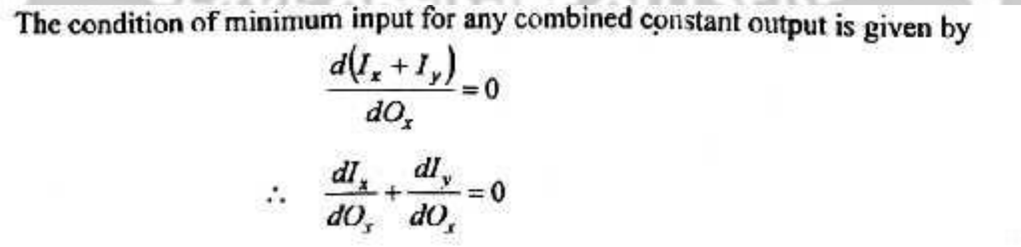


Input-output curves of unit X and Y



Variation of combined input with varying load sharing between X and Y

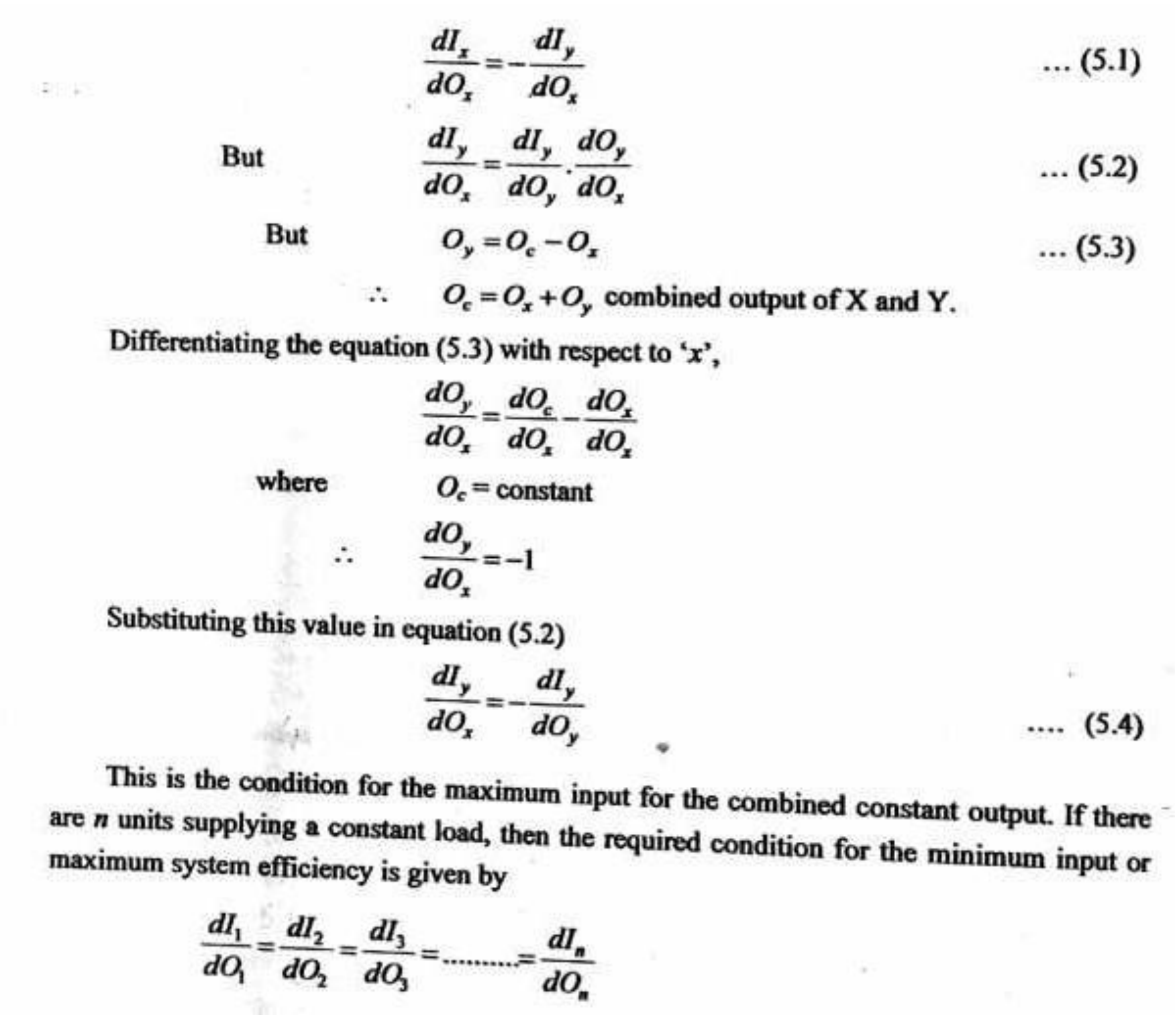
This problem can be resolved by plotting the sum of the inputs of X and Y against the load x for a given constant load on the two limits, as shown in fig above.



