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CHAPTER 50

TARIFFS AND ECONOMIC CONSIDERATIONS

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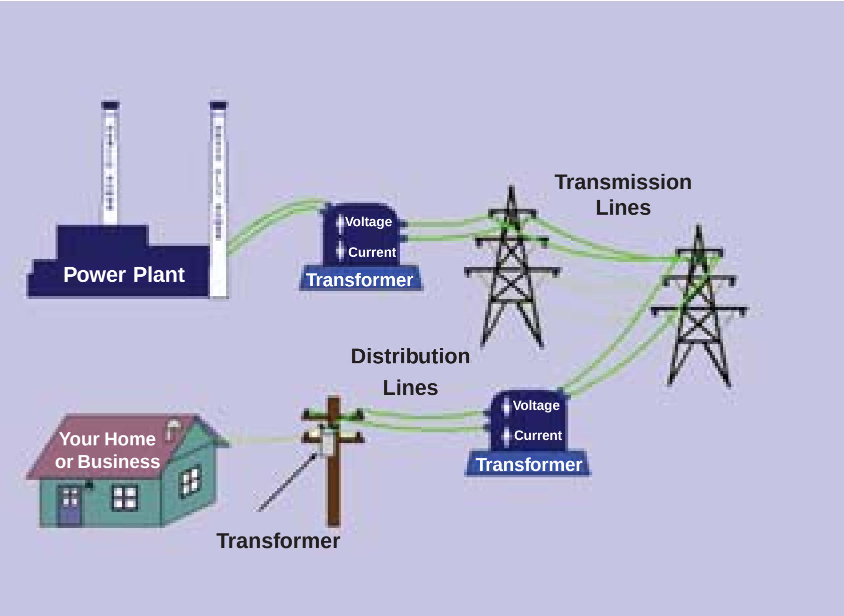

For the successful running of an electricity production, transmission and distribution system, it is necessary to properly account for the various direct and indirect costs involved, before fixing the final kWh charges for the consumers

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50.1. Economic Motive

In all engineering projects with the exception of the construction of works of art or memorial buildings, the question of cost is of first importance. In fact, in most cases the cost decides whether a project will be undertaken or not although political and other considerations may intervene sometimes. However, the design and construction of an electric power system is undertaken for the purpose of producing electric power to be sold at a profit. Hence, every effort is made to produce the power as cheaply as possible. The problem of calculating the cost of any scheme is often difficult because the cost varies considerably with time, tariffs and even with convention. In general, the cost of producing electric power can be roughly devided into the following two portions :

(*a*) Fixed Cost. These do not vary with the operation of the plant *i.e.* these are independent of the number of units of electric energy produced and mainly consist of :

1. Interest on capital investment,

2. Allowance for depreciation (*i.e.* wearing out of the depreciable parts of the plant augmented by obsolescence, buildings, the transmission and distribution system etc.),

3. Taxes and insurance, **4.** most of the salaries and wages, **5.** small portion of the fuel cost.

(*b*) Running or Operating Costs. These vary with the operation of the plant *i.e.* these are proportional to the number of units of electric energy generated and are mostly made up of :

1. most of the fuel cost, **2.** small portion of salaries and wages, **3.** repair and maintenance.

50.2. Depreciation

It is obvious that from the very day the construction of a generating plant is completed, deterioration starts and due to wear and tear from use and the age and physical decay from lapse of time, there results a reduction in the value of the plant — a loss of some part of the capital investment in the perishable property. The rate of wear and disintegration is dependent upon **(*i*)** conditions under which the plant or apparatus is working, **(*ii*)** how it is protected from elements and **(*iii*)** how promptly the required repairs are carried out.

Hence, as the property decreases from its original cost when installed, to its final scrap or salvage value at the end of its useful life, it is essential that the owner will have in hand at any given time as much money as represents the shrinkage in value and at the time of actual retirement of the plant, he must certainly have in hand the full sum of the depreciable part of the property. By adding this amount to the net salvage value of the plant, the owner can rebuild the same type of property as he did in the first instance or he can build some other property of an equivalent earning capacity.

The useful life of the apparatus ends when its repair becomes so frequent and expensive that it is found cheaper to retire the equipment and replace it by a new one.

It may be pointed out here that in addition to depreciation from wear and tear mentioned above, there can also be depreciation of the apparatus due to the inadequacy from obsolescence, both sentimental and economic, from the requirements of the regulating authorities and from accidental damages and if any of these factors become operative, they may force the actual retirement of the apparatus much before the end of its normal useful life and so shorten the period during which its depreciation expenses can be collected. These factors will necessitate increased depreciation rate and the consequent build up of the depreciation reserve as to be adequate for the actual retirement.

Some of the important methods of providing for depreciation are :

1. Straight-line method, **2.** Diminishing-value method,

3. Retirement-expense method, **4.** Sinking-fund method.

In the straight-line method, provision is made for setting aside each year an equal proportional part of the depreciable cost based on the useful life of the property. Suppose a machine costs

Rs. 45,000 and its useful life is estimated as ten years with a scrap value of Rs. 5,000, then the annual depreciation value will be 1/10 of Rs. 40,000 *i.e.* Rs. 4000. This method is extremely simple and easy to apply when the only causes for retirement of the machine are the wear and tear or the slow action of elements. But it is extremely difficult to estimate when obsolescence or accidental damage may occur to the machine. This method ignores the amount of interest earned on the amount set aside yearly.

In the diminishing value method, provision is made for setting aside each year a fixed rate, first applied to the original cost and then to the diminishing value; such rate being based upon the estimated useful life of the apparatus. This method leads to heaviest charges for depreciation in early years when maintenance charges are lowest and so evens out the total expense on the apparatus for depreciation plus the maintenance over its total useful life. This method has the serious disadvantage of imposing an extremely heavy burden on the early years of a new plant which has as yet to develop its load and build up its income as it goes along.

The retirement expense method which is not based on the estimated life of the property, aims at creating an adequate reserve to take care of retirement before such retirements actually occurs. Because of many objections raised against this method, it is no longer used now.

In the sinking-fund method, provision is made for setting aside each year such a sum as, invested at certain interest rate compounded annually, will equal the amount of depreciable property at the end of its useful life. As compared to straight-line method, it requires smaller annual amounts and also the amounts for annuity are uniform. This method would be discussed in detail in this chapter.

Suppose P is the capital outlay required for an installation and r p.a. is the interest per unit (6% is equivalent to $r = 0.06$). The installation should obviously provide rP as annual interest which is added to its annual running cost. Were the installation to last forever, then this would have been the only charge to be made. But as the useful life of the installation has a definite value, it is necessary to provide a sinking fund to produce sufficient amount at the end of the estimated useful life to replace the installation by a new one. Let the cost of replacement be denoted by Q. This Q will be equal to P if the used installation has zero scrap value, less than P if it has positive scrap value and greater than P if it has a negative scrap value. If the useful life is n years, then the problem is to find the annual charge q to provide a sinking fund which will make available an amount Q at the end of n years. Since amount q will earn an annual interest rq, hence its value after one year becomes $q + rq = q(1 + r)$. This sum will earn an interest of $r \times q(1 + r)$ and hence its value at the end of two years will become $q(1 + r) + qr(1 + r)$ or $q(1 + r)^2$. Similarly, its value at the end of three years is $q(1 + r)^3$. *i.e.* its value is multiplied by $(1 + r)$ every year so that the first payment becomes worth $q(1 + r)^n$ at the end of n years. The second payment to the sinking-fund is made at the beginning of the second year, hence its value at the end of the useful life of the installation becomes $q(1 + r)^{n-1}$ because this amount earns interest only for $(n - 1)$ years. The total sum available at the end of n years is therefore

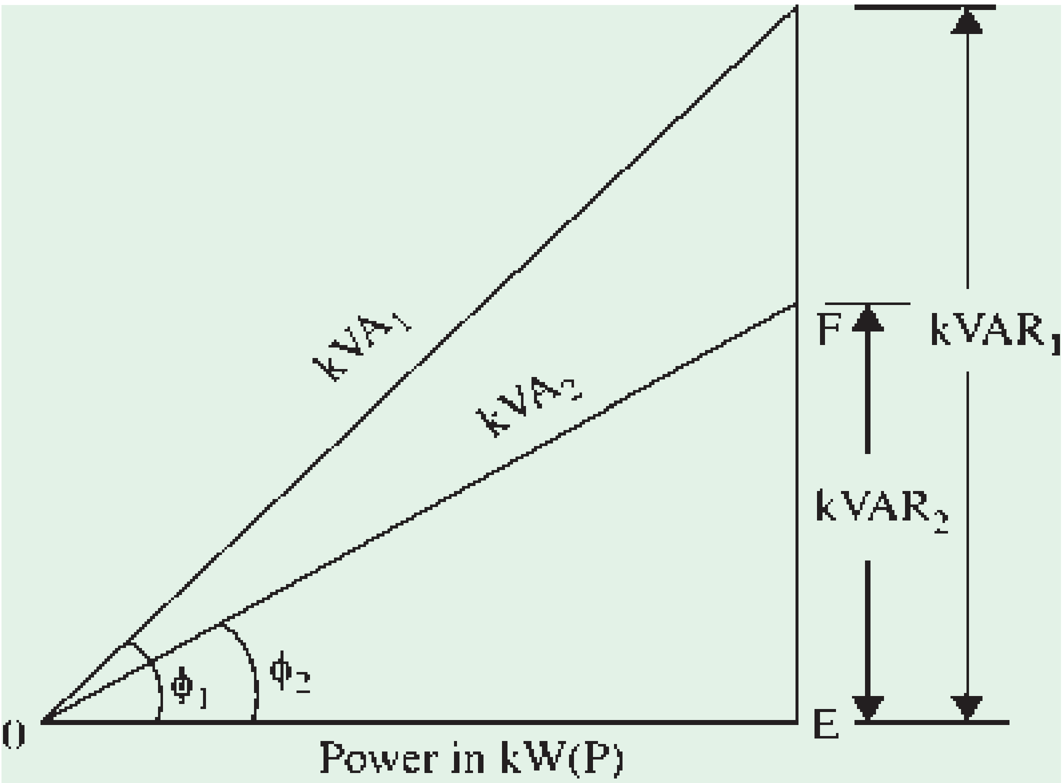
$$= q(1 + r)^n + q(1 + r)^{n-1} + \ldots\ldots\ldots\ldots q(1 + r)^2 + q(1 + r)$$

$$= q\,\frac{(1+r)^{n+1} - (1+r)}{(1+r) - 1} = q\,\frac{1+r}{r}[(1+r)^n - 1]$$

This sum must, obviously, be equal to the cost of renewal Q.

$$\therefore \qquad Q = q\,[(1 + r)^n - 1] \text{ or } q = Q\,\frac{r}{1+r} \div [(1 + r)^n - 1]$$

Hence, the total annual charge on the installation is $(rP + q)$ *i.e.* the plant should bring in so much money every year.



An overview of a combined cycle power plant

50.3. Indian Currency

The basic unit of Indian currency is rupee (Re). Its plural form is rupees (Rs.) One rupee contain 100 paisa. Higher multiples of rupees in common use are :

1 lakh (or lac) = Rs. 100,000 = Rs. 10^5 = Rs. 0.1 million
1 crore = 100 lakh = Rs. 10^7 = Rs. 10 million

Example 50.1. *Find the total annual charge on an installation costing Rs. 500,000 to buy and install, the estimated life being 30 years and negligible scrap value. Interest is 4% compounded annually.*

Solution. Since scrap value is negligible, $Q = P$. Now Q = Rs. 500,000; $r = 0.04$, $n = 30$ years.

$$\therefore \qquad q = 500{,}000 \times \frac{0.04}{1.04} \div [1.04^{30} - 1] = \frac{500{,}000 \times 0.04}{1.04 \times 2.236} = 8{,}600$$

Hence, the total annual charge on the installation is

$$= rP + q = (0.04 \times 500{,}000) + 8{,}600 = \textbf{Rs. 28,600}$$

Example 50.2. *A power plant having initial cost of Rs. 2.5 lakhs has an estimated salvage value of Rs. 30,000 at the end of its useful life of 20 years. What will be the annual deposit necessary if it is calculated by :*

(i) straight-line depreciation method. (ii) sinking-fund method with compound interest at 7%.

(Electrical Engineering-III, Poona Univ.)

Solution. Here, $Q = P$ – scrap value = Rs. 250,000 – Rs. 30,000 = Rs. 220,000

$r = 0.07, n = 20$

(*i*) Total depreciation of 20 years = Rs. 220,000

$\therefore$ annual depreciation = Rs. 220,000/20 = Rs. 11,300.

$\therefore$ annual deposit = $rP + q = 0.07 \times 250,000 + 11,000 =$ **Rs. 28,500**

(*ii*) $$q = Q\frac{r}{r+1} \div [(1+r)^n - 1]$$

$= $ Rs. 220,000 [1.0720 – 1] = Rs. 5015.

Annual deposit = $0.07 \times 250,000 + 5015 =$ **Rs. 22,515**

Example 50.3. *A plant initially costing Rs. 5 lakhs has an estimated salvage value of Rs. 1 lakh at the end of its useful life of 20 years. What will be its valuation half-way through its life **(a)** on the basis of straight-line depreciation and **(b)** on the sinking-fund basis at 8% compounded annually?*

Solution. (*a*) In this method, depreciation is directly proportional to time.

