Power Systems

Load Management

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Load Management

MAXIMUM DEMAND

The maximum demand of a consumer means the maximum power that his circuit is likely to draw at any time. If all the devices and outlets were used simultaneously to the full extent, the maximum demand of the consumer would equal his connected load. Experience has shown that consumers do not use all the devices at full load simultaneously. The maximum demand of each consumer is, therefore, less than his connected load. The maximum demand and the connected load are related by

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Connected load}}$$

If a consumer has 10 bulbs each of 100 watt, his connected load is 1000 watt (assuming that no other electrical device exists in his premises). However he would not use all the 10 lamps simultaneously . At sometime of the day he may use only 3 bulbs, at another time only 2 and still at an another time six. If the maximum number of bulbs used by him simultaneously is six, his maximum demand is 600 watt and demand factor is 0.6.

Each device will run at its rated capacity at sometime during its operation. The demand factor indicates the contribution of the device towards the maximum demand of the consumer. Demand factors for various types of loads vary within very wide limits.

Example

A residential consumer has the following connected load: 8 bulbs of 100 W each, 2 fans of 60 W each and 2 light plug points of 100 W each. His use of electricity during a day is as under:

12 midnight to 5 am	*one fan*
5 am to 7 am	*2 fans and one light point*
7 am to 9 am	*NIL*
9 am to 6 pm	*2 fans*
6 pm to midnight	*2 fans and 4 bulbs*

Find (a) connected load (b) maximum demand (c) demand factor (d) energy consumed during 24 hours (e) energy consumed in 24 hours if all devices are used all the day.

Solution

(a) Connected load = 8 x 100 + 2 x 60 + 2 x 100 = 1120 W

(b) Total wattage at different times is

12 midnight to 5 am	60 W
5 am to 7 am	2 x 60 + 1 x 100 = 220 W
7 am to 9 am	NIL
9 am to 6 pm	2 x 60 = 120 W

6 pm to midnight 2 x 60 + 4 x 100 = 520 W

The maximum demand is 520 W

(c) Demand Factor = $\frac{520}{1120}$ = 0.464

(d) Energy consumed

from 12 midnight to 5 am	60 x 5 = 300 Wh
from 5 am to 7 am	220 x 2 = 440 Wh
from 7 am to 9 am	NIL
from 9 am to 6 pm	120 x 9 = 1080 Wh
from 6 pm to 12 midnight	520 x 6 = 3120 Wh

Total energy consumed during 24 hours = 300 + 440 + 1080 + 3120

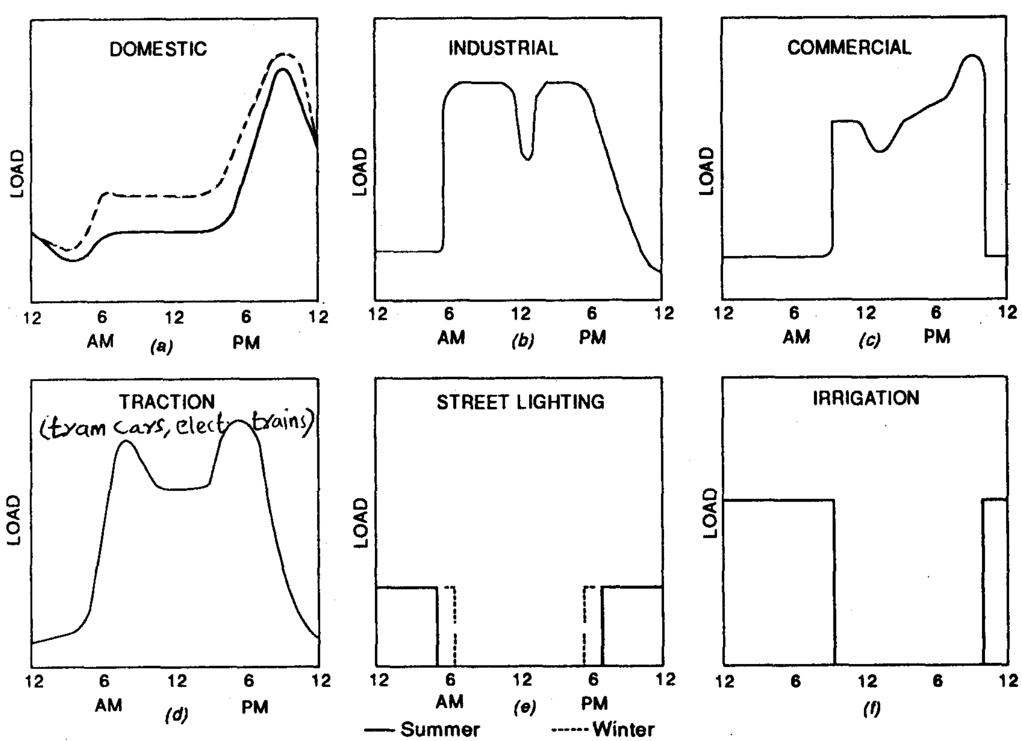
= 4940 Wh = 4.94 kWh

(e) If all devices are used throughout the day, the energy consumed is

= 1120 x 24 = 26880 Wh = 26.88 kWh

TYPES OF LOAD

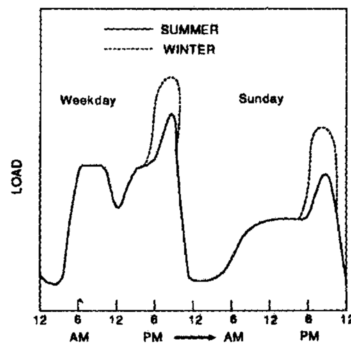
The main types of load on a system are domestic, industrial, commercial, municipal, traction, agriculture etc. A graph showing the hourly variation in demand during the 24 hours of the day is called a chronological load curve. The chronological load curves follow a typical pattern for each of the above loads. Following figure shows some typical chronological load curves for different types of loads. Details are self explanatory.



VARIATION IN DEMAND, CHRONOLOGICAL LOAD CURVE

The system load which is a combination of all he above mentioned loads varies from instant to instant. A graph showing the variation of the system load during the 24 hours of the day is known as the chronological load curve. The most important variations of this curve are the monthly and annual load curves each of which is the average of daily load curves over the period named.

A chronological load curve for a typical week day is different from that for a Sunday, that for a typical summer day being again different from that for a winter day. The curve for a typical metropolitan area is shown in figure.