The condition of minimum input for any combined constant output is given by

$$\frac{d(I_x + I_y)}{dO_x} = 0$$

$$\therefore \quad \frac{dI_x}{dO_x} + \frac{dI_y}{dO_x} = 0$$



$$\frac{dI_x}{dO_x} = -\frac{dI_y}{dO_x} \qquad \ldots (5.1)$$

But $$\frac{dI_y}{dO_x} = \frac{dI_y}{dO_y} \cdot \frac{dO_y}{dO_x} \qquad \ldots (5.2)$$

But $$O_y = O_c - O_x \qquad \ldots (5.3)$$

$\therefore$ $O_c = O_x + O_y$ combined output of X and Y.

Differentiating the equation (5.3) with respect to '*x*',

$$\frac{dO_y}{dO_x} = \frac{dO_c}{dO_x} - \frac{dO_x}{dO_x}$$

where $O_c =$ constant

$$\therefore \quad \frac{dO_y}{dO_x} = -1$$

Substituting this value in equation (5.2)

$$\frac{dI_y}{dO_x} = -\frac{dI_y}{dO_y} \qquad \ldots. (5.4)$$

This is the condition for the maximum input for the combined constant output. If there are *n* units supplying a constant load, then the required condition for the minimum input or maximum system efficiency is given by

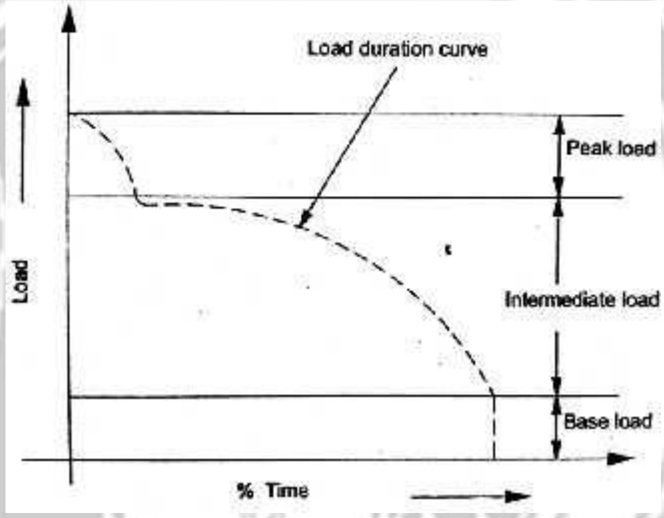
$$\frac{dI_1}{dO_1} = \frac{dI_2}{dO_2} = \frac{dI_3}{dO_3} = \ldots\ldots\ldots = \frac{dI_n}{dO_n}$$

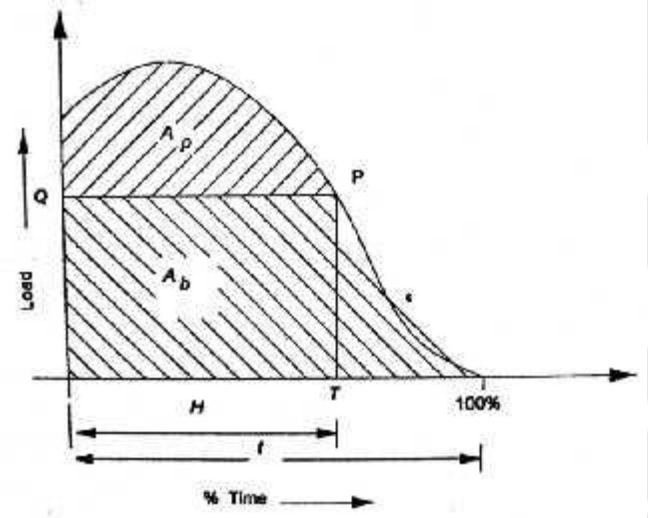
2. Economic load sharing between power plants

Different power plants such as hydro, thermal, nuclear, gas turbine, MHD, etc are operated combinedly to give greater reliability and maximum economic benefits. When the number of power stations works in combination with each other to supply the power to the consumers, the system is known as **interconnected system**.