Total depreciation in 20 years = Rs. (5 – 1) = Rs. 4 lakhs

$\therefore$ depreciation in 10 years = Rs. 4/2 = Rs. 2 lakhs

$\therefore$ its value after 10 years = (5 – 2) = **Rs. 3 lakhs.**

(*b*) Now, $Q = 5 - 1 =$ Rs. 4 lakhs ; $r = 0.08, n = 20$

The annual charge is $$q = Q\frac{r}{r+1} \div [(1+r)^n - 1]$$

$$\therefore \quad q = 4 \times 10^5 \times \frac{0.08}{1.08}[1.08^{20} - 1] = \text{Rs. } 8095$$

At the end of 10 years, the amount deposited in the sinking fund would become

$$= q\frac{1+r}{r}[(1+r)^n - 1] = 8095 \times \frac{1.08}{0.08} \times (1.08^{10} - 1) = \text{Rs. } 126{,}647$$

$\therefore$ value at the end of 10 years = Rs. 500,000 – Rs. 126,647

= Rs. 373,353 = **Rs. 3.73353 lakhs.**

50.4. Factors Influencing Costs and Tariffs of Electric Supply

In the succeeding paragraphs we will discuss some of the factors which determine the cost of

Automation of electricity production, transmission and distribution helps in the effective cost management generating electric energy and hence the rates or tariffs of charging for this energy. The cost is composed of ***(i) standing charges which are independent of the output*** **and** ***(ii) running or operating charges which are proportional to the output.*** The size or capacity of the generating plant and hence the necessary capital investment is determined by the maximum demand imposed on the generating plant.

50.5. Demand

By '***demand***' of a system is meant its load requirement (usually in kW or kVA) averaged over a suitable and specified *interval* of time of short duration.

It should be noted that since '***demand***' means the load averaged over an ***interval*** of time, there is no such thing as ***instantaneous*** demand.

50.6 Average Demand

By ***average*** demand of an installation is meant its average power requirement during some specified period of time of considerable duration such as a day or month or year giving us daily or monthly or yearly average power respectively.

Obviously, the average power demand of an installation during a specific period can be obtained by dividing the energy consumption of the installation in kWh by the number of hours in the period.

In this way, we get the arithmetical average.

$$\text{Average power} = \frac{\text{kWh consumed in the period}}{\text{hours in the period}}$$

50.7. Maximum Demand

The maximum demand of an installation is defined as the greatest of all the demands which have occurred during a given period.

It is measured, according to specifications, over a prescribed time interval during a certain period such as a day, a month or a year.

It should be clearly understood that it is not the greatest instantaneous demand but the greatest average power demand occuring during any of the relatively short intervals of 1-minute, 15-minute or 30 minute duration within that period.

In Fig. 50.1 is shown the graph of an imaginary load extending over a period of 5 hours. The maximum demand on 30 min. interval basis occurs during the interval *AB i.e.* from 8-30 p.m to 9-00 p.m. Its value as calculated in Fig. 50.1 is 288 kW. A close inspection of the figure shows that average load is greater during the 30 min. interval *AB* than it is during any other 30-min interval during this period of 5 hours. The average load over 30-min. interval *AB* is obtained first by scaling kW instantaneous demands at five equidistant points between ordinates *AC* and *BD* and then by taking arithmetic average of these values as shown. Hence, 30 min. maximum demand from the above load graph is 288 kW.

It may be noted that the above method of averaging can be made to yield more accurate results by ***(i)*** considering a large number of ordinates and ***(ii)*** by scaling the ordinates more precisely.

It may also be noted that if the maximum demand were to be based on a 15 min. interval, then it will occur during the 15-min. interval *MN* and its value will be 342 kW as shown in Fig. 50.1. It is seen that not only has the position of maximum demand changed but its value has also changed. The 30-min. maximum demand has lesser value than 15-min. max. demand. In the present case, 1-min. max. demand will have still greater value and will occur somewhere near point *M*.

From the above discussion, it should be clear that the unqualified term "maximum demand" is indefinite and has no specific meaning. For example, a statement that "maximum demand is 150 kW" carries no specific meaning. To render any statement of maximum demand meaningful, it is necessary

(i) to indicate the *period* of load duration under consideration and ***(ii)*** to specify the ***time interval*** used *i.e.* 15-min. or 30-min. etc. and also ***(iii)*** the method used for averaging the demand during that interval.

Now, let us see why it is the *average maximum demand* over a definite *interval* of time that is of interest rather than the *instantaneous maximum demand*.

Maximum demand determinations are mostly used for estimating the capacity (and hence cost) of the generator and other electrical apparatus required for serving a certain specific load.

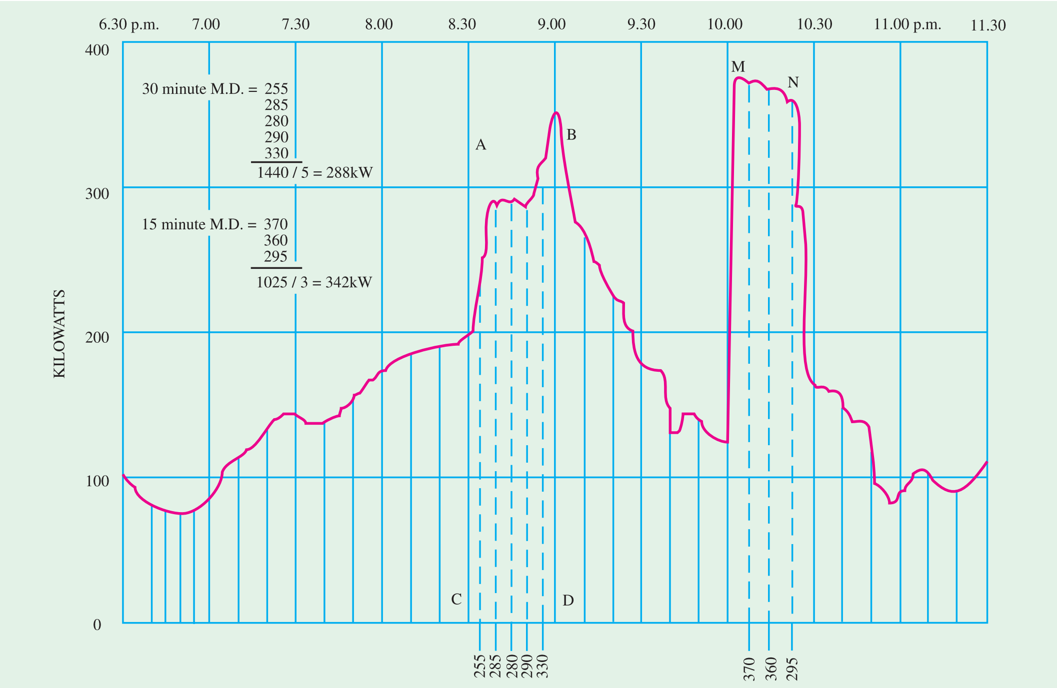


Fig. 50.1

The one main reason why maximam demand values are important is because of the direct bearing they have in establishing the capacity of the generating equipment or indirectly, the initial investment required for serving the consumers. The amount of this investment will have a further effect on fixing of rates for electric service. Since all electric machines have ample overload capacity *i.e.* they are capable of taking 100% or more overloads for short periods without any permanent adverse effects, it is not logical or economically desirable to base the continuous capacity requirements of generators on instantaneous maximum loads which will be imposed on them only momentarily or for very short periods.

Consider the graph of the power load (Fig. 50.2) to be impressed on a certain generator. Let it be required to find the rating of a generator capable of supplying this load. It is seen that there are peak loads of short durations at point *A*, *B*, *C* and *D* of values 250, 330, 230 and 260 kW. However, during the interval *EF* a demand of 210 kW persists for more than half an hour. Hence, in this particular case, the capacity of the generator required, as based on 30-min. maximum demand, should be 210 kW, it being of course, assumed that 4-hour load conditions graphed in Fig. 50.2 are typical of the conditions which exist during any similar period of generator's operation.

In the end, it may be remarked that the exact time interval for maximum demand determinations, over which the greatest demand is averaged varies not only with the characteristics of the load but with the policy of the firm measuring the load. However, 15-min. interval is now most generally used, peak load of shorter durations being considered as temporary overloads.

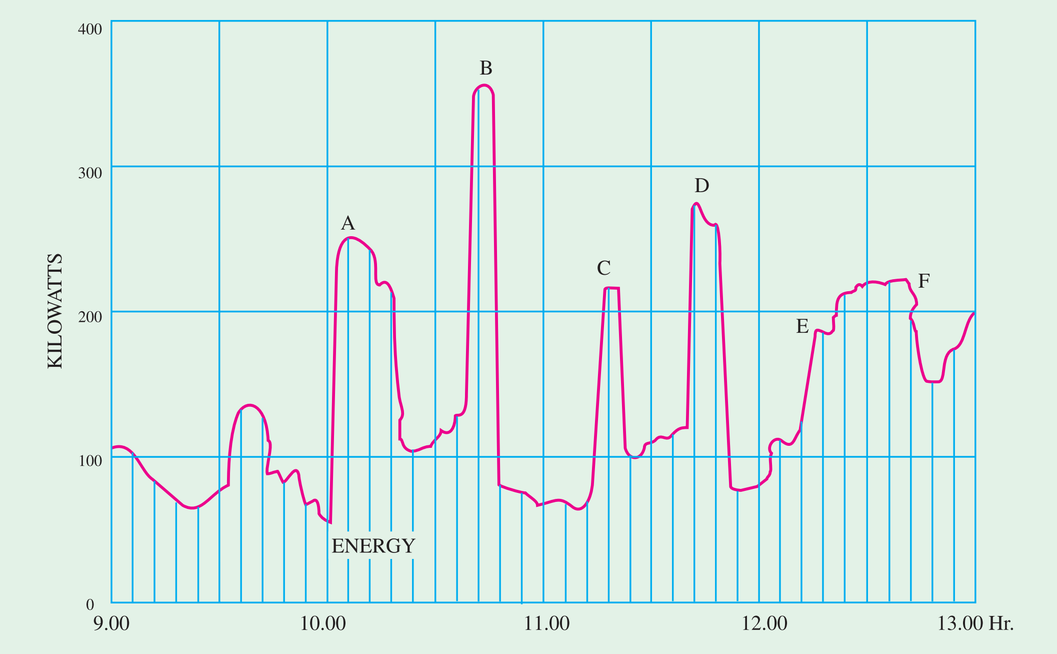


Fig. 50.2

50.8. Demand Factor

Demand factors are used for estimating the proportion of the total connected load which will come on the power plant at one time. It is defined as the ***ratio of actual maximum demand made by the load to the rating of the connected load.***

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

The idea of a demand factor was introduced because of the fact that normally the kW or kVA maximum demand of a group of electrical devices or 'receivers' is always less than the sum of the kW or kVa ratings or capacities of these receivers. There are two reasons for the existence of this condition ***(i)*** the electrical apparatus is usually selected of capacity somewhat greater than that actually required in order to provide some reserve or overload capacity and ***(ii)*** in a group of electrical devices it very rarely happens that all devices will, at the same time, impose their maximum demands which each can impose *i.e.* rarely will all 'receivers' be running full-load simultaneously.

The demand factor of an installation can be determined if ***(i)*** maximum demand and ***(ii)*** connected load are known.

Maximum demand can be determined as discussed in Art. 50.7 whereas connected load can be calculated by adding together the name-plate ratings of all the electrical devices in the installation. The value of demand factor is always less than unity.

Demand factors are generally used for determining the capacity and hence cost of the power equipment required to serve a given load. And because of their influence on the required investment, they become important factors in computing rate schedules.

As an example, suppose a residence has the following connected load : three 60-W lamps; ten 40-W lamps; four 100-W lamps and five 10-W lamps. Let us assume that the demand meter indicates a 30-min. maximum demand of 650 W. The demand factor can be found as follows :

Connected load $= (3 \times 60) + (10 \times 40) + (4 \times 100) + (5 \times 10) = 1{,}030$ W

30-min. max.demand $= 650$ W

Hence, the demand factor of this lighting installation is given as

$$= \frac{\text{max. demand}}{\text{connected load}} = \frac{650}{1.030} = \mathbf{0.631 \text{ or } 63.1\%}$$

Demand factors of lighting installations are usually fairly constant because lighting loads are not subject to such sudden and pronounced variations as like power loads.

50.9. Diversity of Demand

In central-station parlance, diversity of demand implies that maximum demands of various consumers belonging to different classes and the various circuit elements in a distribution system are not coincident. In other words, the maximum demands of various consumers occur at different times during the day and not simultaneously. It will be shown later that from the economic angle, it is extremely fortunate that there exists a diversity or non-simultaneity of maximum demand of various consumers which results in lower costs of electric energy.

For example, residence lighting load is maximum in the evening whereas manufacturing establishments require their maximum power during daytime hours. Similarly, certain commercial establishments like department stores usually use more power in day-time than in the evening whereas some other stores like drug stores etc. use more power in the evening.

The economic significance of the concept of diversity of demand can only be appreciated if one considers the increase in the capacity of the generating and distributing plant (and hence the corresponding increase in investment) that would be necessary, if the maximum demands of all the consumers occurred simultaneously. It is of great concern to the engineer because he has to take it into consideration while planning his generating and distributing plant. Also diversity is an important element in fixing the rates of electric service. If it were not for the fact that the coincident maximum demand imposed on a certain station is much less than the sum of maximum demands of all the consumers fed by that station, the investment required for providing the electric service would have been far in excess of that required at present. Because of the necessity of increase in investment, that cost of electric supply would also have been increased accordingly.