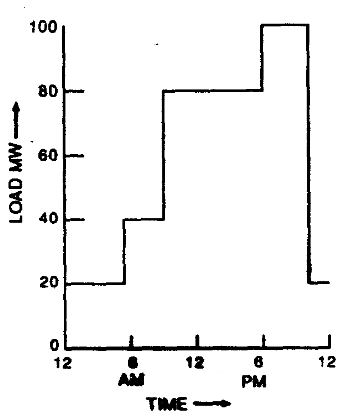


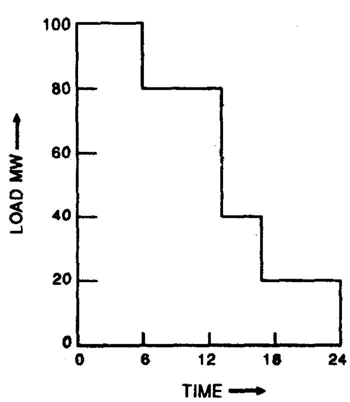
The industrial processes and domestic uses impose a highly variable load on the system.

LOAD DURATION CURVE - ENERGY LOAD CURVE

Energy systems depict a considerable variation in demand. It is necessary, for system planning and operation, to known the total energy requirements and the duration of various loads.

The area under a chronological load curve gives the energy consumed (i.e. kWh) during the 24 hours.





Chronological curve **Load duration curve**

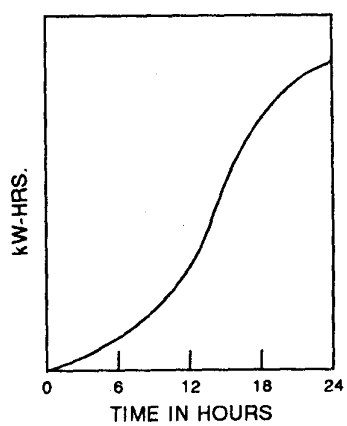
A load duration curve is a re-arrangement of all the load elements of a chronological curve in a descending order. Thus it shows the total number of hours for which a particular lad lasts during he day. The area under the load duration curve is evidently, equal o the area under the chronological load curve. Since the curves are generally of irregular shape, the area can be determined only graphically.

The following points may be noted about load duration curve :

- 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.
- 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.
- 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.*

MASS CURVE

A mass curve is plotted with energy (say in kilowatt-hours) as ordinate and time as abscissa. Thus a mass curve gives the total energy used by the load upto each hour of the day. The mass curve can be easily plotted from the chronological load curve by summing up the energy consumed upto different times starting at the zero tie. The mass curve is as sown in figure.



A mass curve is used in the study of variations between the rate of water flow and the electric load and the determination of the necessary storage.

IMPORTANT FACTORS

Load Factor

Load factor for a system or a plant is the ratio of the average load to the peak load, for a certain period of time.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Peak load}}$$

Load factor can be defined as the ratio of the energy consumed in a certain time (say 24 hours or a year) to the energy which would be consumed if the load is maintained at the maximum value throughout that time.

$$\text{Load factor} = \frac{\text{Energy consumed during a time of } t \text{ hours}}{\text{Peak load x } t}$$

The peak load is generally taken as that prevailing for a half hour period and the average load may be that pertaining to a day, a month or a year, thus giving daily, monthly or yearly load factor.

The load factor depicts the variation of load during a certain period but it does not give any indication of the shape of the load duration curve.

Plant Factor

The plan capacity factor (also known as plant factor) is the ratio of the average annual load to the power plant capacity.

$$\text{Plant factor} = \frac{\text{Average annual load}}{\text{Rated plant capacity}}$$

It can also be defined as the ratio of the energy produced by the plant in a year to the maximum energy that the plant could have produced. If the plant is always run at its rated capacity, the capacity factor is 100 %.

The capacity factor depicts he extent of the use of the generating station. It is different from load factor because of the reason that the rated capacity of each plant is always greater than the expected maximum load. The power plants have always some reserve capacity o take into account the future expansion increase in load and maintenance.

$$\text{Plant factor} = \frac{\text{Maximum load}}{\text{Plant capacity}} \text{ x Load Factor}$$

It is evident that if the rated plant capacity equals he maximum load, the capacity factor and load factor become identical.

Utilisation Factor

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

$$\text{Utilisation factor} = \frac{\text{Maximum load}}{\text{Rated Plant Capacity}}$$

Diversity factor

The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor i.e., Diversity factor = Sum of individual max. demands/Max. demand on power station

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.

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.

Plant use factor = Station output in kWh/ Plant capacity × Hours of use

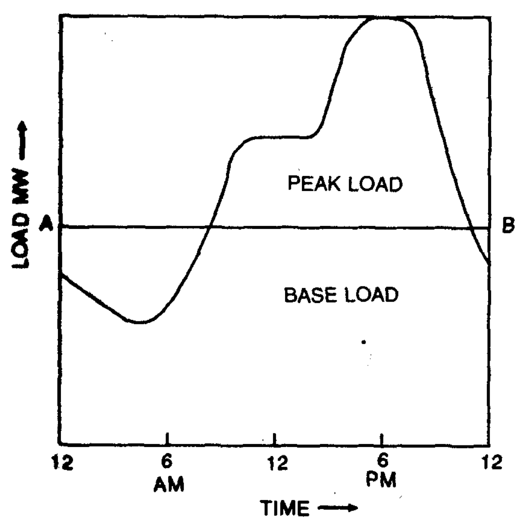
Suppose a plant having installed capacity of 20 MW produces annual output of $7{\cdot}35 \times 10^6$ kWh and remains in operation for 2190 hours in a year.

Then Plant use factor = $\dfrac{7.35x10^6}{(20x10^3)x2190} = 0.167 = 16.7\%$

BASE LOAD AND PEAK LOAD PLANTS

The system load varies from time to time. A typical chronological curve is as shown in figure.

The maximum demand is M. If the total demand is supplied from one power plant having an installed capacity M (or somewhat higher to keep some reserve capacity), the plant will be running under loaded most of the time, thus making the operation uneconomical.



A better method is to divided the load into two portions, one below the line AB and the other above the line AB. These loads are referred to as base load and peak load respectively. These two loads are supplied from separate plants called the base load plant and the peak load plant. A base load plant operates at a high load facto and should be one which has low operating costs. The peak load plant operates at a low load factor. Sometimes the load curve can be divided into three portions i.e. base load, intermediate load and peak load.