In an interconnected system, the major problem is division of load among the power plants. The load distribution among the power plants depends upon the operating characteristics of the power plant. The distribution of load among the power plant in an interconnected system is done in such a way that the overall efficiency is achieved.

In the load duration curve, as shown below, the entire area under the load curve is divided into three parts as base load, intermediate load, and peak load. It is not economical to design a power plant to load to the maximum peak load as it works in under-load condition for the most of the time. In order to achieve the maximum possible is the loading of the most efficient power station in the order of merit of low fuel cost. It is made possible by establishing central control room which can control number of power plants simultaneously in the grid system. This also saves the fuel consumption per kW of power generation. In addition to the fuel consumption, there is also savings due to reduced spare capacity required and also due to the employment of large size units.





Peak load plants operate only when required for short time and takes up the load on upper part of the load curve. Plant capacity factor is low as it is operated for short duration. Fuel cost is very high but the total capital cost is less. Diesel and gas turbine plants are classified under this category.

For a known load duration curve, the economic load sharing between base load and peak load plants operating in parallel can be found as follows.

Let, the operating costs are known and they are given by

$$C_1 = A_1/(kW) + B_1/(kWhr) \quad \text{--- for base load plant}$$

$$C_2 = A_2/(kW) + B_2/(kWhr) \quad \text{--- for peak load plant}$$

where A_1 and A_2 = Fixed cost of base load and peak load plants respectively, and

B_1 and B_2 = Running cost of base load and peak load plants respectively

Peak load of the peak load plant is given by

$$P_p = P - P_b$$

where P = Peak load of the system in kW

P_b = Peak load on the base plant in kW

Number of units generated by the peak load plant N_p is given by

$$N_p = N - N_b$$

where N = total number of units generated by the system in kWh

N_b = units generated by base load plant

$$\therefore \quad C_1 = A_1 P_b + B_1 N_b$$

$$C_2 = A_2 P_p + B_2 N_p = A_2(P - P_b) + B_2(N - N_b)$$

Cost of the system C is given by

$$C = C_1 + C_2 = (A_1 P_b + B_1 N_b) + [A_2(P - P_b) + B_2(N - N_b)]$$

Minimum total cost can be calculated by

$$\frac{dC}{dP_b} = 0$$

$$\therefore (A_1 - A_2) + (B_1 - B_2)\frac{dN_b}{dP_b} = 0$$

$$\therefore \frac{dN_b}{dP_b} = \left(\frac{A_1 - A_2}{B_1 - B_2}\right) hrs$$

Thus, for economic load sharing, the area under the load curve is divided by a horizontal line. Its magnitude is given by

$$H = \frac{A_1 - A_2}{B_2 - B_1} \quad \text{in hours}$$

It indicates that for economic load sharing, the peak load plant should work for H hours per year. The value of H should always be higher.