50.10. Diversity Factor

The non-coincidence of the maximum demands of various consumers is taken into consideration in the so-called diversity factor which is defined as the ratio of the sum of the individual maximum demands of the different elements of a load during a specified period to the simultaneous (or coincident) maximum demand of all these elements of load during the same peirod.

$$\text{Diversity factor}^{*} = \frac{\text{maximum demand}}{\text{connected load}}$$

Its value is usually much greater than unity. It is clear that if all the loads in a group impose their maximum demands simultaneously, then diversity factor is equal to unity. High value of diversity factor means that more consumers can be supplied for a given station maximum demand and so lower prices can be offered to consumers. Usually domestic load gives higher value of diversity factor than industrial load. As shown in Fig. 50.3, suppose that the maximum demands of six elements of a load as observed from their maximum demand meters M_1 and M_2 etc. are 620 W, 504 W, 435 W, 380 W, 160 W and 595 W respectively.

* Sometimes, the diversity factor is given by certain authors as the reciprocal of the value so obtained.

Also, suppose that the (coincident) maximum demand of the whole group as observed by the maximum demand meter *MT* is only 900 W. It is so because the maximum demands of all load elements did not occur simultaneously.

Sum of individual maximum demands

$$= 620 + 504 + 435 + 380 + 160 + 595 = 2694 \text{ W} = 2.694 \text{ kW}$$

$\therefore$ diversity factor $= 2.694/0.9 =$ **2.99**

It may be noted here that because of the diversity of demand, the maximum demand on a transformer is less than the sum of the maximum demands of the consumers supplied by that transformer. Further, the maximum demand imposed on a feeder is less than the sum of the maximum demands of transformers connected to that feeder. Similarly, the maximum demand imposed on the generating station is less than the sum of the maximum demands of all the feeders suplied station is less than the sum of the maximum demands of all the feeders supplied from the station. The effective demand of a consumer on a generator is given as follows :

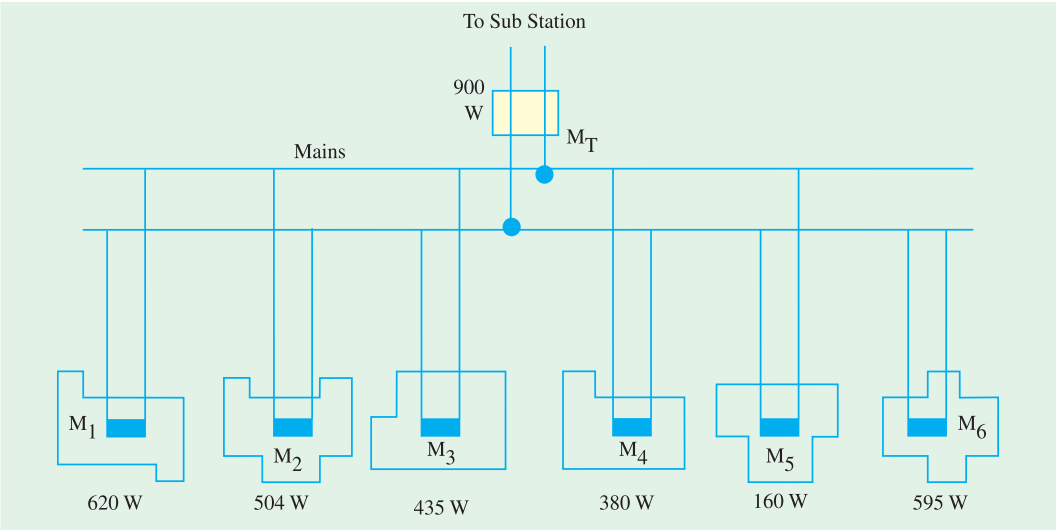


Fig. 50.3

Multiply this connected load by demand factor and then divide the product by diversity factor for consumer to generator.

As an example, let us find the total diversity factor for a residence lighting system whose component diversity factors are : between consumers 2.6 ; between transformers 1.32 ; between feeders 1.13 and between sub-stations 1.1. The total diversity factor between the consumers and the generating equipment would be the product of these component factors *i.e.*

$$= 2.6 \times 1.32 \times 1.13 \times 1.1 = 4.266$$

The factor may now be used in determining the effective demand of consumers on the generator.

It may be proved that generating equipment can be economized by grouping on one supply source different elements of load having high diversity factor. In fact, the percentage of the generating equipment which can be eliminated is equal to 100 percent minus the reciprocal of diversity factor expressed as a percentage. Suppose four loads of maximum demand 120, 360, 200 and 520 kVA respectively are to be supplied. If each of these loads were supplied by a separate transformer, then aggregate transformer capacity required would be = 120 + 360 + 200 + 520 = 1200 kVA. Suppose these loads had a diversity factor of 2.5 among themselves, then (coincident) maximum demand of the whole group would be 1200/2.5 = 480 kVA.

In other words, a single 480 kVA transformer can serve the combined load. The saving = 1200 – 480 = 720 kVA which expressed as a percentage is 720 × 100/1200 = 60%. Now, reciprocal of diversity factor = 1/2.5 = 0.4 or 40 %. The percentage saving in the required apparatus is also = 100 – 40 = 60% which proves the statement made above.

50.11. Load Factor

It is defined ***as the ratio of the average power to the maximum demand***.

It is necessary that in each case the time interval over which the maximum demand is based and the ***period**** over which the power is averaged must be definitely specified.

If, for example, the maximum demand is based on a 30-min. interval and the power is averged over a month, then it is known as 'half-hour monthly' load factor.

Load factors are usually expressed as percentages. The average power may be either generated or consumed depending on whether the load factor is required for generating equipment or receiving equipment.

When applied to a generating station, annual load factor is

$$= \frac{\text{No. of units actually supplied/year}}{\text{Max. possible No. of units that can be supplied}}$$

It may be noted that *maximum* in this definition means the value of the maximum peak load and *not the maximum* kW *installed capacity of the plant equipment of the station.*

$$\therefore \quad \text{annual load factor} = \frac{\text{No. of units actually supplied/year}}{\text{Max. possible demand} \times 8760}$$

$$\text{Monthly load factor} = \frac{\text{No. of units actually supplied/month}}{\text{Max. possible demand} \times 24 \times 30}$$

When applied to a consuming equipment

$$\text{annual load factor} = \frac{\text{No. of units consumed/year}}{\text{Max. demand} \times 8760}$$

$$\text{monthly load factor} = \frac{\text{No. of units consumed/month}}{\text{Max. demand} \times 24 \times 30}$$

$$\text{Daily load factor} = \frac{\text{No. of units consumed/day}}{\text{Max. demand} \times 24}$$

$$\text{In general, load factor} = \frac{\text{Average power}}{\text{Max. demand}} \text{ per year or per month or per day}$$

The value of maximum demand can be found by using a maximum demand meter set for 30-min. or 15-min. interval as already explained in Art. 50.7. The average power can also be found either by graphic method explained below or by using a planimeter.

In the graphic method, momentary powers are scaled or read from the load-graph at the end of a number of suitable and equal time intervals over the entire time comprehended by the graph. Then these are added up. Average power is obtained by dividing this sum by the number of periods into which the total time was apportioned.

* If not specified, it is assumed to be one year of 24 × 365 = 8,760 hours.

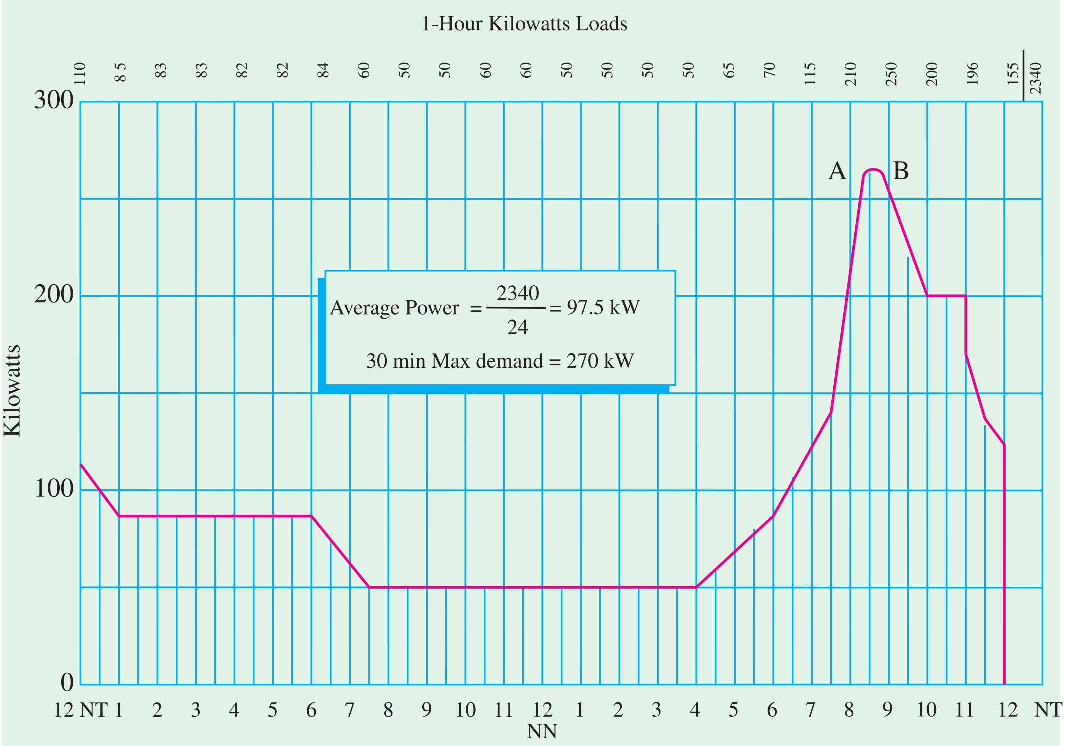


Fig. 50.4

The number of time intervals into which the entire time is apportioned is determined by the contour of the graph and the degree of accuracy required.

The general, the accuracy will increase with the increase in the number of the intervals. For a graph having a smooth contour and comprehending 24 hours, sufficient accuracy can be obtained by taking 1 hour intervals. However, in the case of a graph which has extremely irregular contours and comprehends short time intervals, reasonable accuracy can only be obtained if 15-min. or even 1 min. intervals are used.

As an example, let us find the load factor of a generating equipment whose load graph (imaginary one) is shown in Fig. 50.4. For calculating average power over a period of 24 hours, let us take in view of the regularity of the curve, a time interval of 1 hour as shown. The average power is 97.5 kW. Now, the 30-min. maximum demand is 270 kW and occurs during 30-min. interval of *A B*. Obviously load factor = 97.5 × 100/270 = 36.1%.

50.12. Significance of Load Factor

Load factor is, in fact, an index to the proportion of the whole time a generator plant or system is being worked to its full capacity. The generating equipment has to be selected on the basis of maximum power demand that is likely to be imposed on it. However, because of general nature of things, it seldom happens that a generating equipment has imposed on it during all the 8,760 hrs of a year the maximum load which it can handle. But whether the equipment is being worked to its full capacity or not, there are certain fixed charges (like interest, depreciation, taxes, insurance, part of staff salaries etc.) which are adding up continuously. In other words, the equipment is costing money to its owner whether working or idle. The equipment earns a net profit only during those hours when it is fully loaded and the more it is fully loaded, the more is the profit to the owner. Hence, from the standpoint of economics, it is desirable to keep the equipment loaded for as much time as possible i.e. it is economical to obtain high load factors.

If the load factor is poor *i.e.* kWh of electric energy produced is small, then charge per kWh would obviously be high. But if load factor is high *i.e.* the number of kWh generated is large, then cost of production and hence charge per kWh are reduced because now the standing charges are distributed over a larger number of units of energy.

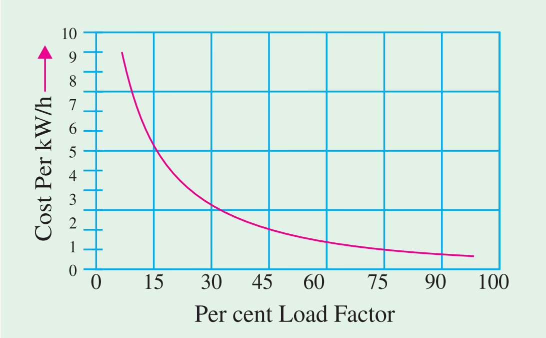


Fig. 50.5

The fact that fixed charges per kWh increase with decreasing load factor and vice versa is brought out in Ex. 50.15 and is graphically shown in Fig. 50.5.

It may be remarked here that increase of diversity in demand increases the load factor almost in direct proportion.

Load factor of a generating plant may be improved by seeking and accepting off-peak loads at reduced rates and by combining lighting, industrial and inter-urban railway loads.

Example 50.4. *A consumer has the following connected load : 10 lamps of 60 W each and two heaters of 1000 W each. His maximum demand is 1500 W. On the average, he uses 8 lamps for 5 hours a day and each heater for 3 hours a day. Find his total load, montly energy consumption and load factor.* **(Power Systems-I, AMIE, Sec. B, 1993)**

Solution. Total connected load = $10 \times 60 + 2 \times 1000$ = **2600 W**.

Daily energy consumption is = $(8 \times 60 \times 5) + (2 \times 1000 \times 3)$ = 8400 Wh = **8.4 kWh**

Monthly energy consumption = 8.4×30 = **252 kWh**

$$\text{Monthly load factor} = \frac{252}{1500 \times 10^{-3} \times 24 \times 30} = \mathbf{0.233 \text{ or } 23.3\ \%}$$

Example 50.5. *The load survey of a small town gives the following categories of expected loads.*

	Type	*Load in kW*	*% D.F.*	*Group D.F.*
1.	*Residential lighting*	*1000*	*60*	*3*
2.	*Commercial lighting*	*300*	*75*	*1.5*
3.	*Street lighting*	*50*	*100*	*1.0*
4.	*Domestic power*	*300*	*50*	*1.5*
5.	*Industrial power*	*1800*	*55*	*1.2*

What should be the kVA capacity of the S/S assuming a station p.f. of 0.8 lagging ?