Example

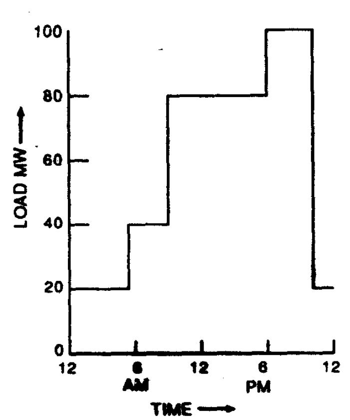
The load on a power plant on a typical day is as under:

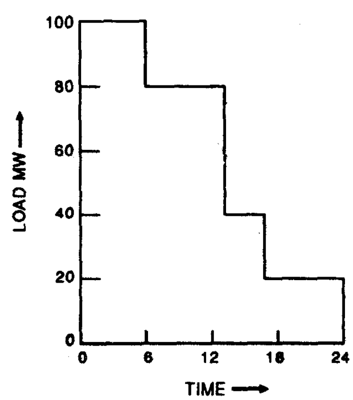
Time	*: 12am - 5 am*	*5am - 9am*	*9am - 6pm*	*6pm - 10pm*	*10pm - 12am*
Load(MW)	*: 20*	*40*	*80*	*100*	*20*

Plot the chronological load curve and load duration curve. Find the load factor of the plant and the energy supplied by the plant 24 hours.

Solution

The chronological load curves plotted in following figure.





(a) Chronological curve **(b) Load duration curve**

The duration of loads is as under:

Load(MW)	*:*	*100*	*80 and above*	*40 and above*	*20 and above*
Duration (hrs.)	*:*	*4*	*13*	*17*	*24*

The load duration curve is plotted in fig (b). The energy produced by the plant in 24 hours is

$$= 100 \times 4 + 80 \times (13 - 4) + 40 (17 - 13) + 20 (24 - 17) = 1420 \text{ MWh}$$

$$\text{Load Factor} = \frac{1420}{100x24} = 0.5917 \text{ or } 59.17\%$$

Example

The plant of previous example has an installed capacity of 125 MW. Find the plant factor and the utilisation factor.

Solution

$$\text{Plant factor} = \frac{100}{125} \times 0.5917 = 0.473 \quad \text{(or capacity factor)}$$

$$\text{Utilisation factor} = \frac{100}{125} = 0.8$$

Example

Plot the energy load curve and the mass curve for the chronological load curve of previous example.

Solution

The energy at different load levels is as under:

Load = 20 MW, Energy = 24 x 20 = 480 MWh

Load = 40 MW, Energy = 480 + 20 x 17 = 820 MWh

Load = 80 MW, Energy = 820 + 40 x 13 = 1340 MWh

Load = 100 MW, Energy = 1320 + 20 x 4 = 1420 MWh

The energy load curve is plotted in fig.(a). The energy supplied upto different times of the day is as under:

Energy supplied upto 5 am = 20 x 5 = 100 MWh

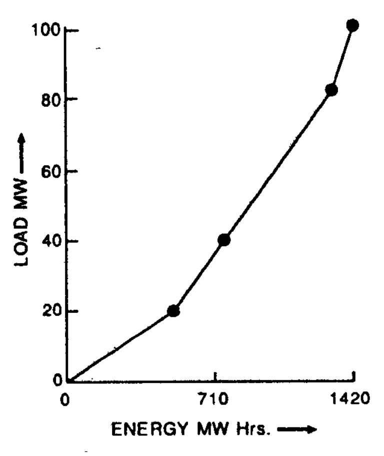
Energy supplied upto 9 am = 100 + 40 x 4 = 260 MWh

Energy supplied upto pm = 260 + 80 x 9 = 980 MWh

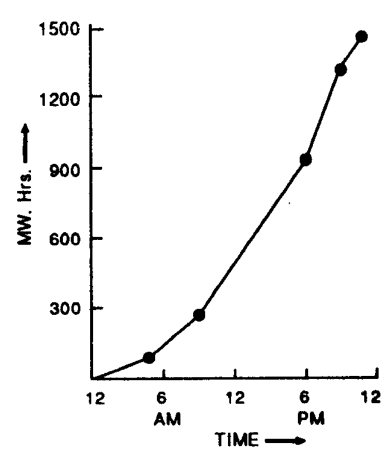
Energy supplied upto 10 pm = 80 + 100 x 4 = 1380 MWh

Energy supplied upto 12 pm = 1380 + 20 x 2 = 1420 MWh

The mass curve is plotted in fig. (b).



Energy load curve



Mass curve

Example

The maximum demand of a power plant is 40 MW. The capacity factor is 0.5 and the utilisation factor is 0.8. Find

a) *load factor*
b) *plant capacity*
c) *reserve capacity*
d) *annual energy production.*

Solution

(a) Load factor = $\dfrac{\text{Capacity factor}}{\text{Utilisation factor}} = \dfrac{0.5}{0.8} = 0.625$

(b) Plant capacity = $\dfrac{\text{Max. demand}}{\text{Utilisaton factor}} = \dfrac{40}{0.8} = 50$ MW

(c) Reserve capacity = 0 - 40 = 10 MW

(d) Annual energy production = 40 x 0.625 x 8760 = 219000 MWh

Example

A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being 61·5 × 10^6 per annum. Calculate (i) the demand factor and (ii) load factor.

Solution

Demand factor = max demand/connected load = 20/43 = 0.465

Average demand = (units generated/annum)/hours in year

= 61.5 x 10^6/8760 = 7020 kW

Load Factor = average demand/max demand = 7020/(20 x 10^3)

= 0.351 or 35.1%

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.