$$\therefore A_1 > A_2 \text{ and } B_2 > B_1$$

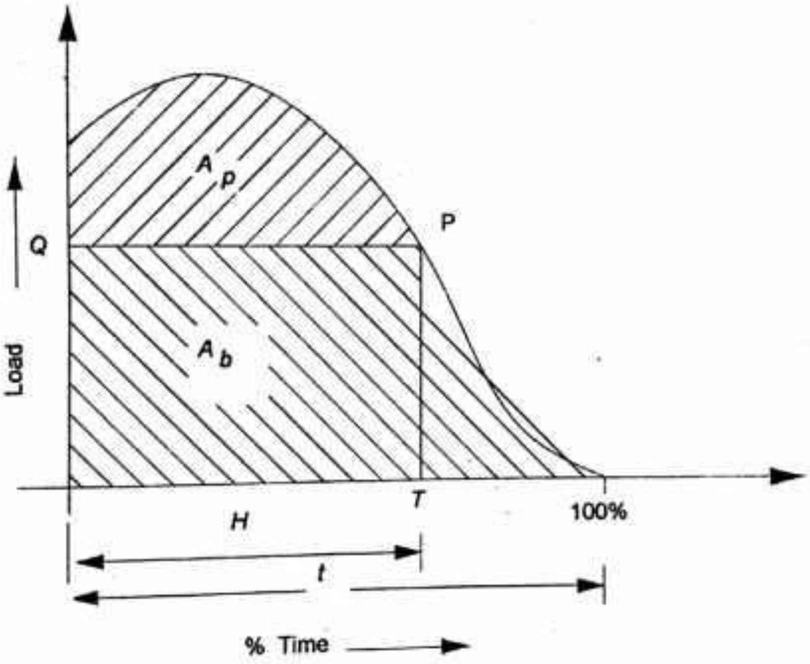


Figure 5.10

A_1 is higher and B_1 is lower for base load plant as compared to peak load plants. The point T is marked on the x-axis of load curve for the distance of H hours in percentage $\left(\frac{H}{8760} \times 100\right)$. The vertical line is drawn through T which meets the load curve at point P. The horizontal line PQ is drawn as shown in Figure 5.10. Now, the area A_p above the line PQ gives the energy generated by peak load plant and area below gives the energy generated by the base load plant. The scale taken for drawing load curve is $1cm = x$ % along time axis and $1cm = y$ in kW along the load axis.

$$\therefore \quad 1cm^2 = (x\%) \times y$$

$$100\% = 8760\text{hrs}$$

$$1cm^2 = \left(\frac{x}{100} \times 8760\right) \times y \text{ in } kWh$$

If areas A_b and A_p in cm^2 are known, then

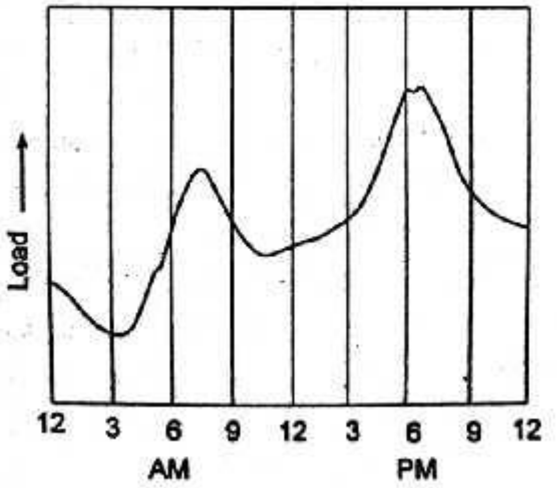
$$N_b = A_b \times \left(\frac{x}{100} \times 8760\right) \times y \text{ in } kWh \text{ for base load plant}$$

$$N_p = A_p \times \left(\frac{x}{100} \times 8760\right) \times y \text{ in } kWh \text{ for peak load plant}$$

Thus, the load sharing between two power plants can be achieved and it results the overall efficiency of operation.

LOAD CURVE

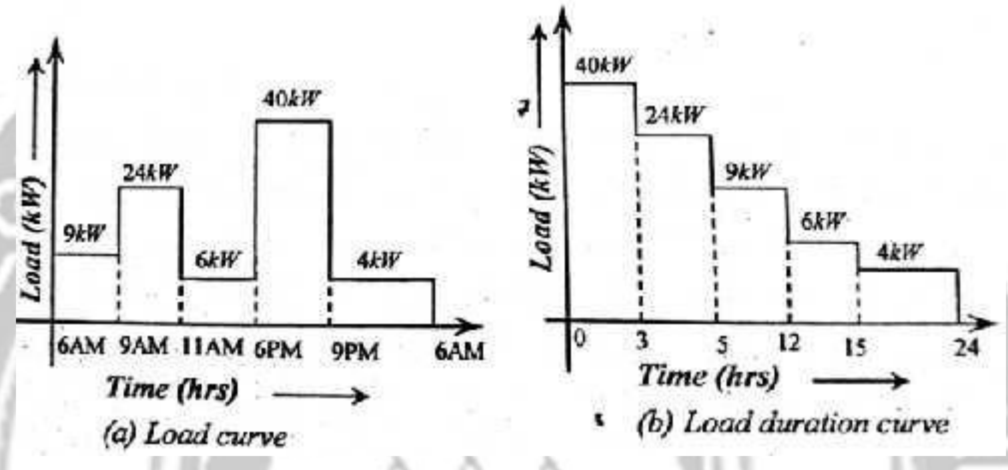
It is the graphical representation showing the power demand for every instant during a certain time period. It is drawn between load in kW and time in hours, if it is plotted for one hour, it is called as **hourly load curve** and if the time considered is of 24 hours then it is called **daily load curve,** and if plotted for one year (8760 hours) , then it is **annual load curve.** The area under the load curve represents the energy generated in the period considered. If we divide the area under the curve by the total number of hours, then it will give the average load on the power station. The peak load indicated by the load curve represents the maximum demand of the power station.