Solution. (*i*) Residential lighting. Total max. demand = 1000×0.6 = **600 kW**

Max. demand of the group = 600/3 = **200 kW**

(*ii*) Commercial lighting Total max. demand = 300×0.75 = **225 kW**

Max. demand of the group = 225/1.5 = **150 kW**

(*iii*) Street lighting Total max. demand = **50 kW**

Max. demand of the group = 50/1 = **50 kW**

(*iv*) Domestic power Total max. demand = 300×0.5 = **150 kW**

Max. demand of the group = 150/1.5 = **100 kW**

(v) Industrial power Total max. demand $= 1800 \times 0.55 =$ **990 kW**

Max. demand of the group $= 990/1.2 =$ **825 kW**

Total max. demand at the station = 200 + 150 + 50 + 100 + 825 = **1325 kW.**

Capacity of the sub-station required at a p.f. of 0.8 lagging = 1325 / 0.8 = **1656 kVA**

Example 50.6. *A consumer has the following load-schedule for a day :*

From midnight (12 p.m.) to 6 a.m. = 200 W ; From 6 a.m. to 12 noon = 3000 W

From 12 noon to 1 p.m. = 100 W ; From 1 p.m. to 4 p.m. = 4000 W

From 4 p.m. to 9 p.m. = 2000 W ; From 9 p.m. to mid-night (12 p.m.) = 1000 W

Find the load factor.

If the tariff is 50 paisa per kW of max. demand plus 35 paisa per kWh, find the daily bill the consumer has to pay. **(Electrical Engineering-III, Poona Univ.)**

Solution. Energy consumed per day *i.e.* in 24 hours

$= (200 \times 6) + (3000 \times 6) + (100 \times 1) + (4000 \times 3) + (2000 \times 5) + (1000 \times 3) = 44{,}300$ Wh

Average power = 44,300/24 = 1846 W = 1.846 kW

$$\text{Daily load factor} = \frac{\text{average power}}{\text{max. power demand}} = \frac{1846}{4000} = 0.461 \text{ or } \mathbf{46.1\%}$$

Since max. demand = 4 kW M.D. charge $= 4 \times 1/2 =$ Rs. 2/-

Energy consumed = 44.3 kWh Energy charge $=$ Rs. $44.3 \times 35/100 =$ Rs. 15.5/-

$\therefore$ daily bill of the consumer = Rs. 2 + Rs. 15.5 = **Rs. 17.5**

Example 50.7. *A generating station has a connected load of 43,000 kW and a maximum demand of 20,000 kW, the units generated being 61,500,000 for the year. Calculate the load factor and demand factor for this case.*

Solution.
$$\text{Demand factor} = \frac{\text{maximum demand}}{\text{connected load}} = 0.465 \text{ or } \mathbf{46.5\%}$$

Average power = 61,500,000/8,760 = 7020 W ($\because$ 1 year = 8760 hr)

$$\therefore \quad \text{Load factor} = \frac{\text{average power}}{\text{max. power demand}} = \frac{7020}{20{,}000} = 0.351 \text{ or } \mathbf{35.1\%}$$

Example 50.8. *A 100 MW power station delivers 100 MW for 2 hours, 50 MW for 6 hours and is shut down for the rest of each day. It is also shut down for maintenance for 45 days each year. Calculate its annual load factor.* **(Generation and Utilization, Kerala Univ.)**

Solution. The station operates for (365 − 45) = 320 days in a year. Hence, number of MWh supplied in one year $= (100 \times 2 \times 320) + (50 \times 6 \times 320) = 160{,}000$ MWh

Max. No. of MWh which can be supplied per year with a max. demand of 100 MW is

$= 100 \times (320 \times 24) = 768{,}000$ MWh

$$\therefore \quad \text{load factor} = \frac{160{,}000}{760{,}000} \times 100 = \mathbf{20.8\%}$$

Example 50.9. *Differentiate between fixed and running charges in the operation of a power company.*

Calculate the cost per kWh delivered from the generating station whose

(i) *capital cost = Rs.* 10^6, **(ii)** *annual cost of fuel = Rs.* 10^5,

(iii) *wages and taxes = Rs.* 5×10^5, **(iv)** *maximum demand laod = 10,000 kW,*

(v) *rate of interest and depreciation = 10%* **(vi)** *annual load factor = 50%.*

Total number of hours in a year is 8,760. **(Electrical Technology-I, Bombay Univ.)**

Solution. Average power demand = max. load $\times$ load factor = 10,000 $\times$ 0.5 = 5,000 kW

Units supplied/year = 5,000 $\times$ 8,760 = 438 $\times 10^5$ kWh

Annual cost of the fuel plus wages and taxes = Rs. 6 $\times 10^5$

Interest and depreciation charges/year = 10% of Rs. 106 = Rs. 10^5

Total annual charges = Rs. 7 $\times 10^5$; Cost / kWh = Rs. 7 $\times 10^5$/438 $\times 10^5$ = **1.6 paisa**

Example 50.10. *A new colony of 200 houses is being established, with each house having an average connected load of 20 kW. The business centre of the colony will have a total connected load of 200 kW. Find the peak demand of the city sub-station given the following data.*

	Demand factor	*Group D.F.*	*Peak D.F.*
Residential load	*50%*	*3.2*	*1.5*
Business load	*60%*	*1.4*	*1.2*

Solution. The three demand factors are defined as under :

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

$$\text{group D.F.} = \frac{\text{sum of individual max. demands}}{\text{actual max. demand of the group}}$$

$$\text{Peak D.F.} = \frac{\text{max. demand of consumer group}}{\text{demand of consumer group at the time of system peak demand}}$$

Max. demand of each house = 2 $\times$ 0.5 = 1.0 kW

Max. demand of residential consumer = 1 $\times$ 200/3.2 = 62.5 kW

Demand of the residential consumer at the time of the system peak = 62.5 / 1.5 = 41.7 kW

Max. demand of commercial consumer = 200 $\times$ 0.6 = 120 kW

Max. demand of commercial group = 120/1.4 = 85.7 kW

Commercial demand at the time of system peak = 85.7 / 1.2 = 71.4 kW

Total demand of the residential and commercial consumers at the time of system peak

= 41.7 + 71.4 = **113 kW**

Example 50.11. *In Fig. 50.6 is shown the distribution network from main sub-station. There are four feeders connected to each load centre sub-station. The connected loads of different feeders and their maximum demands are as follows :*

Feeder No.	*Connected load, kW*	*Maximum Demand, kW*
1.	*150*	*125*
2.	*150*	*125*
3.	*500*	*350*
4.	*750*	*600*

If the actual demand on each load centre is 1000 kW, what is the diversity factor on the feeders? If load centres B, C and D are similar to A and the diversity factor between different load centres is 1.1, calculate the maximum demand of the main sub-station. What would be the kVA capacity of the transformer required at the main sub-station if the overall p.f. at the main sub-station is 0.8 ?

Solution. Diversity factor of the feeders

$$= \frac{\text{total of max. demand of different feeders}}{\text{simultaneous max. demand}} = \frac{125 + 125 + 350 + 600}{1000} = 1.2$$

Total max. demand of all the 4 load centre sub-stations = 4 × 1000 = **4000 kW**

Diversity factor of load centres = 1.1

Simultaneous max. demand on the main sub-station = 4000/1.1 = 3636 kW

The kVA capacity of the transformer to be used at the sub-station = 3636/0.8 = **4545**

Example 50.12. *If a generating station had a maximum load for the year of 18,000 kW and a load factor of 30.5% and the maximum loads on the sub-stations were 7,500, 5,000, 3,400, 4,600 and 2,800 kW, calculate the units generated for the year and the diversity factor.*

Solution. Load factor $= \dfrac{\text{average power}}{\text{maximum power demand}} \quad \therefore \; 0.305 = \dfrac{\text{average power}}{18{,}000}$

$\therefore$ average power $= 18{,}000 \times 0.305$ kW

kWh generated per year $= 8{,}000 \times 0.305 \times 8.760 =$ **48.09 × 106 kWh**

Sum of individual maximum demands = 7,500 + 5,000 + 3,400 + 4,600 + 2,800 = 23,300

$\therefore$ diversity factor=23,300/18,000 = **1.3 (approx.)**

Example 50.13. *A power station is supplying four regions of load whose peak loads are 10MW, 5 MW, 8 MW and 7 MW. the diversity factor of the load at the station is 1.5 and the average annual load factor is 60%. Calculate the maximum demand on the station and the annual energy supplied from the station. Suggest the installed capacity and the number of units taking all aspects into account.* **(A.M.I.E. Sec. B, Winter 1990)**

Solution. Diversity factor $= \dfrac{\text{sum of individual max. demands}}{\text{max. demands of the whole load}}$

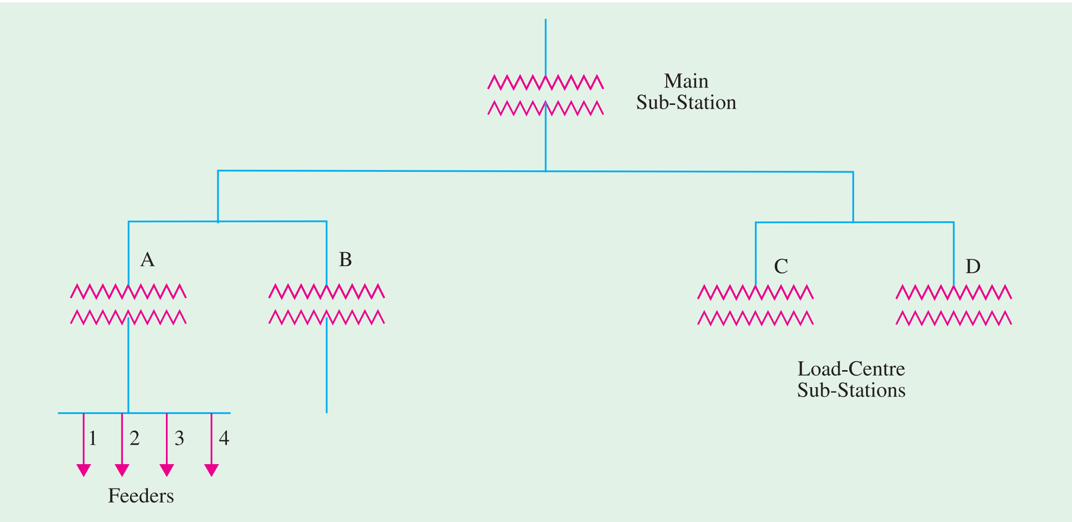


Fig. 50.6

$\therefore$ Max. demand of the whole load imposed on the station = (10 + 5 + 8 + 7)/1.5 = **20 MW**

Now, annual load factor $= \dfrac{\text{No. of units supplied/year}}{\text{Max. demand} \times 8760}$

$\therefore$ No. of units supplied / year $= 0.6 \times 20 \times 10^3 \times 8760 =$ **105.12×10^6 kWh**

Provision for future growth in load may be made by making installed capacity 50% more than the maximum demand of the whole load. Hence, installed capacity is $20 \times 1.5 = 30$ MW. Four generators, two of **10 MW** each and other two of **5 MW** each may be installed.

Example 50.14. *The capital cost of 30 MW generating station is Rs. 15×10^6. The annual expenses incurred on account of fuel, taxes, salaries and maintenance amount to Rs. 1.25×10^6. The station operates at an annual load factor of 35%. Determine the generating cost per unit delivered, assuming rate of interest 5% and rate of depreciation 6%.* **(Electrical Power-I, Bombay Univ.)**

Solution. Average power = max. power × load factor = $30 \times 10^6 \times 0.35$ = 10,500 kW

Units produced/year = $10{,}500 \times 8{,}760 = 91.98 \times 10^6$ kWh; Annual expenses = Rs. 1.25×10^6

Depreciation plus interest = 11% of capital cost = 11% of Rs. 15×10^6 = Rs. 1.65×10^6

Total expenses/year = Rs. 1.25×10^6 + Rs. 1.65×10^6 = Rs. 2.9×10^6

∴ cost/kWh = Rs. $2.9 \times 10^6 / 91.98 \times 10^6$ = **3.15 paisa / kWh.**

Example 50.15. *A generating plant has a maximum capacity of 100 kW and costs Rs.300,000. The fixed charges are 12% consisting of 5% interest, 5% depreciation and 2% taxes etc. Find the fixed charges per kWh generated if load factor is **(i)** 100% and **(ii)** 25%.*

Solution. Annual fixed charges = Rs. 300,000 × 12/100 = Rs. 36,000

With a load factor of 100%, number of kWh generated per year = 100 × 1 × 8,760

= 876,000 kWh.

Similarly, units generated with a load factor of 25% = 100 × 0.25 × 8,760 = 219,000 kWh.

(i) Fixed charge / kWh = 36,000 × 100/876,000 = **4.1 paisa**

(ii) Fixed charge / kWh = 36,000 × 100/219,000 = **16.4 paisa**

As seen, the charge has increased four-fold. In fact, charge varies inversely as the load factor.