Solution

(i) Load factor = average demand/max demand

or 0.60 = ave. demand/25

average demand = 25 x 0.60 = 15 MW

Plant capacity factor = average demand/plant capacity

∴ Plant capacity = average demand/plant capacity factor = 15/0.5 = 30 MW

∴ Reserve capacity of plant

= Plant capacity − maximum demand

= 30 − 25 = 5 MW

(ii) Daily energy produced

= Average demand × 24

= 15 × 24 = 360 MWh

(iii) Max energy that can be produced

= actual energy produced in a day/plant use factor

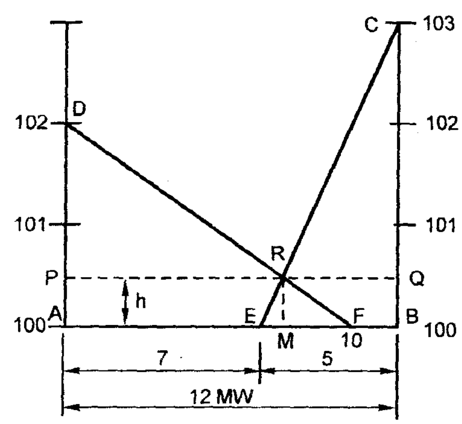
= 360/0.72 = 500 MWh/day

Example (AMIE S08, 8 marks)

Two 50 Hz small hydroelectric power stations (power stations A and B) are interconnected. Power station A of 10 MW capacity has a uniform speed regulation from no load to full load of 2%. Power station B has a capacity of 5 MW with uniform speed regulation of 3%. If the demand on station A is 8 MW and that of station B is 4 MW due to consumers in their respective areas. Determine (i) power contributed by each station, (ii) power transmitted from one station to another station, and (iii) frequency, if the nominal frequency is 50 Hz.

Solution

Following figure is drawn between kW and speed as assuming straight line characteristics. let A' load be AM and B' load be BM and MR = h.



∴ AM + MB = (8 + 4) = 12 MW

We draw a horizontal line PQ through R which is the point of intersection. From similar triangles AFD and PRD we have

$$PR = \frac{AF}{AD} xPD \text{ P}$$

But PD = (2 – h)

∴ $$PR = \frac{10}{2}(2-n) = 5(2-n)$$

Also from similar triangles BCE and QCR

$$RQ = \frac{BE}{BC} xQC = \frac{5}{3}(3-h)$$

∴ $$PR + RQ = 5(2-h) + \frac{5}{3}(3-h) = 12$$

h = 0.45

∴ PR = 5(2 – 0.45) = 7.75 MW

and RQ = (5/3)(3 – 0.45) = 4.25 MW

(i) Power contributed by station A is 7.75 MW and that by station B is 4.25 MW.

(ii) As demand on station A is 8 MW, hence power of 8 – 7.75 = 0.25 MW will be transmitted from station B to station A.

(iii) Frequency at point m = 50 – 0.45 = 49.55 Hz

Problem

A generating station has a connected load of 40 MW and a maximum demand of 20 MW : the units generated being 60 × 10^6. Calculate (i) the demand factor (ii) the load factor.

Answer: (i) 0·5 (ii) 34·25%

Problem

A generating station has a maximum demand of 25 MW, a load factor of 60%, a plant capacity factor of 50%, and a plant use factor of 72%. Find (a) the daily energy produced (b) the reserve capacity of the plant and (c) maximum energy that could be produced daily if the plant, while running as per schedule, were fully loaded.

Answer: 360 MWh, 5 MW, 500 MWh/day

COST OF ELECTRICAL ENERGY

The generation cost per kWh of energy depends on the cost covering the purchase, installation and erection of equipment, cost of fuel, labour, repair etc. The generation cost can be divided into fixed cost i.e. the cost which depends on the extent of plant investment and financial rates and remains a fixed one irrespective of the amount of energy generated and operating cost which includes the expenditure for fuel, labour, supervision etc. The operating costs of a plant are generally variable in magnitude and depend on the amount of energy produced.

CAPITAL COST OF PLANTS

In addition to the costs mentioned above, the capital cost of a hydro-electric plant includes the costs of dam, earth work, excavation, railhead, highways and other civil works and compensation to property owners whose lands would be submerged in the reservoir.

ANNUAL FIXED COST

Components

The annual fixed cost of a plant consists of interest, taxes, insurance, depreciation, managerial and general maintenance costs and rate of return.

(a) **Interest, taxes and insurance**. The capital for setting up the plant may be provided by the Government or the private owner) or acquired through a loan from a financial institution or institution or acquired by the sale of stock or bonds or both. The annual interest and dividend have to be included in the total cost of service. The utility may have to pay various taxes to town, state and federal authorities. However, only the taxes which are a function of the capital investment should be included in the fixed costs and h other taxes should b included in the operating costs.

Every well managed utility has to incur expenditure on insurance against accidents to equipment and personnel. The list of risks and insurance is usually very long e.g. fire, flood, hail, earthquake, explosion, public liability, workmen compensation etc. The insurance may be obtained from insurance companies.

(b) **Depreciation.** Every equipment deteriorate or depreciates due to wear and tear, corrosion, weathering etc. In addition, the equipment may become inadequate due to increase in demand or become obsolete and may need replacement by a modern one.

It is necessary for the financial stability and safety that the capital of an enterprise must remain intact. When a plant becomes useless, funds must be available to replace it.

(c) **Managerial and general maintenance costs**. A part of total wage bill of a power plant is constant irrespective of the amount of energy generated. Similarly a certain amount of supervision and maintenance is needed even when it is not producing any energy. These costs are proportional to the size of the plant and the equipment and should be included in fixed costs.

(d) **Rate of return.** An undertaking can be successful only if it earns profit. It is a private limited company and has floated shares or bonds, it must pay a good dividend so that the value of the shares may be high and the undertaking may be successful. Therefore, a certain rate of return on investment should be taken into account in calculating the annual fixed costs.

FIXED CHARGE RATE

The annual costs are calculated by multiplying the costs are calculated by multiplying he capital cost by a decided fixed charge rate. The value of the fixed charge rate is fixed on the basis of the above mentioned components of annual fixed costs. Thus

$$AFC_k = (FCR_k)\,(UC_k)\,(C_k)$$

Where, AFC_k = annual fixed cost of k h unit, (Rs. per year)

FCR_k = fixed charge rate of k th unit

UC_k = unit capital cost of k th unit, (Rs/MW)

C_k = capacity of k th unit, (MW)

The total annual fixed cost of an installation having a number of units is, evidently, the sum of individual annual fixed costs of different units.

OPERATING COST OR PRODUCTION COST

Components

(a) **Fuel.** This is the largest item of expense in thermal, diesel and gas turbine stations. The fuel may be in the form of coal, oil, natural gas, wood scrap etc. The cost of fuel depends on the type of fuel, calorific value, availability and freight rates. The annual fuel cost of a station depends on he amount of energy produced, the efficiency of the plant and the unit price of fuel.

(b) **Operating labour.** The operation of a plant needs staff and labour. In a steam plant labour is needed for unloading and storing of fuel, disposal of refuse, operation of boiler, prime mover etc.

(c) **Maintenance cost.** Every plant needs preventive maintenance (inspection, cleaning, repair, overhauling etc.) to keep it in good condition.