Load curve

LOAD DURATION CURVE

This curve represents the re-arrangement of all the load elements of load curve in order of decreasing magnitude. This curve is derived from load curve.



(a) Load curve (b) Load duration curve

COST OF ELECTRICITY

A power plant should provide a reliable supply of electricity at minimum cost to the consumers / customers. The cost of electricity may be determined by the following: Fixed cost or capital cost and Operating costs. The total cost of energy produced is the sum total of fixed charges and operating charges.

Total cost = Fixed costs + Operating costs

Fixed cost or capital cost: It is the cost required for the installation of the complete power plant. This cost includes

1. The cost of land, equipments, buildings, transmission and distribution lines cost of planning and designing the plant and many others.
2. Interest,
3. Depreciation cost,
4. Insurance,
5. Management costs, etc

1. **The cost of land, equipments, buildings** - The cost of land and buildings does not change much with different types of power plants but the equipment cost changes considerably. The cost of buildings can be reduced by eliminating the superstructure on the oiler house and turbine house. To reduce the cost of equipment, unit system may be adopted, reduced by simplifying the piping system and elimination of duplicate system such as steam headers and boiler feed heaters.The cost of equipment or the plant investment cost is usually expressed on the basis of kW capacity installed. The per kWcapacity may not vary for various thermal power plant where as for hydro-electric power plant, it changes a lot because the cost of hydro-electric power plant depends on the foundation availability, types of dam, available head and spillways used.

2. **Interest: -** the money needed or an investment may be obtained as loans, through bonds and shares. The interest is the difference between money borrowed and money returned. The rate of interest may be simple rate expressed as % per annum or may be compounded. A suitable rate of interest must be considered on the capital invested.

3. **Depreciation cost**: - it is the amount to be set aside per year from income to meet the depreciation caused by the ages of service, wear and tear of machinery, and the decrease in the value of equipment due to obsolescence. The power plant and equipment in the plant will have a certain period useful life. After years of use, the equipment loses its efficiency or becomes obsolete and needs replacement. Sometimes equipment may have to be replaced even when they fairly new, due to more efficient machines are available in the market. Some money is put aside annually to enable for this replacement, when necessary. This is known as depreciation fund.

Methods for calculating the depreciation cost: -

- Straight line method
- Sinking fund method
- Diminishing value method

4. **Insurance: -** nowadays, it becomes necessary to insure the costly equipments especially for the fire or accident risks. A fixed sum is set aside per year as insyrance charges. The insurance premium may be 2 to 3% of the equipment cost but annual installment is quite heavy when the capital cost of the equipment is high.

5. **Management cost; -** this cost includes the salary of the management employees working in the plant. This must be paid whether the plant is working or not. Therefore, this cost is included in the fixed cost.

Operatring cost: - the operational cost includes

a) The cost of fuel,
b) The cost of lubricatibg oil, greases, cooling water,
c) The cost of maintenance and repairs,
d) The cost of operating labour,
e) The supervision cost and
f) Taxes.

These costs vary with the amount of electrical energy produced.

a) Cost of fuel: - the fuel consumption depends on the amount of energy produced. As load increases the fuel consumption will increase so does the cost of fuel. The efficiency of the prime mover is the highest at the rated load.

At lower loads, efficiency decreases and so the fuel consumption will increase. The selection of the fuel and the maximum economy in its use are, therefore, very important consideration in thermal plant design. The cost of the fuel includes not only its price but also its transportation and handling costs also. The cost of fuel depends on the calorific value and its availability.

b) The cost of lubricating oil, greases, cooling water: - the cost of these materials also proportional to the amount of energy generated. this cost increases with an increase in life of the power plant as the efficiency of the power plant decreases with age.