Example 50.16. *The annual working cost of a thermal station is represented by the formula Rs. (a + b kW + c kWh) where a, b and c are constants for that particular station, kW is the total installed capacity and kWh is the energy produced per annum.*

*Determine the values of a, b and c for a 100 MW station having annual load factor of 55% and for which **(i)** capital cost of buildings and equipment is Rs. 90 million, **(ii)** the annual cost of fuel, oil, taxation and wages and salaries of operating staff is Rs. 1,20,000, **(iii)** interest and depreciation on buildings and equipment are 10% p.a., **(iv)** annual cost of orginasation, interest on cost of site etc. is Rs. 80,000.*

Solution. In the given formula, *a* represents the fixed cost, *b* semi-fixed cost and *c* the running cost. Here, *a* = **Rs. 80,000**

An overview of a thermal power plant

Now, $b \times$ kW minimum demand = semi-fixed cost

or, $b \times 100 \times 10^3 = 90 \times 10^6 \quad \therefore\ b =$ **900**

Total units generated per annum = kW max. demand $\times$ load factor $\times$ 8760

$= 100 \times 10^3 \times 0.55 \times 8760 = 438 \times 10^6$ kWh

Since running cost is Rs. 1,20,000

$\therefore \quad c \times 438 \times 10^6 = 1{,}20{,}000$ or $c =$ **0.00027**

Example 50.17. *In a steam generating station, the relation between the water evaporated W kg and coal consumed C kg and power in kW generated per 8-hour shift is as follows :*

$$W = 28{,}000 + 5.4 \text{ kWh}; \ C = 6000 + 0.9 \text{ kWh}$$

What would be the limiting value of the water evaporated per kg of coal consumed as the station output increases ? Also, calculate the amount of coal required per hour to keep the station running at no-load.

Solution. For an 8-hour shift, Wt. of water evaporated per kg of coal consumed is

$$\frac{W}{C} = \frac{28{,}000 + 5.4 \text{ kWh}}{6{,}000 + 0.9 \text{ kWh}}$$

As the station output increases, the ratio W/C approaches the value 5.4 / 0.9 = 6

Hence, weight of water evaporated per kg of coal approaches a limiting value of **6 kg** as the station output increases.

Since at no-load, there is no generation of output power, kWh = 0. Substituting this value of kWh in the above ratio we get,

Coal consumption per 8-hour shift = 6000 kg

$\therefore$ coal consumption per hour on no-load $= \dfrac{6000}{8}$ **= 725 kg.**

Example 50.18. *Estimate the generating cost per kWh delivered from a generating station from the following data :*

Plant capacity = 50 MW ; annual load factor = 40%; capital cost = Rs. 3.60 crores; annual cost of wages, taxation etc. = Rs. 4 lakhs; cost of fuel, lubrication, maintenance etc. = 2.0 paise per kWh generated, interest 5% per annum, depreciation 5% per annum of initial value.

(Electrical Technology, M.S. Univ. Baroda)

Solution. Average power over a year = maximum power $\times$ load factor

$= 50 \times 10^6 \times 0.4 = 2 \times 10^7 \text{ W} = 2 \times 10^4$ kW

Units produced/year $= 20{,}000 \times 8{,}760 = 1{,}752 \times 10^5$ kWh

Depreciation plus interest = 10% of initial investment $= 0.1 \times 3.6 \times 10^7$

= **Rs. 3.6 × 10^6**

Annual wages and taxation etc. = Rs. 4 lakhs = Rs. 0.4×10^6

Total cost/year = Rs. $(3.6 + 0.4) \times 10^6$ = Rs. 4×10^6

Cost / kWh $= 4 \times 10^6 \times 100/1{,}752 \times 10^5$ = **2.28 paisa**

Adding the cost of fuel, lubrication and maintenance etc., we get

Cost per kWh delivered = 2.0 + 2.28 = **4.28 paisa.**

Example 50.19. *The following data relate to a 1000 kW thermal station :*

Cost of Plant	=	*Rs. 1,200 per kW*
Interest, insurance and taxes	=	*5% p.a.*
Depreciation	=	*5% p.a.*

Cost of primary distribution system	=	*Rs. 4,00,000*
Interest, insurance, taxes and depreciaton	=	*5% p.a.*
Cost of coal including transportation	=	*Rs. 40 per tonne*
Operating cost	=	*Rs. 4,00,000 p.a.*
Plant maintenance cost : fixed	=	*Rs. 20,000 p.a.*
variable	=	*Rs. 30,000 p.a.*
Installed plant capacity	=	*10,000 kW*
Maximum demand	=	*9,000 kW*
Annual load factor	=	*60%*
Consumption of coal	=	*25,300 tonne*

Find the cost of power generation per kilowatt per year, the cost per kilowatt-hour generated and the total cost of generation per kilowatt-hour. Transmission/primary distribution is chargeable to generation. **(Power Systems-I, AMIE, Sec. B, 1993)**

Solution. Cost of the plant = Rs. 1200 per kW

Fixed cost per annum is as under :

(*i*) on account of capital cost $= (1200 \times 10{,}000) \times 0.1 + 400 \times 103 \times 0.05$

$= \textbf{Rs. } \mathbf{1.22 \times 10^6}$

(*ii*) part of maintenance cost $=$ Rs. $20{,}000 =$ Rs. 0.02×10^6

$\therefore$ total fixed cost $= 1.22 \times 10^6 + 0.02 \times 10^6 =$ **Rs.** $\mathbf{1.24 \times 10^6}$

Running or variable cost per annum is as under : (*i*) operation cost = Rs. 4,00,000, (*ii*) part of maintenance cost = Rs. 30,000,

(*iii*) fuel cost = Rs. $25{,}300 \times 40$ = Rs. 10,12,000

Total cost $= 4{,}00{,}000 + 30{,}000 + 10{,}12{,}000 =$ Rs. 1.442×10^6

$$\text{Load factor} = \frac{\text{average demand}}{\text{maximum demand}} \quad \text{or} \quad 0.6 = \frac{\text{average demand}}{9{,}000 \times 8{,}760}$$

$\therefore$ average demand = **47,305 MWh**

Total cost per annum $= 1.24 \times 10^6 + 1.442 \times 10^6 =$ Rs. 2.682×10^6

Cost per kWh generated $= 2.682 \times 10^6 / 47{,}305 \times 10^3 =$ Rs. $0.0567 =$ **5.7 paisa.**

Since total installed capacity is 10,000 kW, the cost per kW per year

$= 2.682 \times 10^6 / 10{,}000 =$ **Rs. 268.2**

Example 50.20. *A consumer has an annual consumption of 176,400 kWh. The charge is Rs. 120 per kW of maximum demand plus 4 paisa per kWh.*

(i) *Find the annual bill and the overall cost per kWh if the load factor is 36%.*

(ii) *What is the overall cost per kWh, if the consumption were reduced 25% with the same load factor ?*

(iii) *What is the overall cost per kWh, if the load factor is 27% with the same consumption as in (i)* **(Utili. of Elect. Power, AMIE Sec. B)**

Solution. (*i*) Since load factor is 0.36 and there are 8760 hrs in a year,

Annual max. demand $= 176{,}400/0.36 \times 8760 =$ **55.94 kW**

The annual bill will be based on maximum annual demand charges plus the annual energy consumption charge.

$\therefore$ annual bill $=$ Rs. $(55.94 \times 120 + 176{,}400 \times 0.04) =$ **Rs. 13,768**

Overall cost/kWh $=$ Rs. $13{,}768 / 176{,}400 =$ **7.8 paisa.**

(*ii*) In this case, the annual consumption is reduced to $176,400 \times 0.75 = 132,300$ kWh but the load factor remains the same.

$$\text{Annual max. demand} = 132,300/0.36 \times 8760 = 41.95 \text{ kW}$$

$$\therefore \quad \text{annual bill} = \text{Rs. } (41.95 \times 120 + 132,300 \times 0.04) = \textbf{Rs. 10,326}$$

$$\text{Overall cost/kWh} = 10,326/132,300 = \textbf{7.8 paisa}$$

It will be seen that the annual max. demand charge is reduced but the overall cost per kWh remains the same.

(*iii*) Since, load factor has decreased to 0.27,

$$\text{Annual max. demand} = 176,400/0.27 \times 8760 = 74.58 \text{ kW}$$

$$\text{Annual bill} = \text{Rs. } (74.58 \times 120 + 176,400 \times 0.04) = \text{Rs. } 16,006$$

$$\text{Overall cost/kWh} = \text{Rs. } 16,006/176,400 = \textbf{9.1 paisa}$$

Here, it will be seen that due to decrease in load factor, the annual bill as well as cost per kWh have increased.

50.13. Plant Factor or Capacity Factor

This factor relates specifically to a generating plant unlike load factor which may relate either to generating or receiving equipment for the whole station.

It is defined as the ***ratio of the average load to the rated capacity of the power plant i.e. the aggregate rating of the generators***. It is preferable to use continuous rating while calculating the aggregate.

$$\therefore \quad \text{plant factor} = \frac{\text{average load}}{\text{rated capacity of plant}} = \frac{\text{average demand on station}}{\text{max. installed capacity of the station}}$$

It may be of interest to note that if the maximum load corresponds exactly to the plant ratings, then load factor and plant factor will be identical.

50.14. Utilization Factor (or Plant Use Factor)

It is given by the ratio of the kWh generated to the product of the capcity of the plant and the number of hours the plant has been actually used.

$$\text{Utilization factor} = \frac{\text{station output in kWh}}{\text{plant capacity} \times \text{hours of use}}$$

If there are three units in a plant of ratings kW_1, kW_2 and kW_3 and their operation hours are h_1, h_2 and h_3 respectively, then

$$\text{Utilization factor} = \frac{\text{station output in kWH}}{(kW_1 \times h_1) + (kW_2 \times h_2) + (kW_3 \times h_3)}$$

50.15. Connected Load Factor

The factor relates only to the receiving equipment and is defined as the ratio of the average power input to the connected load.

To render the above value specific, it is essential*

(*i*) to define the period during which average is taken and

(*ii*) to state the basis on which the connected load is computed.

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* Wherever feasible, it should be stated on continuous-rating basis. Lighting connected load is taken equal to the sum of the wattages of all lamps in the installation whereas motor connected load is equal to the sum of the name-plate outputs of all motors (and not their input ratings).

$$\text{Connected-load factor} = \frac{\text{average power input}}{\text{connected load}}$$

It can be proved that the connected-load factor of a ***receiving*** equipment is equal to the product of its demand factor and its load factor.

$$\text{Connected-load factor} = \frac{\text{average power input}}{\text{connected load}}$$

$$= \frac{\text{Average power}}{\text{Max. demand}} \times \frac{\text{max demand}}{\text{connected load}} = \text{load factor} \times \text{demand factor}$$

50.16. Load Curves of a Generating Station

The total power requirement of a generating station can be estimated provided variation of load with time is known. Following curves help to acquire this knowledge.

(*i*) Load Curve (or Chronological Curve)

It represents the load in its proper time sequence. As shown in Fig. 50.7 (*a*), this curve is obtained by plotting the station load (in kW) along *Y*-axis and the time when it occurs along *X*-axis. Usually, such curves are plotted for one day *i.e.* for 24 hours by taking average load (kW) on hourly basis. The area under the curve represents the total energy consumed by the load in one day. Following information can be obtained from the load curve :

(*a*) maximum load imposed on the station, **(*b*)** size of the generating unit required and **(*c*)** daily operating schedule of the station.

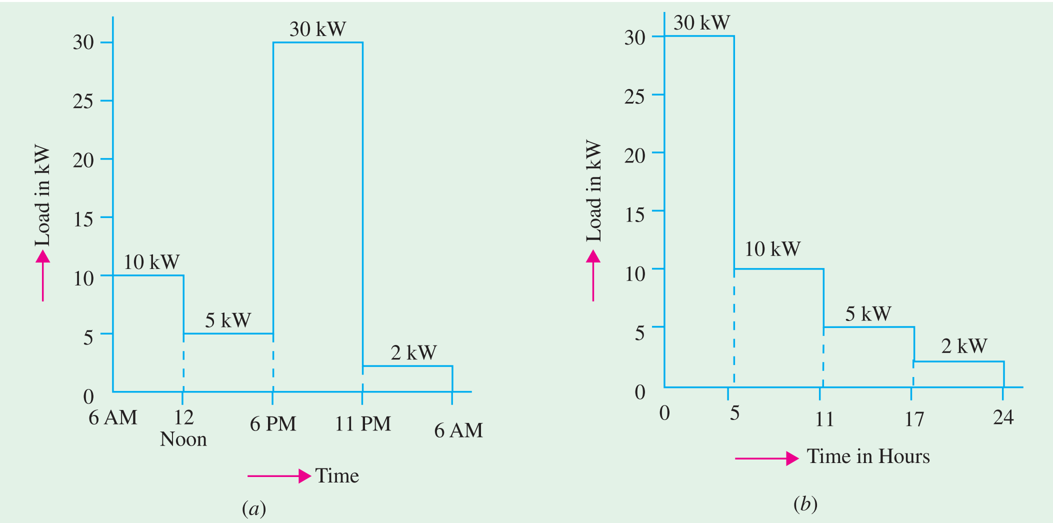


Fig. 50.7

(*ii*) Load Duration Curve

It represents the same data (*i.e.* load *vs* time) but the ordinates are rearranged in magnitude sequence (not time sequence). Here, greatest load is plotted on the left, lesser load towards the right and the least load on the extreme right. In other words, loads are plotted in descending order. As seen from Fig. 50.7 (*a*) maximum load on the station is 30 kW which lasts for 5 hours from 6 p.m. to 11 p.m. It is plotted first in Fig. 50.7 (*b*). The next lower load is 10 kW from 6 a.m. to 12 noon *i.e.* for 6 hours. It has been plotted next to the highest load. The other lesser loads are plotted afterwards. The areas under the load curve and load duration curve are equal and each represents the total units consumed during a day of 24 hours.