(d) **Supplies.** This item includes the cost of water for make up, cooling purposes and general use, lubricating oil and other consumable materials.

Calculations of operating cost

The annual operating cost of the k th unit of a power plant can be written as:

$$AOC_k = FC_k + OM_k$$

Where, AOC_k = annual operating cost of k the unit, (Rs. Per year)

FC_k = annual fuel cost of k th unit, (Rs. Per year)

OM_k = annual cost of operating labour, maintenance and supplies of k th unit, (Rs. Per year)

The annual fuel cost FC_k is the product of the total amount of fuel consumed in one year and the unit cost of fuel. The total annual operating cost of a station having a number of units is the sum of the individual annual operating costs of different units.

AMOUNT PLAN COST

The annual plant cost (of a unit) can be straight-away written from eq.14 and eq.15.

$$APC_k = AFC_k + AOC_k$$

Where, APC_k = annual plant cost of the k th unit (Rs. Per year)

AFC_k and AOC_k have already defined.

The total annual station cost for he entire generating station having n generating units is the sum of individual plant costs of different units. Thus

$$TASC = \sum_{k=1}^{n} APC_k$$

where TASC = Total annual station cost (Rs. Per year)

GENERATION COST

It is usually necessary to estimate the generation cost (i.e. cost of unit energy generated) for a generating unit. This information is needed when different generating units are to be compared. For this purpose it is necessary to calculate the expected energy output of the generating unit for one year. This is given by:

$$E_k = 8760\,(CF_k)\,(C_k) \times 10^3$$

where E_k = expected annual energy output of k th unit (kWh per year)

CF_k = capacity factor of k th unit

C_k = capacity of k th unit (MW)

The generation cost of k th unit is

$$GC_k = 100\,\frac{APC_k}{E_k}$$

Where GC_k = generation cost of k h unit (paisa/kWh)

The overall generation cost of a generating station having n generating units, can be calculated by dividing the total annual station cost by the total energy generating by all the n units in the station. Thus

$$OGC = \frac{100(TASC)}{\sum_{k=1}^{n} E_k} = \frac{(100)\left(\sum_{k=1}^{n} APC_k\right)}{\sum_{k=1}^{n} E_k}$$

Where OGC = overall generation cost of the station (paisa/kWh)

The generation cost in a power system having many generating stations can be calculated by dividing the total annual cost of the system by the total energy generated by the system.

Example

A steam station has two 110 MW units. The cost data is as under:

Unit 1	***Unit 2***
UC_1 = Rs.8000 per kW	*UC_2 = Rs.10000 per kW*
FCR_1 = 10 percent	*FCR_2 = 10 percent*
CF_1 = 0.55	*CF_2 = 0.60*
Fuel consumption = 1 kg/kWh	*Fuel consumption = 0.9 kg/kWh*
Fuel cost = Rs.500 per 1000 kg	*Fuel cost = Rs.500 per 1000 kg*
OM_1 = 20 percent of annual fuel cost	*OM_2 = 15 percent of annual fuel cost*
Utilisation factor = 1	*Utilisation factor = 1*

Calculating (a) annual plant cost and generation cost of unit 1

(b) annual plant cost and generation cost of unit 2

(c) overall generation cost of the station.

Solution

(a) $AFC_1 = \text{Rs.} \left(\frac{10}{100}\right) (8000)(110 \times 10^3) = \text{Rs. } 88 \times 10^6$

$E_1 = 8760 (.55)(110 \times 10^3) = 52998 \times 10^4$ kWh

Annual fuel consumption of unit 1 = 52998×10^4 kg

$FC_1 = (52998 \times 10^4)\left(\frac{500}{1000}\right) = \text{Rs. } 26499 \times 10^4$

$OM_1 = 0.2 (26499 \times 10^4) = \text{Rs.}52998000$

$AOC_1 = \text{Rs.}(26499 \times 10^4 + 52998000) = \text{Rs.}317988 \times 10^3$

$APC_1 = \text{Rs.}(88 \times 10^6 + 317988 \times 10^3) = \text{Rs.}405988 \times 10^3$

$GC_1 = \frac{405988 x 10^3}{52998 x 10^4} = 76.6$ paisa/kWh

(b) $AFC_2 = \text{Rs.}\left(\frac{10}{100}\right)(10000)(110 \times 10^3) = \text{Rs. } 110 \times 10^6$

$E_2 = 8760 (.60)(110 \times 10^3) = 57816 \times 10^4$ kWh

Annual fuel consumption of unit 2 = $0.9 (57816 \times 10^4) = 520344 \times 10^3$ kg

$FC_2 = \text{Rs.}(520344 \times 10^3)\left(\frac{500}{1000}\right) = \text{Rs. } 260172000$

$OM_2 = \text{Rs.}(0.15)(260172000) = \text{Rs. } 39025800$

AOC_2 = Rs. (260172000 + 39025800) = Rs. 299197800

APC_2 = Rs. (110 x 10^6 + 299197800) = Rs. 409197800

$$GC_2 = \frac{409197800 \ x100}{57816 \ x10^4} = 70.78 \text{ paisa/kWh}$$

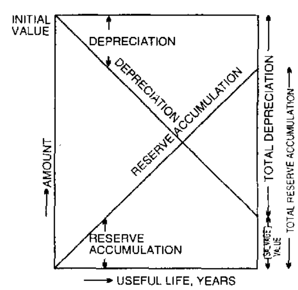
(c) $$OGC = \frac{(405988000 + 409197800)100}{52998x10^4 + 57816x10^4} = 73.56 \text{ paisa/kWh}$$

DEPRECIATION

The value of the power plant decreases from its initial vale to the salvage value at the end of its useful life. This depreciation is due to ageing, wear and tear of machinery, corrosion, weathering, inadequacy and obsolescence of equipment etc. At the end of the useful life of the plant, funds must be available to replace the equipment. The depreciation charge represents the amount which is set aside from income every year and placed in depreciation reserve. For calculating this charge, it is necessary to estimate the useful life of plant. The life of heavy electrical equipment and steam turbines is generally taken as 20-25 years, hydraulic turbines 30 years and civil engineering works 50 years. The depreciation charge may be based on straight line method or sinking fund method or fixed percentage method.

Straight Line Method

This method assumes that depreciation occurs according to a straight line law.



$$\text{Straight line annual} = \frac{\text{Initial cost - Salvage value}}{\text{Number of years of useful life}}$$

This method neglects the interest that the depreciation reserve would earn. It is very popular because of its simplicity.