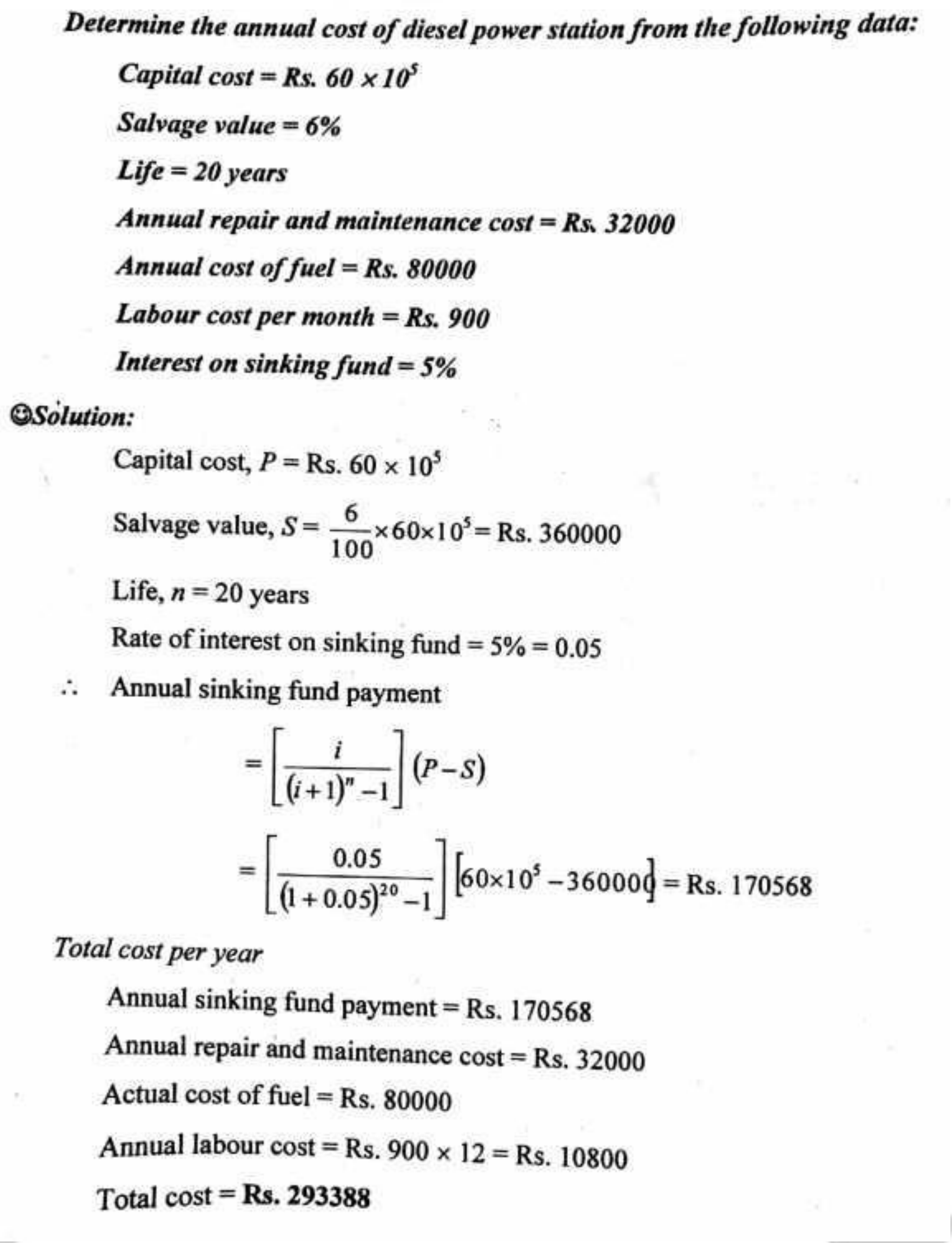
c) The cost of maintenance and repairs: - in order to avoid breakdowns, maintenance is necessary. it includes periodic cleaning, adjustments and overhauling of equipments. the materials used for maintenance and repairs are also charged under this head. it is necessary to repair when the plant breakdown or steps due to fault in mechanism. the repairs may be major or minor and are charged to the depreciation fund of the equipment. the cost is higher for thermal power plants than hydro power plants.

d) The cost of operating labour: - this includes the salary and wages for the operating labour working in the plant. maximum labours are needed in a thermal power plant using coal as a fuel. a hydro power plant or a diesel power plant of same capacity requires a less number of labours. in automated power plant, labour cost is reduced to a greater extent.

e) The supervision cost: - it includes the salary of the supervising staff and executives. a good supervision reduces the breakdowns and extends the plant life. the supervising staff includes chief engineer, superintendent, engineers, stores in charges, purchase officers, other supporting staffs and executives, etc.

f) Taxes: - the various taxes are included in this head. These are income tax, sales tax, provisional tax, commercial tax, etc.