(*iii*) Load Energy Curve (or Integrated Load Duration Curve)

It represents the relation between a particular load on the station and the total number of kWhs produced ***at or below this load***. The load in kW is taken along the ordinate (Y-axis) and kWh generated ***upto this load*** along the abscissa (X-axis) as shown in Fig. 50.8. This curve is derived from the load duration curve. For example, for a load of 2 kW, the number of units generated is $2 \times 24 = 48$ kWh. It corresponds to point A on the curve. For a load of 5 kW, the units generated are $= 5 \times 17 + 2 \times 7 = 99$ kWh. It corresponds to point B. For a load of 10 kW, the units generated are $= 10 \times 11 + 5 \times 6 + 2 \times 7 = 154$ kWh (point C). Finally, for a load of 30 kW, the number of units generated is $= 30 \times 5 + 10 \times 6 + 5 \times 6 + 2 \times 7 = 254$ kWh (point D.)

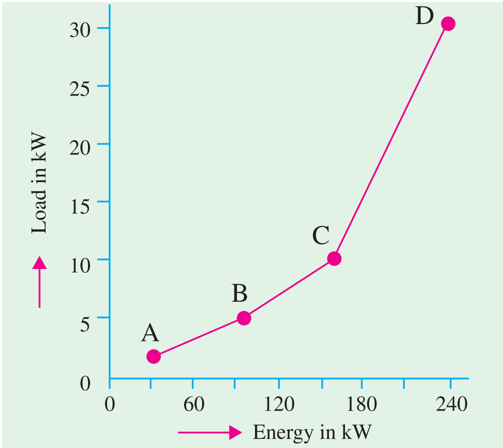


Fig. 50.8

Example 50.21. *A power station has a load cycle as under :*

60 MW for 6 hr; 200 MW for 8 hr ; 160 MW for 4 hr ; 100 MW for 6 hr

If the power station is equipped with 4 sets of 75 MW each, calculate the load factor and the capacity factor from the above data. Calculate the daily fuel requirement if the calorific value of the oil used were 10,000 kcal/kg and the average heat rate of the station were 2,860 kcal/kWh.

(Electric Power Systems-III, Gujarat Univ.)

Solution. Daily load factor $= \dfrac{\text{units actually supplied in a day}}{\text{max. demand} \times 24}$

Now, MWh supplied per day $= (260 \times 6) + (200 \times 8) + (160 \times 4) + (100 \times 6) = 4{,}400$

$\therefore$ station daily load factor $= \dfrac{4{,}440}{260 \times 24} = 0.704$ or **70.4%**

Capacity factor $= \dfrac{\text{average demand on station}}{\text{installed capacity of the station}}$

No. of MWh supplied/day $= 4{,}400$ $\quad \therefore$ average power/day $= 4{,}400/24$ MW

Total installed capacity of the station $= 75 \times 4 = 300$ MW

$\therefore$ capacity factor $= \dfrac{4{,}400/24}{300} = 0.611$ or **61.1%**

Energy supplied/day $= 4{,}400$ MWh $= 44 \times 10^5$ kWh

Heat required/day $= 44 \times 10^5 \times 2{,}860$ kcal

Amount of fuel required/day $= 44 \times 2{,}860 \times 10^5 / 10^5$ kg $=$ **125 tonne.**

Example 50.22. *A generating station has two 50 MW units each running for 8,500 hours in a year and one 30 MW unit running for 1,250 hours in one year. The station output is 650×10^6 kWh per year. Calculate* **(*i*)** *station load factor,* **(*ii*)** *the utilization factor.*

Solution. (*i*) $kW_1 \times h_1 = 50 \times 10^3 \times 8{,}500 = \mathbf{425 \times 10^6}$ **kWh**

(*ii*) $kW_2 \times h_2 = 50 \times 10^3 \times 8{,}500 = \mathbf{425 \times 10^6}$ **kWh**

(*iii*) $kW_3 \times h_3 = 30 \times 10^3 \times 1{,}250 = \mathbf{37.5 \times 10^6}$ **kWh**

$\therefore \quad \Sigma\,(kW) \times h = (2 \times 425 + 37.5) \times 10^6 = \mathbf{887.5 \times 10^6}$ **kWh**

Total installed capacity of the station $= 2 \times 50 + 30 = 130 \times 10^3$ kW

(*i*) Assuming that maximum demand equals installed capacity of the station,

$$\text{annual load factor} = \frac{\text{units generated/year}}{\text{max. demand} \times 8{,}760} = \frac{650 \times 10^6}{130 \times 10^3 \times 8760} = \mathbf{0.636 \text{ or } 63.6\%}$$

Note. In view of the above assumption, this also represents the plant or capacity factor.

(*ii*) $$\text{utilization factor} = \frac{\text{station output in kWh}}{\Sigma(\text{kW}) \times h} = \frac{650 \times 10^6}{887.5 \times 10^6} = \mathbf{0.732 \text{ or } 73.2\%}$$

Example 50.23. *The yearly duration curve of a certain plant may be considered as a straight line from 40,000 kW to 8,000 kW. To meet this load, three turbo-generators, two rated at 20,000 kW each and one at 10,000 kW are installed. Determine* **(a)** *the installed capacity,* **(b)** *plant factor,* **(c)** *maximum demand,* **(d)** *load factor and* **(e)** *utilization factor.* **(Ranchi Univ.)**

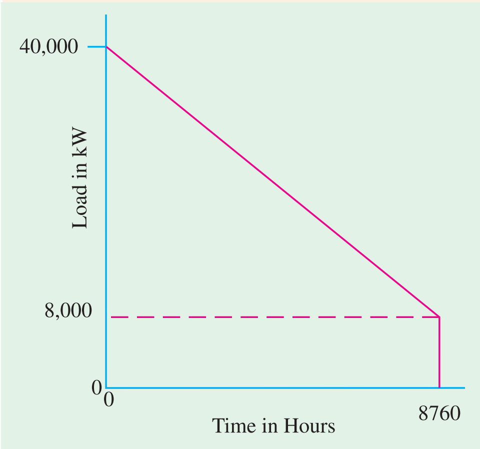


Fig. 50.9

Solution. (*a*) installed capacity

= 20 + 20 + 10 = **50 MW**

(*b*) Average demand on plant = (40,000 + 8,000)/2

= 24,000 kW

plant factor = av. demand / installed capacity

= 24,000/50,000 = **0.48% or 48%**

(*c*) Max. demand, obviously, is **40,000 kW**

(*d*) From load duration curve, total energy generated/year

$= 24{,}000 \times 8760$ kWh $= 21 \times 10^7$ kWh.

Load factor $= 21 \times 10^7 / 40{,}000 \times 8{,}760 =$ **0.6 or 60%**

(*e*) $$\text{u.f.} = \frac{\text{max. demand}}{\text{plant capacity}} \times 100 = \frac{40{,}000}{50{,}000} \times 100 = \mathbf{80\%}$$

Example 50.24. *The load duration curve of a system is as shown in Fig. 50.10. The system is supplied by three stations; a steam station, a run-of-river station and a reservoir hydro-electric station. The ratios of number of units supplied by the three stations are as below :*

Steam	:	*Run of river*	:	*Reservoir*
7	:	*4*	:	*1*

The run-of-river station is capable of generating power continuosly and works as a peak load station. Estimate the maximum demand on each station and also the load factor of each station. **(Ranchi Univ.)**

Solution. Here 100% time will be taken as 8760 hours.

Total units generated = area under the curve

$$= \frac{1}{2}(160 + 80) \times 10^3 \times 8760 = 1051.2 \times 10^6 \text{ kWh}$$

From the given ratio, the number of units supplied by each station can be calculated

Units Generated

Run-of-river-station $= 1051.2 \times 10^6 \times 4/12 = 350.4 \times 10^6$ kWh

Steam station $= 1051.2 \times 10^6 \times 7/12 = 613.2 \times 10^6$ kWh

Reservoir HE station $= 1051.2 \times 10^6 \times 1/12 = 87.6 \times 10^6$ kWh

Max. demand of *ROR* station $= 350.4 \times 10^6 / 8760 =$ **40 MW**

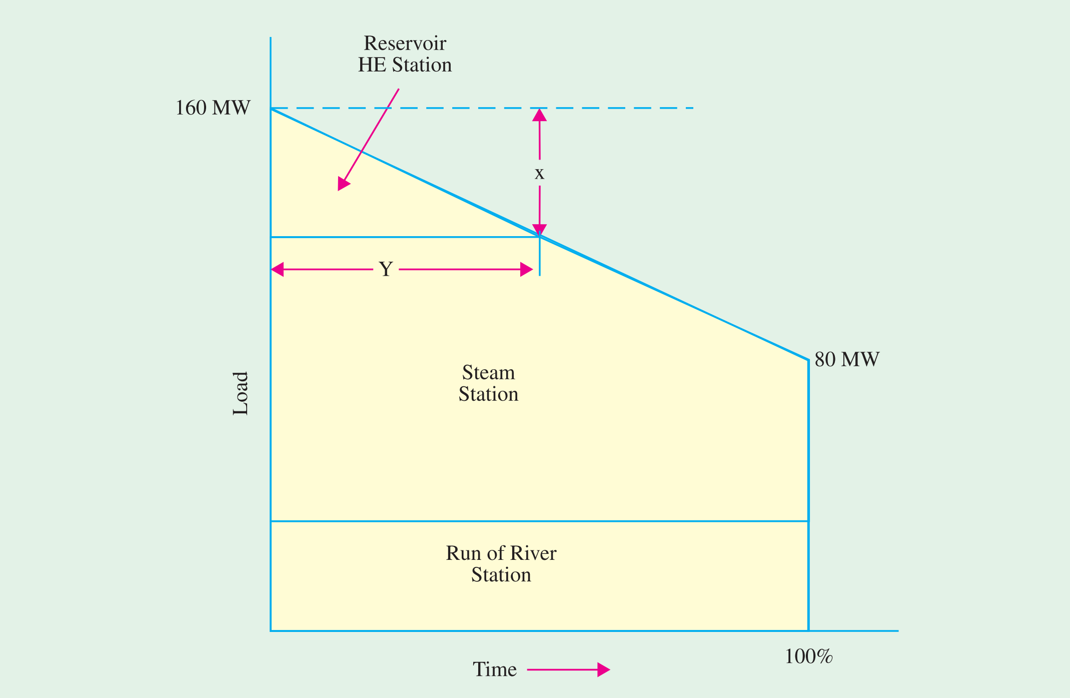


Fig. 50.10

Let x MW be the maximum demand of the reservoir plant. As shown in Fig. 50.10. let it operate for y hours.

Obviously, $y = \frac{x}{80} \times 8760$

Area under the curve for reservoir station = $\frac{1}{2} xy \times 10^3$ kWh

$$= \frac{1}{2} x \times \frac{x}{80} \times 8760 \times 10^3 = 54,750\, x^2$$

$\therefore$ $54,750\, x^2 = 87.6 \times 10^6$; x = **40 MW**

$\therefore$ max. demand of steam station= 160 – (40 + 40) = **80 MW.**

Load factor

Since ROR station works continuously as a base load station, its load factor is **100%.**

Reservoir station $= 87.6 \times 10^6 / 40 \times 10^3 \times 8760$ = **0.25 or 25%**

Steam station $= 613.2 \times 10^6 / 80 \times 10^3 \times 8760$ = **0.875 or 87.5%.**

Example 47.25. *A load having a maximum value of 150 MW can be supplied by either a hydro-electric plant or a steam power plant. The costs are as follows :*

Capital cost of steam plant = Rs. 700 per kW installed

Capital cost of hydro-electric plant = Rs. 1,600 per kW installed

Operating cost of steam plant = Rs. 0.03 per kWh

Operating cost of hydro-electric plant = Rs. 0.006 per kWh

Interest on capital cost 8 per cent. Calculate the minimum load factor above which the hydro-electric plant will be more economical.

Solution. Let x be the total number of units generated per annum.

Steam Plant

Capital cost = Rs. $700 \times 150 \times 10^3$ = **Rs. 10.5×10^7**

Interest charges = 8% of Rs. 10.5×10^7 = **Rs. 8.4×10^6**

$\therefore$ fixed cost/unit = Rs. $8.4 \times 10^6 / x$; operating cost / unit = **Re. 0.03**

$\therefore$ total cost/unit generated = **Rs. $(8.4 \times 10^4 / x + 0.03)$**

Hydro Plant

Capital cost = Rs. $1600 \times 150 \times 10^3$ = **Rs. 24×10^7**

Interest charges = 8% of Rs. 24×10^7 = **Rs. 19.2×10^6**

Total cost/unit = **Rs. $(19.2 \times 10^6 / x + 0.006)$**

The two overall costs will be equal when

$$(8.4 \times 10^6 / x) + 0.03 = (19.2 \times 10^6 / x) + 0.006 \; ; \; x = 45 \times 10^7 \text{ kWh}$$

Obviously, if units generated are more than 45×10^7 kWh, hydro-electric station will be cheaper.

Load factor = $45 \times 10^7 / 150 \times 10^3 \times 8760$ = **0.342 or 34.2%**

This represents the minimum load factor beyond which hydro-electric station would be economical.