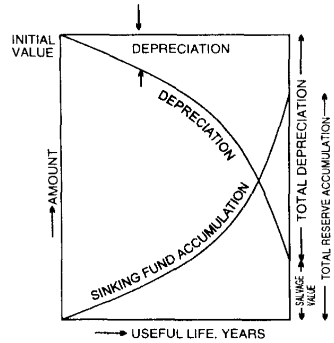
Sinking Fund Method

This method is based on the fact that the annual depreciation reserve, when invested at compound interest, will accumulate to the difference between the initial cost and the salvage value at the end of the end of the useful life of the equipment.

Annual sinking fund depreciation reserve

$$= [\text{Initial cost - Salvage value}] \text{ x } \left[\frac{r}{(1+r)^n - 1}\right]$$

Where r is the interest rate and n is the number of year. The sinking fund method is illustrated in figure below.



Example

A steam station is erected at a cost of Rs. 2 x10^8. Assuming a salvage value of 15%, a useful life of 25 years and interest rate 8%, find the annual depreciation reserve

(a) by straight line method

(b) by sinking fund method

Solution

(a) Annual straight line depreciation reserve

$$= \text{Rs. } \frac{2x10^8(1-0.15)}{25} = \text{Rs. } 6.8 \times 10^6 \text{ per year}$$

(b) Annual sinking fund depreciation reserve

$$= \text{Rs. } [\,2 \times 10^8\,(1\text{-}0.15)]\left[\frac{0.08}{(1.08)^{25}-1}\right] = \text{s. } 2.23 \times 10^6 \text{ per year}$$

Fixed Percentage Method

In this method the depreciation reserve during any year is a fixed percentage (say x)of the remaining balance of initial investment minus total accumulated depreciation at the beginning of the year. This method is also known as declining balance method.

Let C be the initial investment and n year be the life of the equipment.

The remaining balance at the end of n years will be equal to salvage value S. Thus

$$C\left(1-\frac{x}{100}\right)^n = S$$

Here C,S and n are known and hence x can be found.

Example

A power plant has an initial cost of Rs. 2 x 10^8. Assuming a salvage value of 15 % and useful life of 25 years, *(a) find rate of depreciation by fixed percentage method.*

(b) Also find accumulated depreciation at the end of 10^{th} year.

Solution

C = Rs. 2×10^8, n = 25 years, S = Rs. $2 \times 10^8 \times 0.15$

(a) Using above eq.

$$2 \times 10^8 \left(1 - \frac{x}{100}\right)^{25} = 2 \times 10^8 \times 0.15$$

Therefore

$$1 - \frac{x}{100} = (0.15)^{1/25} = 0.92 \quad \text{or} \quad x = 7.3\ \%$$

(b) Remaining balance at the end of 10^{th} year = $2 \times 10^8 \left(1 - \frac{7.3}{100}\right)$ = Rs.0.937×10^8

Accumulated depreciation at the end of 10^{th} year

= Rs.2×10^8 - Rs.0.937×10^8 = Rs. 1.063×10^8

EFFECT OF LOAD FACTOR ON UNIT ENERGY COST

The unit cost of energy generated by a power plant depends quite substantially on the load factor. The fixed costs remain constant irrespective of the load factor. Thus at low load factors the fixed costs are shared by a smaller number of units of energy resulting in a relatively higher unit energy cost. At high load factors, the same fixed costs are shared by a large number of units of energy thereby reducing the unit energy cost. At 100 % load factor, the installed capacity is used to the maximum extent, maximum energy is generated and the unit energy cost is minimum. As load factor decreases, the unit energy cost increases, the effect becoming more pronounced as load factor becomes too low.

Example

Determine the generation cost per unit of energy from the following plant data:

Installed capacity = 120 MW

Capacity cost of plant = Rs.10000 per kW

Interest and depreciation = 15 %

Fuel consumption = 0.64 kg/kWh

Fuel cost = Rs.500 per 1000 kg

Salaries, wages, repairs and other operating costs per annum = Rs.10,000,000

Peak load = 100 MW

Load factor = 60 %

Solution

Average load = 100 x 0.6 = 60 MW

Energy generated = 60 x 1000 x 8760 = 5256 x 10^5 kW-hr

Total Investment = 120 x 10^3 x 10000 = Rs.1200 x 10^6

Interest and depreciation = Rs.1200 x 10^6 x $\frac{15}{100}$ = Rs.180 x 10^6 per year

Fuel consumption = 0.64 x 5256 x 10^5 kg/year = 363.84 x 10^4 kg per year

Fuel cost = Rs.363.84 x 10^4 x $\frac{500}{1000}$ per year = Rs.18.192 x 10^6 per year

Salaries, wages etc. = Rs. 10 x 10^6 per year

Annual plant cost = Rs. 35819.2 x 10^4 per year

Generation cost = Rs. $\frac{35819.2x10^4}{5256x10^5}$ = Rs.068 per unit.

Example

A region has a maximum demand of 500 MW at a load factor of 50%. The load duration curve can be assumed to be a triangle. The utility has to meet this load by setting up a generating system which is partly hydro and partly thermal. The costs are as under:

Hydro plant :Rs.3600 per kW per annum + operating expenses Rs.0.18 per kW

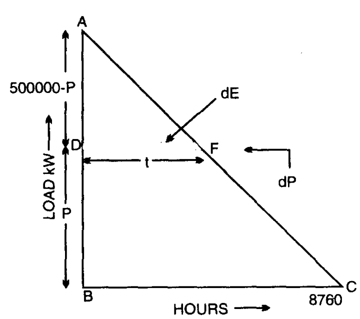
Thermal plant: Rs.1800 per kW annum + operating expenses Rs.0.78 per kWh

Determine the capacity of hydro plant, capacity of thermal plant, energy generated annually by each and overall generation cost per kWh.

Solution

Total energy generated per year = 500 x 1000 x 0.5 x 8760 = 219 x 10^7 kWh

The load duration curve is shown in figure. Since operating cost of hydro plant is low, the base load should be supplied by the hydro plant and peak load by the thermal plant.



Let the hydro capacity be P kW and the energy generated by hydro plant be E kWh/year.