EXAMPLE: 01



Determine the annual cost of diesel power station from the following data:

Capital cost = Rs. 60 × 10^5

Salvage value = 6%

Life = 20 years

Annual repair and maintenance cost = Rs. 32000

Annual cost of fuel = Rs. 80000

Labour cost per month = Rs. 900

Interest on sinking fund = 5%

☺***Solution:***

Capital cost, P = Rs. 60×10^5

Salvage value, $S = \frac{6}{100} \times 60 \times 10^5$ = Rs. 360000

Life, n = 20 years

Rate of interest on sinking fund = 5% = 0.05

∴ Annual sinking fund payment

$$= \left[\frac{i}{(i+1)^n - 1}\right](P - S)$$

$$= \left[\frac{0.05}{(1+0.05)^{20} - 1}\right]\left[60 \times 10^5 - 360000\right] = \text{Rs. } 170568$$

Total cost per year

Annual sinking fund payment = Rs. 170568

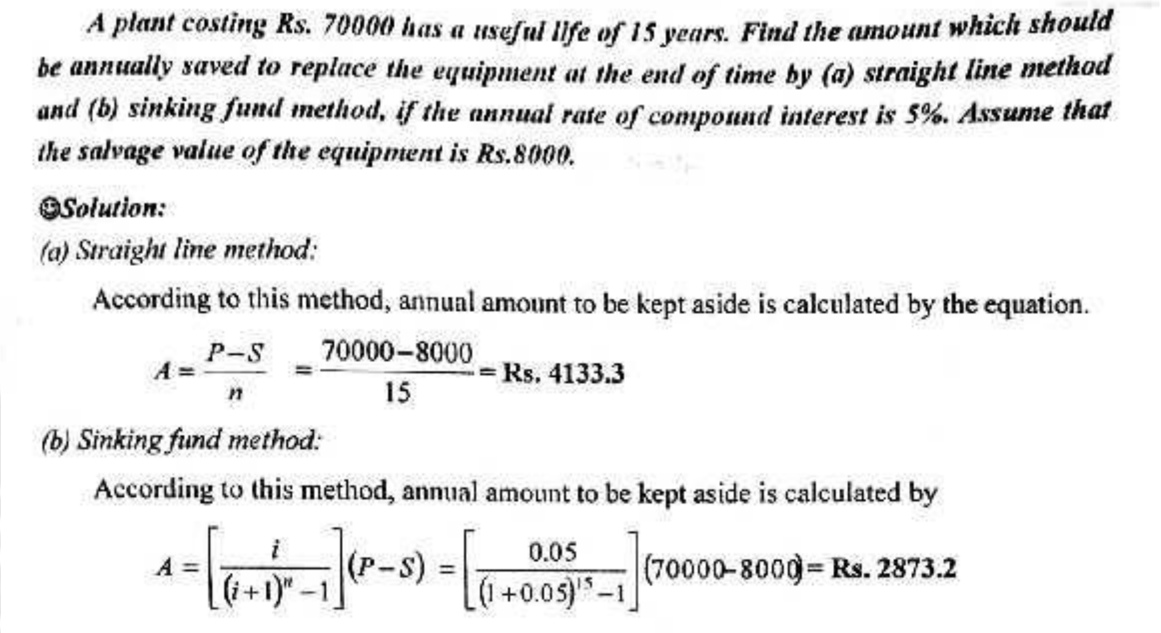
Annual repair and maintenance cost = Rs. 32000

Actual cost of fuel = Rs. 80000

Annual labour cost = Rs. 900 × 12 = Rs. 10800

Total cost = **Rs. 293388**

EXAMPLE: 02



A plant costing Rs. 70000 has a useful life of 15 years. Find the amount which should be annually saved to replace the equipment at the end of time by (a) straight line method and (b) sinking fund method, if the annual rate of compound interest is 5%. Assume that the salvage value of the equipment is Rs.8000.

☺***Solution:***

(a) Straight line method:

According to this method, annual amount to be kept aside is calculated by the equation.