Example 50.26. *A power system having maximum demand of 100 MW has a load 30% and is to be supplied by either of the following schemes :*

(a) a steam station in conjunction with a hydro-electric station, the latter supplying 100×10^6 units per annum with a max. output of 40 MW,

(b) a steam station capable of supply the whole load,

(c) a hydro station capable of supplying the whole load,

Compare the overall cost per unit generated assuming the following data :

	Steam	*Hydro*
Capital cost / kW	*Rs. 1,250*	*Rs. 2,500*
Interest and depreciation on the capital cost	*12%*	*10%*
Operating cost/kWh	*5 paise*	*1.5 paise*
Transmission cost/kWh	*Negligible*	*0.2 paise*

Show how overall cost would be affected in case (ii) and (iii) above if the system load factor were improved to 90 per cent. **(Elect. Power System-III, Gujarat Univ.)**

Solution. Average power = $100 \times 0.3 = 30$ MW = 3×10^4 kW

Units generated in one year = $3 \times 10^4 \times 8{,}760 = 262.8 \times 10^6$ kWh

(*a*) Steam Station in Conjunction with Hydro Station

Units supplied by hydro-station = **100×10^6 kWh**

Units supplied by steam station = $(262.8 - 100) \times 10^6$ = **162.8×10^6 kWh**

Since, maximum output of hydro-station is 40 MW, the balance (100 – 40) = 60 MW is supplied by the steam station.

(*i*) Steam Station

Capital cost = Rs. $60 \times 10^3 \times 1{,}250$ = **Rs. 75×10^6**

Annual interest and depreciation - Rs. $0.12 \times 75 \times 10^6$ = **Rs. 9×10^6**

Operating cost = Rs. $0.5 \times 162.8 \times 10^6/100$ = **Rs. 8.14×10^6**

Transmission cost = negligible

Total annual cost = Rs. $(9 + 8.14) \times 10^6$ = **Rs. 17.14×10^6**

(ii) Hydro Station

Capital cost $= \text{Rs. } 40 \times 10^3 \times 2{,}500 = \text{Rs. } 100 \times 10^6$

Annual interest and depreciation $= \text{Rs. } 0.1 \times 100 \times 10^6 = \text{Rs. } 10 \times 10^6$

Operating cost $= \text{Rs. } 0.15 \times 100 \times 10^6/100 = \text{Rs. } 1.5 \times 10^6$

Transmission cost $= \text{Rs. } .02 \times 100 \times 10^6 / 100 = \text{Rs. } 0.2 \times 10^6$

Total annual cost $= \text{Rs. } (10 + 1.5 + 1.2) \times 10^6 = \text{Rs. } 11.7 \times 10^6$

Combined annual charge for steam and hydro stations

$= \text{Rs. } (17.14 + 11.7) \times 10^6 = \text{Rs. } 28.84 \times 10^6$

$\therefore$ Overall cost/kWh $= \text{Rs. } \dfrac{28.84 \times 10^6}{262.8 \times 10^6} =$ **10.97 paise**

(b) Steam Station Alone

Capital cost $= \text{Rs. } 1{,}250 \times 100 \times 10^3 = \text{Rs. } 125 \times 10^6$

Annual interest and depreciation $= \text{Rs. } 0.12 \times 125 \times 10^6 = \text{Rs. } 15 \times 10^6$

$\therefore$ fixed charge / unit $= \text{Rs. } 15 \times 10^6/262.8 \times 10^6 = 5.71$ paise

Operating cost/unit = 5 paisa ; Transmission cost / unit = 0

$\therefore$ overall cost per unit = (5.71 + 5) = **10.71 paise**

(c) Hydro Station Alone

Annual interest and depreciation on capital cost

$= \text{Rs. } 0.1\ (2{,}500 \times 100 \times 10^3) = \text{Rs. } 25 \times 10^6$

$\therefore$ fixed charge / unit $= \text{Rs. } 25 \times 10^6 / 262.8 \times 10^6 = 9.51$ paise

Operating cost/unit = 1.5 paisa ; Transmission cost/unit = 0.2 paise

$\therefore$ overall cost/unit = (9.51 + 1.5 + 0.2) = **11.21 paise**

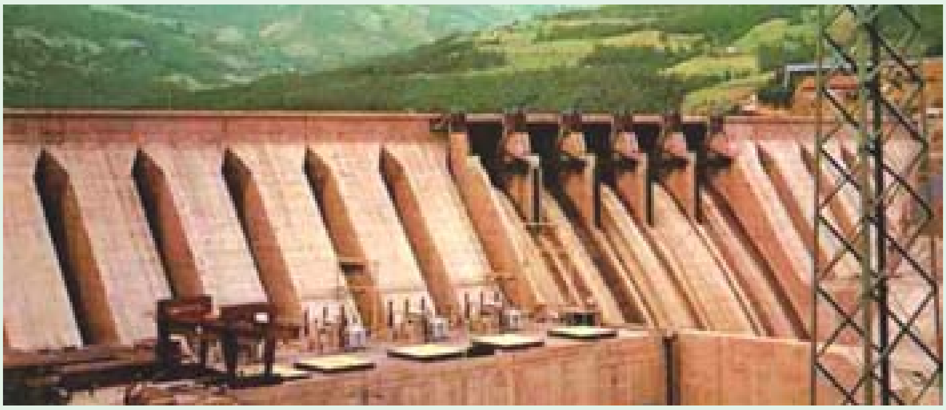
(d) (i) Steam Station

Since number of units generated will increase three-fold, fixed charge per unit will decrease to one-third of its previous value *i.e.* to 5.71/3 = 1.9 paisa. Since other charges are unaffected by change in load factor.

$\therefore$ Overall cost/unit = (1.9 + 5) = **6.9 paise**

(ii) Hydro Station

For same reasons, fixed cost per unit becomes 9.51/3 = 3.17 paise Overall cost/unit = (3.17 + 1.5 + 0.2) = **4.87 paise**



An overview of a hydroelectric plant

Example 50.27. *The capital cost of a hydro-power station of 50,000 kW capacity is Rs. 1,200 per kW. The annual charge on investment including depreciation etc. is 10%. A royality of Rs. 1 per kW per year and Rs. 0.01 per kWh generated is to be paid for using the river water for generation of power. The maximum demand is 40,000 kW and the yearly load factor is 80%. Salaries, maintenance charges and supplies etc. total Rs. 6,50,000. If 20% of this expense is also chargeable as fixed charges, determine the generation cost in the form of A per kW plus B per kWh.*

(A.M.I.E. Sec. B,)

Solution. Capital cost of station $= \text{Rs. } 1200 \times 50{,}000 = \text{Rs. } 6 \times 10^7$

Annual charge on investment including depreciaiton

$= 10\% \text{ of Rs. } 6 \times 10^7 = \text{Rs. } 6 \times 10^6$

Total running charges $= 80\% \text{ of Rs. } 6{,}50{,}000 = \text{Rs. } 5{,}20{,}000$

Fixed charges $= 20\% \text{ of Rs. } 6{,}50{,}000 = \text{Rs. } 1{,}30{,}000$

Total annual fixed charges $= \text{Rs. } 6 \times 10^6 + \text{Rs. } 0.13 \times 10^6 = \text{Rs. } 6.13 \times 10^6$

Cost per M.D. kW due to fixed charges $= \text{Rs. } 6.13 \times 10^6 / 40{,}000 = \text{Rs. } 153.25$

Cost per M.D. kW due to royalty $= \text{Rs. } 1$

Total cost per M.D. kW $= \text{Rs. } 154.25$

Total No. of units generated per annum $= 40{,}000 \times 0.8 \times 8760 = 28 \times 10^7 \text{ kWh}$

Cost per unit due to running charges $= \text{Rs. } 5{,}20{,}000 / 28 \times 10^7 = 0.18 \text{ p}$

Royalty cost/unit $= 1 \text{ p}$

$\therefore$ total cost/unit $= 1.18 \text{ p}$

$\therefore$ generation cost $= \text{Rs. } 154.25 \text{ kWh} + 1.18 \text{ p kWh}$

$= \textbf{Rs. (154.25 kW + 1.18} \times \textbf{10}^{-2} \textbf{ kWh)}$

Example 50.28. *The capital costs of steam and water power stations are Rs. 1,200 and Rs. 2,100 per kW of the installed capacity. The corresponding running costs are 5 paise and 3.2 paise per kWh respectively.*

The reserve capacity in the case of the steam station is to be 25% and that for the water power station is to be 33.33% of the installed capacity.

At what load factor would the overall cost per kWh be the same in both cases ? Assume interest and depreciation charges on the capital to be 9% for the thermal and 7.5% for the hydro-electric station. What would be the cost of generating 500 million kWh at this load factor ?

Solution. Let x be the maximum demand in kWh and y the load factor.

Total No. of units produced $= xy \times 8760 \text{ kWh}$

Steam Station

installed capacity $= 1.25\,x$ (including reserve capacity)

capital cost $= \text{Rs. } 1200 \times 1.25\,x = \text{Rs. } 1500\,x$

annual interest and depreciation $= 9\% \text{ of Rs. } 1500\,x = \text{Rs. } 135\,x$

annual running cost $= \text{Rs. } 8760\,xy \times 5/100 = \text{Rs. } 438\,xy$

Total annual cost $= \text{Rs. } (135\,x + 438\,xy)$

$\therefore$ total cost / unit $= \textbf{Rs. (135}\,\boldsymbol{x}\textbf{ + 438}\,\boldsymbol{xy}\textbf{ / 8760}\,\boldsymbol{xy}$

Hydro-electric Station

installed capacity $= 1.33\,x$ (including reserve capacity)

capital cost $= \text{Rs. } 1.33\,x \times 2100 = \text{Rs. } 2800\,x$

annual interest and depreciation $= 7.5\% \text{ of Rs. } 2800\,x = \text{Rs. } 210\,x$

annual running cost $= \text{Rs. } 8760xy \times 3.2/100 = \text{Rs. } 280\,xy$

$\therefore$ total annual cost $=$ Rs. $(210x + 280\,xy)$

$\therefore$ total cost/unit $=$ Rs. $(210x + 280\,xy)/8760\,xy$

For the two costs to be the same, we have

$$\frac{135\,x + 438\,xy}{8760\,xy} = \frac{210\,x + 280\,xy}{8760\,xy}, \quad y = \mathbf{0.475 \text{ or } 47.5\%}$$

Cost of 500×10^6 Units

Now, maximum demand $= 500 \times 10^6 / 8760 \times 0.475 = 12 \times 10^4$ kW

$\therefore$ $x = 12 \times 10^4,\ y = 0.475$

$\therefore$ generating cost $=$ Rs. $(136 \times 12 \times 10^4 + 438 \times 12 \times 10^4 \times 0.475) =$ **41,166,000**

Example 50.29. *In a particular area, both steam and hydro-stations are equally possible. It has been estimated that capital cost and the running costs of these two types will be as follows:*

Capital cost/kW	*Running cost/kWh*	*Interest*
Hydro : Rs. 2,200	*1 Paise*	*5%*
Steam : Rs. 1,200	*5 Paise*	*5%*

If expected average load factor is only 10%, which is economical to operate : steam or hydro? If the load factor is 50%, would there be any change in the choice ? If so, indicate with calculation.

(Electric Power-II Punjab Univ. 1991)

Solution. Let x be the capacity of power station in kW.

Case I. Load factor = 10%

Total units generated/annum $= x \times 0.1 \times 8760 = 876\,x$ kWh

(*a*) Hydro Station

capital cost $=$ Rs. $2200\,x$

annual fixed charges $=$ 5% of Rs. $2200\,x =$ Rs. $110\,x$

annual running charges $=$ Rs. $876x \times 1/100 =$ Rs. $8.76\,x$

total annual charges $=$ Rs. $(110 + 8.76)x$

total cost/unit $=$ Rs. $(110 + 8.76)\,x / 876\,x =$ **13.5 p**

(*b*) Steam Station

capital cost $=$ Rs. $1200\,x$

annual fixed charges $=$ 5% of Rs. $1200\,x =$ Rs. $60\,x$

annual running charges $=$ Rs. $876\,x \times 5/100 =$ Rs. $43.8\,x$

total annual charges $=$ Rs. $(60 + 43.8)x$

overall cost/unit $=$ Rs. $103.8\,x/8.76\,x =$ **11.85 p**

Obviously, steam station is more economical to operate.

Case II. Load factor = 50%

Total units generated/annum $= x \times 8760 \times 0.5 = 4380\,x$

(*a*) Hydro Station

If we proceed as above, we find that total cost/unit = **3.5 p**

(*b*) Steam Station

total cost/unit = **6.35 p**

Obviously, in this case, hydro-station is more economical.

Example 50.30. *The annual working cost of a thermal station can be represented by a formula Rs. (a + b kW + c kWh) where a, b and c are constants for a particular station, kW is the total installed capactiy and kWh the energy produced per annum. Explain the significance of the constants a, b and c and the factors on which their values depend.*

Determine the values of a, b and c for a 60 MW station operating with annual load factor of 40% for which :

(i) *capital cost of buildings and equipment is Rs.* 5×10^5

(ii) *the annual cost of fuel, oil, taxation and wages and salaries of operating staff is Rs.90,000*

(iii) *the interest and depreciation on buildings and equipment are 10% per annum*

(iv) *annual cost of organisation and interest on cost of site etc. is Rs. 50,000.*

Solution. Here, *a* represents fixed charge due to the annual cost of the organisation, interest on the capital investment on land or site etc.

The constant *b* represents semi-fixed cost. The constant *b* is such that when multiplied by the maximum kW demand on the station, it equals the annual interest and depreciation on the capital cost of the buildings equipment and the salary of the charge engineer.

Constant *c* repesents running cost and its value is such that when multiplied by the annual total kWh output of the station, it equals the annual cost of the fuel, oil, taxation, wages and salaries of the operating staff.