Thermal capacity = (500000 - P) kW

Thermal energy = (219×10^7 - E) kWh

APC_h i.e. Annual cost of hydro plant = 3600 P + 0.18 E

APC_t i.e. Annual cost of thermal plant = 1800 (500000 - P) + 0.78 (219×10^7 - E)

Total cost C = 3600 P + 0.18 E + 1800 (500000 - P) + 0.78 (19×0^7 - E)

For minimum cost

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

$$\frac{dC}{dP} = 0 = 3600 + 0.18\frac{dE}{dP} - 1800 - 0.78\frac{dE}{dP}$$

which gives dE = 3000 dP

From fig. dE = dP x t $\therefore$ t = 3000 hours

From triangle ADF and ABC $\frac{500000 - P}{500000} = \frac{3000}{8760}$

$\therefore$ P = 500000 - $\frac{3000}{8760}$ x 500000 = 38767 kW, say 330 MW

Capacity of thermal plant = 170 MW

Energy generated by thermal plant = $\frac{170x3000x1000}{2}$ = 255×10^6 kWh

Energy generated by hydro plant = 1935×10^6 kWh

Total annual cost = Rs.2041.20×10^6 per year

Overall generation cost (OGC) = $\frac{2041.20x10^6}{219x10^7}$ x 100 = 93.2 paisa/kWh

Problem

A region has a maximum demand of 500 MW at a load factor of 50%. The load duration curve can be assumed to be a triangle. The utility has to meet this load by setting up a generating system, which is partly hydro and partly thermal. The costs are as under

Hydro plant: Rs. 600 per kW per annum and operating expanses at 3 p per kWh.

Thermal plant: Rs. 300 per kW per annum and operating expanses at 13 p per kWh.

Determine the capacity of hydro plant, the energy generated annually by each, and overall generation cost per kWh.

Answer: 330 MW, 1935 x 10^6 kWh (hydro plant), 255 x 10^6 kWh (thermal plant), 15.53 paise/kWh

FIXED AND OPERATING COST OF STEAM PLANTS

The capital cost of a steam plant includes the cost of land, design specifications, installation, power house building, equipment, installation, testing, commissioning, etc. The annual fixed costs include the interest on the capital cost, depreciation, taxes, insurance and fixed managerial and general maintenance cost.

The operating cost of steam plant includes the cost (including coal and ash handling), oil, water, stores, repair, maintenance, salaries and wages of operating staff etc. The effect of cost of coal on the total cost of steam power is quite considerable. A change in fuel cost by 25 % may cause around 10% change in the total cost per kWh of steam energy.

FIXED AND OPERATING COST OF HYDRO PLANTS

The capital cost of a hydro plant includes the cost of preliminary survey, detailed survey, dam, earthwork, highways, bridges, excavation, railhead, other civil engineering works, compensation to land owners whose lands would be submerged in the reservoir, power house substructure and superstructure, design, specifications, equipment, installation, testing, commissioning etc. The capital cost is very much affected by topographical and geological conditions. The annual fixed costs include the interest on the capital cost, depreciation, taxes, insurance and fixed managerial and general maintenance.

The operation costs o hydro plants include salaries and wages of operating and maintenance staff and supplies. Because of the absence of fuel cost, the operating cost of a hydro plant is very small.

TARIFFS

Flat Rate Tariff

The flat demand rate can be expressed in the form, $A = cx$ i.e. the bill depends only on the maximum demand irrespective of the amount of energy consumed.

This is the earliest form of tariff and the bill in those days was based on the total number of lamps installed in the premises. Now-a-days the use of this tariff is restricted to sign lighting, signal system, street lighting etc. where the number of hours are fixed and energy consumption can be easily predicted. Its use is very common for supplies to irrigation tube wells since the number of hours for which the tube well feeders are switched on are fixed. The charge is made according to the horse power of the motor installed. The cost of metering equipment and meter reading is eliminated by the use of this form of tariff.

The advantage of such a tariff is that 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 etc. 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. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

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.

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

This tariff, also known as two part tariff, can be expressed in the form

$$A = cx + dy$$

Thus the total bill includes a demand charge based on the maximum demand plus a charge based on energy consumed. The factors *e* and *d* may be constant or may vary as per sliding scale. This tariff is used for industrial customers. This tariff introduces the problem of measuring the maximum power demand of the customers. This maximum demand can either be taken as a certain fraction of the connected load or measured by a maximum demand meter. It is usual to specify a minimum demand that must be paid for.

Advantages

- It is easily understood by the consumers.
- It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages

- The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.
- There is always error in assessing the maximum demand of the consumer.

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 :

- **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.
- **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 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.

Example

A factory to be set up is to have a fixed load of 760 kW at 0.8 p.f. The electricity board offers to supply energy at the following alternate rates:

(a) LV supply at Rs. 32/kVA max demand/annum + 10 paise/kWh

(b) HV supply at Rs. 30/kVA max demand/annum + 10 paise/kWh

The HV switchgear costs Rs. 60/kVA and switchgear losses at full load amount to 5 %. Interest, depreciation charges for the switchgear are 12% of the capital cost. If the factory is to work for 48 hours/week, determine the more economical tariff.

Solution

Maximum demand = 760/0.8 = 950 kVA

Loss in switchgear = 5%

∴ Input demand = 950/0.95 = 1000 kVA

Cost of switchgear = 60 x 1000 = Rs. 60,000

Annual charges on depreciation = 0.12 x 60, 000 = Rs. 7200

Annual fixed charges due to maximum demand corresponding to tariff (b)

= 30 x 1000 = Rs. 30,000

Annual running charges due to kWh consumed

= 1000 x 0.8 x 48 x 52 x 0.10 = Rs. 199680

Total charges/annum = Rs. 236880

Max. demand corresponding to tariff (a) = 950 kVA

Annual fixed charges = 32 x 950 = Rs. 30,400

Annual running charges for kWh consumed

= 950 x 0.8 x 48 x 52 x 0.10 = Rs. 189696

Total = Rs. 220096

Therefore tariff (a) is economical.

ASSIGNMENT

Q.1. (AMIE W06, 8 marks): Write short note on (i) load curve (ii) base load (iii) peak load

Q.2. (AMIE S09, 11, W11, 12 marks): Define each of the following and their effect on cost of electricity (i) load factor (ii) diversity factor (iii) demand factor (iv) plant use factor.

Q.3. (AMIE W07, 11, 6 marks): What do you understand by load curve? What are the information conveyed by load curve?

Q. 4.(AMIE W08, S11, 6 marks): Explain (i) chronological load curve (ii) load duration curve (iii) energy load curve

Q.5. (AMIE S05, 6 marks): Discuss the important points to be taken into consideration while selecting the size and number of units from load duration curve.