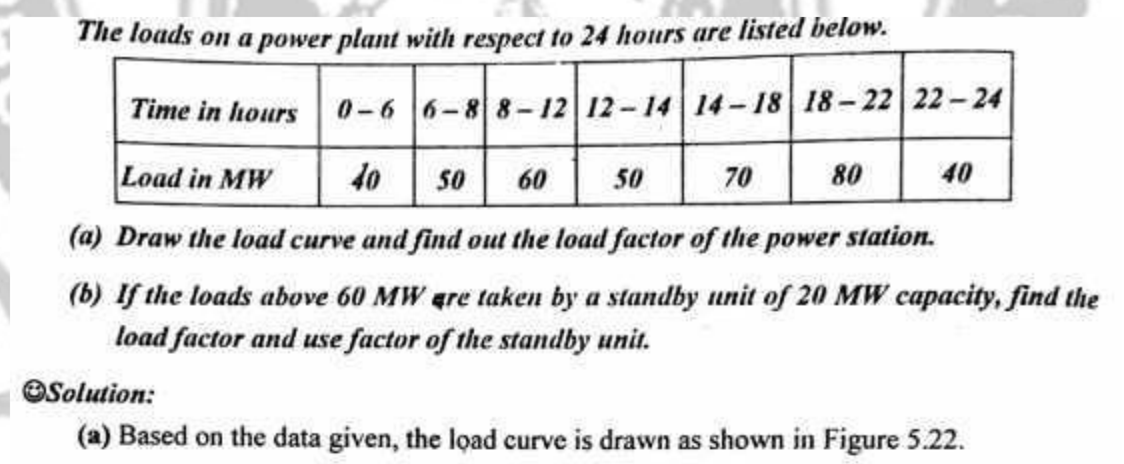
$$A = \frac{P-S}{n} = \frac{70000-8000}{15} = \text{Rs. } 4133.3$$

(b) Sinking fund method:

According to this method, annual amount to be kept aside is calculated by

$$A = \left[\frac{i}{(i+1)^n - 1}\right](P-S) = \left[\frac{0.05}{(1+0.05)^{15}-1}\right](70000-8000) = \text{Rs. } 2873.2$$

EXAMPLE: 03



The loads on a power plant with respect to 24 hours are listed below.

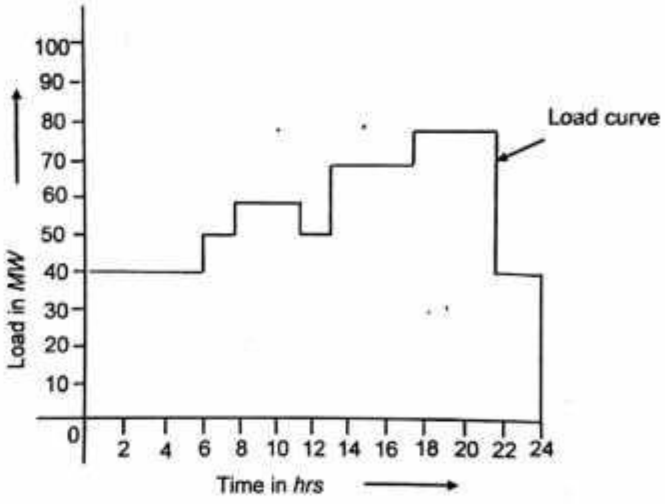
Time in hours	*0 – 6*	*6 – 8*	*8 – 12*	*12 – 14*	*14 – 18*	*18 – 22*	*22 – 24*
Load in MW	*40*	*50*	*60*	*50*	*70*	*80*	*40*

(a) Draw the load curve and find out the load factor of the power station.

(b) If the loads above 60 MW are taken by a standby unit of 20 MW capacity, find the load factor and use factor of the standby unit.

☺***Solution:***

(a) Based on the data given, the load curve is drawn as shown in Figure 5.22.



Energy generated = area under the load curve

$$= 40\times6 + 50\times2 + 60\times4 + 50\times2 + 70\times4 + 80\times4 + 40\times2$$

$$= 1360 MWh$$

$$\text{Average load} = \frac{1360}{24} = 56.667 MW$$

$$\text{Load factor} = \frac{\text{Averageload}}{\text{Maximumdemand}} = \frac{56.667}{80} = 0.708$$

(b) If the load above 60 *MW* is supplied by a standby unit of 20*MW* capacity, the energy generated by it can be calculated as follows:

Only 70 *MW* and 80 *MW* powers are more than 60 *MW* power. Therefore,

Energy generated by 70 *MW* power between 14 - 18 hours i.e. 4 hours is

$$= 10 \times 4 = 40\ MWh$$

Energy generated by 80 *MW* power between 18 - 22 hours i.e. 4 hours is

$$= 20 \times 4 = 80\ MWh$$

Total Energy generated by 70 *MW* and 80 *MW* power is

$$= 40 + 80 = 120\ MWh$$

Time during which the standby unit remains in operation = 4 + 4 = 8*hours*

$$\text{Average load} = \frac{120}{8} = 15\ MW$$

$$\text{Load factor} = \frac{15}{20} = 0.75$$

$$\text{Use factor} = \frac{\text{Energygenerated}}{\text{Plantcapacity} \times \text{Operatinghours}} = \frac{120}{20\times8} = 0.75$$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