Q.6. (AMIE W06, 9 marks): Define the following terms in generation of electrical energy (i) connected load (ii) maximum load (iii) demand factor

Q. 7.(AMIE S07, 10, 6 marks): Explain different methods of "load forecasting" and mention advantage of forecasting the load.

Q. 8.(AMIE S07, 6 marks): Explain how you would find the economic loading of base and peak load stations for a given load duration curve.

Q.9. (AMIE W06, 09, 5 marks): What do you understand by tariff? Discuss the objective of tariff.

Q. 10.(AMIE W08, 10, 11, S09, 10, 11, 6 marks): What is tariff? Explain with suitable examples (i) flat rate tariff (ii) block rate tariff (iii) two part tariff (iv) power factor tariff

Q.11. (AMIE S10, 12 marks): Discuss the conditions, with reasonings under which electric generation by (i) hydropower station (ii) thermal power station (iii) diesel power station (iv) nuclear power station become economical? Which one of them would be recommended for base load and peak load operation.

Q.12. (AMIE W10, 10 marks): What do you understand by "peak load plant" and "base load plant"? Which of the following plants are suitable for use as base load plants? Give reasons for your answers. (i) run off river plants (ii) storage hydro plant (iii) pumped storage plant (iv) steam power plant (v) nuclear power plant.

Q. 13.(AMIE W06, 6 marks): A generating station has a connected load of 43 MW and a maximum demand of 20 MW; the units generated being 61.5 x 10^6 kW per annum. Calculate:

(i) demand factor

(ii) load factor

Answer: 0.465, 35.1%

Q. 14.(AMIE S08, 10 marks): A generating station has a maximum demand of 80 MW and a connected load of 150 MW. If MWhr generated in a year are 400 x 10^3, calculate (i) load factor (ii) demand factor.

Answer: 57%, 53.3%

Q.15. (AMIE W09, 12 marks): The maximum demand of a power plant is 40 MW. The capacity factor is 0.5 and utilisation factor is 0.8. Find (i) load factor (ii) plant capacity (iii) reserve capacity (iv) reserve capacity (v) annual energy production.

Answer: 0.5, 25 MW, 15 MW, 480 MWh

Q.16. (AMIE W11, 6 marks): If the maximum load demand of a thermal plant is 150 MW, with a load factor of 75% and plant capacity factor 60%, plant use factor 75%, then determine the (i) daily energy produced (ii) installed capacity of the plant (iii) minimum energy that could be produced daily, if the plant is running at full load.

Answer: 2700 kWh, 4500 x 10^3 kWh, 3375 kWh

Q. 17.(AMIE W06, 8 marks): The monthly readings of a consumer's meter are as follows:

maximum demand = 50 kW

Energy consumed = 36, 000 kWh

Reactive power = 23, 400 kVAR

If the tariff is Rs. 80 per kW of maximum demand plus 8 paise per unit plus 0.5 paise per unit for each 1% of power factor below 0.86, calculate the monthly bill of the consumer.

Answer: Rs. 7332/-

Q. 18.(AMIE S07, 8 marks): A hydroelectric station has to operate with a mean head of 30 m and is supplied from a reservoir, which drains a catchment area of 250 km^2 over which the average rainfall is 125 cm per annum. If 70% of the rainfall can be utilised and the expected load factor for the station is 80%, calculate the power (in kW) for which the station should be designed. The head loss in pipes, penstocks, etc. can be neglected. Take the mechanical efficiency of turbines as 90% and the efficiency of generators as 95%.

Answer: 2965 H.P.

Q. 19.(AMIE S07, 8 marks): The capital cost of a power station having maximum demand of 125 MW and load factor of 50%, is Rs. 0.80/kW per annum with 5 paise per kWh transmitted. The annual capital charges for transmission and distribution systems are Rs. 2.5 x 10^6 and Rs. 2 x 10^6 respectively and the respective diversity factors are 1.3 and 1.5. The efficiency of transmission and distribution system is 90% and 80% respectively. Determine the annual cost per kW demand and cost/kWh supplied, at (i) substation (ii) consumer premises.

Answer: (i) Rs. 20.8, 5 paise (ii) Rs. 24.533, 6.94 paise

Q. 20.(AMIE W08, 8 marks): The yearly duration curve of a certain plant can be considered as a straight line from 140 MW to 30 MW. Power is supplied with one generating unit of 95 MW capacity and two units of 45 MW capacity each. Determine (i) installed capacity (ii) load factor (iii) plant capacity factor (iv) maximum demand (v) utilization factor.

Answer: 185 MW, 0.60, 0.46, 140 MW, 0.46

Q.21. (AMIE W10, 10 marks): The motor of a 30 hp condensate pump has got burnt beyond economical repairs. Two alternatives have been proposed to replace it:

Motor A cost = Rs. 1,50,000; efficiency at full load = 90 % and at half load = 86 %.

Motor B cost = Rs. 1,00,000; efficiency at full load = 85 % and at half load = 82%.

The life of each is 20 years and its salvage value is 10% of the initial cost. The rate of interest is 5% annually. The motor operates at full load for 25 % of the time and at half load for the remaining period. The annual maintenance cost for motor A is Ks. 10,500 and that of motor B is Rs. 6000. The energy rate is Rs. 2.50 per kWh. Which motor will you recommend and why?

Answer: Motor A, annual charges of A = Rs. 100125.00, of B = 119600.00

Q.22. (AMIE W11, 10 marks): The capital cost of a hydro power station of 120 MW capacity is Rs. 3000 per kW. The annual depreciation charges are 15% of the capital cost. A royalty of Rs. 15 per kW per year and Re. 0.10 per kWh generated is to be paid for using the river water for generation of power. The maximum demand on the power station is 85 MW and annual load factor is 60%. Annual cost of salaries, maintenance charges, etc. is Rs. 20,00,000. If 25% of this expense is also chargeable as fixed charges, calculate the generation cost in two part form.

Q.23. (AMIE W11, 10 marks): How does the steady state change in speed vary with change in load demand in an isolated power system? Two generators, rated 100 MW and 200 MW, are operating in parallel. The drop characteristics of the governors are 4% and 5% , respectively from no load of full load. Assuming that the generators are operating at 50 Hz at no load, how would a load of 300 MW be shared by them ? What will be the system frequency at this load ? Assume free governor operation.