An overview of a thermal power plant near Tokyo, Japan

(i) Here, $a = \mathbf{50{,}000}$

(ii) $b \times$ max. kW demand = annual interest on the capital cost of the buildings and equipment etc. $= 0.1 \times 5 \times 10^5$

$\therefore \quad b \times 60 \times 10^3 = 0.5 \times 10^5$ or $b = \mathbf{0.834}$

(iii) annual average power $= 0.5 \times 60 \times 10^3 = 30 \times 10^3$ kW

Units produced annually $= 30 \times 10^3 \times 8{,}760 = 262.8 \times 10^6$ kWh

$\therefore \quad c \times 262.8 \times 10^6 = 90{,}000$; $c = \mathbf{0.0034}$

50.17. Tariffs

The size and cost of installations in a generating station is determined by the maximum demand made by the different consumers on the station. Each consumer expects his maximum demand to be met at any time of the day or night. For example, he may close down his workshop or house for a month or so but on his return he expects to be able to switch on his light, motor and other equipment without any previous warning to the supply company. Since electric energy, unlike gas or water cannot be stored, but must be produced as and when required, hence the generating equipment has to be held in ‘readiness’ to meet every consumer's full requirement at all hours of the day.

This virtually amounts to allocating a certain portion of the generating plant and the associated distribution system to each consumer for his individual use. Hence, it is only fair that a consumer should pay the fixed charges on that portion of the plant that can be assumed to have been exclusively allocated to him plus the charges proportional to the units actually used by him.

Hence, any method of charging or tariff, in the fairness to the supply company, should take into account the two costs of producing the electric energy **(*i*)** fixed or standing cost proportional to the maximum demand and **(*ii*)** running cost proportional to the energy used. Such two-part tariffs are in common use. Some of the different ways of rate making are described below :

50.18. Flat Rate

This was the earliest type of tariff though it is not much used these days because, strictly speaking, it is not based on the considerations discussed above. In this system, charge is made at a simple flat rate per unit. But the lighting loads and power loads are metered separately and charged at different rates. Since the lighting load has a poor load factor *i.e.* the number of units sold is small in relation to the installed capacity of the generating plant, the fixed cost per kWh generated is high and this is taken into account by making the price per unit comparatively high. But since the power load is more predictable and has a high load factor, the cost per kWh generated is much lower which results in low rate per unit.

50.19. Sliding Scale

In this type of tariff, the fixed costs are collected by charging the first block of units at a higher rate and then reducing the rates, usually in many steps, for units in excess of this quantity.

50.20. Two-part Tariff

This tariff is based on the principles laid down in Art. 50.16. It consists of two parts **(*i*)** a fixed charge proportional to the maximum demand (but independent of the units used) and **(*ii*)** a low running charge proportional to the actual number of units used.

The maximum demand during a specified period, usually a quarter, is measured by a maximum demand indicator. The maximum demand indicator is usually a watt-hour meter which returns to zero automatically at the end of every half hour but is fitted with a tell-tale pointer which is left behind at the maximum reduing reached during the quarter under consideration.

This type of tariff is expressed by a first degree equation like Rs. $A \times$ kW + $B \times$ kWh where Rs. A is the charge per annum per kW of maximum demand and B is the price per kWh.

Sometimes, the customer is penalized for his poor load power factor by basing the fixed charges on kVA instead of per kW of maximum demand.

Example 50.31. *Compute the cost of electrical energy and average cost for consuming 375 kWh under 'block rate tariff' as under :*

First 50 kWh at 60 paisa per kWh ; next 50 kWh at 50 paisa per kWh; next 50 kWh at 40 paisa per kWh; next 50 kWh at 30 paisa per kWh.

Excess over 200 kWh at 25 paisa per kWh. **(Utilisation of Elect. Power, AMIE Sec. B)**

Solution. Energy charge for the first 50 kWh is = Rs. 0.6 $\times$ 50 = Rs. 30

Energy charge for the next 50 kWh at 50 paisa / kWh = Rs. 0.5 $\times$ 50 = Rs. 25

Energy charge for the next 50 kWh at 40 paisa / kWh = Rs. 0.4 $\times$ 50 = Rs. 20

Energy charge for the next 50 kWh at 30 paisa / kWh = Rs. 0.3 $\times$ 50 = Rs. 15

Energy charge for the rest (375 – 200) *i.e.* 175 kWh =Rs. 0.25 $\times$ 175 = Rs. 43.75

Total cost of energy for 375 kWh = Rs. (30 + 25 + 20 + 15 + 43.75) = **Rs. 133.75**

Average cost of electrical energy/kWh = Rs. 133.75 / 375 = **36 paise.**

Example 50.32. *The output of a generating station is 390 $\times$ 10^6 units per annum and installed capacity is 80,000 kW. If the annual fixed charges are Rs. 18 per kW of isntalled plant and running charges are 5 paisa per kWh, what is the cost per unit at the generating station ?*

(Eletrical Technology, Bombay Univ.)

Solution. Annual fixed charges $= \text{Rs. } 18 \times 80{,}000 = \text{Rs. } 1.44 \times 10^6$

Fixed charges/kWh $= \text{Rs. } 1.44 \times 10^6/390 \times 10^6 = 0.37$ paisa

Running charges/kWh $= 5$ paisa

Hence, cost at the generating station is $= 5 + 0.37 =$ **5.37 paise/kWh.**

Example 50.33. *A power station has an installed capacity of 20 MW. The capital cost of station is Rs. 800 per kW. The fixed costs are 30% of the cost of investment. On full-load at 100% load factor, the variable costs of the station per year are 1.5 times the fixed cost. Assume no reserve capacity and variable cost to be proportional to the energy produced, find the cost of generation per kWh at load factors of 100% and 20%. Comment on the results.* **(Ranchi University)**

Solution. Capital cost of the station = Rs. $800 \times 20{,}000$ = Rs. 16×10^6

(*a*) At 100% load factor

Fixed cost $= \text{Rs. } 16 \times 10^6 \times 13/100 = \text{Rs. } 2.08 \times 10^6$

Variable cost $= \text{Rs. } 1.5 \times 2.08 \times 10^6 = \text{Rs. } 3.12 \times 10^6$

Total operating cost per annum $= \text{Rs. } (2.08 + 3.12) \times 10^6 = \text{Rs. } 5.2 \times 10^6$

Total No. of units generated $= \text{kW max. demand} \times \text{LF} \times 8760 = 20{,}000 \times 1 \times 8760$

$= 175.2 \times 10^6$ kWh

Cost of generation per kWh $= 5.2 \times 10^6 \times 100/175.2 \times 10^6 =$ **3.25 paise.**

(*b*) At 20% load factor :

Fixed cost $= \text{Rs. } 2.08 \times 10^6$ as before

Total units generated per annum $= 20{,}000 \times 0.2 \times 8760 = 35.04 \times 10^6$ kWh

Since variable cost is proportional generated, the variable $= \text{Rs. } 3.12 \times 10^6 \times 35.04 \times 10^6 / 175.2 \times 10^6$ to kWh

cost at load of 20% is $= \text{Rs. } 0.624 \times 10^6$

Total operating cost $= \text{Rs. } (2.08 + 0.624) \times 10^6 = 2.704 \times 10^6$

Cost of generation per kWh $= 2.704 \times 10^6 \times 100/35.04 \times 10^6 =$ **7.7 paise**

It is obvious from the above calculations that as the station load factor is reduced, the cost of electric generation is increased.

Example 50.34. *The annual output of a generating sub-station is 525.6×10^6 kWh and the average load factor is 60%. If annual fixed charges are Rs. 20 per kW installed plant and the annual running charges are 1 paisa per kWh, what would be the cost per kWh at the bus bars ?*

Solution. Average power supplied per annum $= 525.6 \times 10^6 / 8760 = 60{,}000$ kW

Max. demand $= \dfrac{\text{average power}}{\text{load factor}} = \dfrac{60{,}000}{0.6} = 100{,}000$ kW*

Annual fixed charges $= \text{Rs. } 20 \times 100{,}000 = \text{Rs. } 2 \times 10^6$

Fixed charges / kWh $= \dfrac{2 \times 10^6}{525.6 \times 10^6} = \dfrac{2 \times 100}{525.6} = 0.38$ paisa

Annual running charges per kWh = 1 paisa. Hence, cost per kWh at the bus-bars = **1.38 paisa.**

* It has been assumed that the installed capacity is equal to the maximum demand of 100,000 kW.

Example 50.35. *A certain factory working 24 hours a day is charged at Rs. 10 per kVA of max. demand plus 5 paisa per kV ARh. The meters record for a month of 30 days; 135,200 kWh, 180,020 kV ARh and maximum demand 310 kW. Calculate*

(i) *M.D. charges,* ***(ii)*** *monthly bill,* ***(iii)*** *load factor,* ***(iv)*** *average power factor.*

(Electric Engineering-II, Bangalore Univ.)

Solution. Average deamnd = 135,200/24 × 30 = 188 kW

Average reactive power = 180,020/24 × 30 = 250 kVAR

Now, $\tan\phi$ = kVAR/kW = 250/88 ; $\phi = 53°$; $\cos\phi = 0.6$;

M.D. kVA = 310/0.6 = 517

(i) M.D. charge = Rs. 10 × 517 = **Rs. 5170**

(ii) reactive energy charges = Rs. 5 × 180,020/100 = Rs. 9001

∴ monthly bill = **Rs. 14,171**

(iii) monthly load factor = 188/310 = 0.606 or 60.6% (*iv*) average p.f. = **0.6**

Example 50.36. *The cost data of a power supply company is as follows :*

Station maximum demand = 50 MW ; station load factor = 60% ; Reserve capacity = 20% ; capital cost = Rs. 2,000 per kW; interest and depreciation = 12% ; salaries (annual) = Rs. 5×10^5; fuel cost (annual) = Rs. 5×10^6 ; maintenance and repairs (annual) Rs. 2×10^5 ; losses in distribution = 8% ; load diversity factor = 1.7.

Calculate the average cost per unit and the two-part tariff, assuming 80 per cent of salaries and repair and maintenace cost to be fixed. **(Electrical Power-I, Bombay Univ.)**

Solution. Station capacity = 50 + 20% of 50 = 60 MW

Average power = $60 \times 0.6 = 36$ MW = 36×10^3 kW

Capital investment = Rs. $60 \times 10^3 \times 2000$ = Rs. 12×10^7

Interest + depreciation = Rs. $0.12 \times 12 \times 10^7$ = Rs. 14.4×10^6

Total cost both fixed and running

= Rs. 14.4×10^6 + Rs. 5×10^5 + Rs. 5×10^6 + Rs. 2×10^5 = Rs. 201×10^5

No. of units generated annually = $8760 \times 36 \times 10^3$

∴ overall cost/unit = Rs. $\dfrac{201 \times 10^5}{8760 \times 36 \times 10^3}$ = **6.37 paise**

Fixed charges

Annual interest and depreciation = Rs. 14.4×10^6

80% of salaries = Rs. $0.8 \times 5 \times 10^5$ = Rs. 4×10^5

80% of repair and maintenance cost = Rs. $0.8 \times 2 \times 10^5$ = Rs. 1.6×10^5

Total fixed charges = Rs. 149.6×10^5

Aggregate maximum demand of all consumers

= Max. demand on generating station × diversity factor

= $60 \times 10^3 \times 1.7 = 10^2 \times 10^3$ kW

∴ annual cost/kW of maximum demand = Rs. $149.6 \times 10^5/10^2 \times 10^3$ = **Rs. 149.6**

Running Charges

Cost of fuel = Rs. 50×10^5 ; 20% of salaries = Rs. 1×10^5

20% of maintenance = 0.4×10^5 ;

Total = Rs. 51.4×10^5

Considering distribution loss of 8%, cost per unit delivered to the consumer is

$$= \text{Rs. } 51.4 \times 105/0.92 \times 8760 \times 36 \times 10^3 = \textbf{1.77 paise}$$

Hence, two-part tariff is : **Rs. 149.6 per kW max.** demand plus **1.77 paisa per kWh** consumed.

Example 50.37. *A certain electric supply undertaking having a maximum demand of 110 MW generates 400 × 10^6 kWh per year. The supply undertaking supplies power to consumers having an aggregate demand of 170 MW. The annual expenses including capital charges are :*

Fuel = Rs. 5 × 10^6

Fixed expenses connected with generation = Rs. 7 × 10^6

Transmission and distribution expenses = Rs. 8 × 10^6

Determine a two-part tariff for the consumers on the basis of actual cost.

Assume 90% of the fuel cost as variable charges and transmission and distrbution losses as 15% of energy generated. **(Electrical Power-I. Bombay Univ.)**

Solution. Total fixed charges per annum are as under :

Fixed charges for generation = Rs. 7 × 10^6

Transmission and distribution expenses = Rs. 8 × 10^6

10% of annual fuel cost = Rs. 0.5 × 10^6 Total = Rs. 15.5 × 10^6

This cost has to be spread over the aggregate maximum demand of all consumers *i.e.* 170 MW.

∴ cost per kW of maximum deamnd = Rs. 15.5 × 10^6 / 170 × 10^3 = **Rs. 91.2**

Running charges = 90% of fuel cost = Rs. 4.5 × 10^6

These charges have to be spread over the number of kWh acutally delivered.

No. of units delivered = 85% of No. of units generated

= 0.85 × 400 × 10^6 = 340 × 10^6

∴ running cost / kWh = Rs. 4.5 × 10^6/340 × 10^6 = **1.32 paise**

Hence, the two-part tariff for the consumer would be **Rs. 91.2 per kW** of maximum demand and **1.32 paisa per kWh** consumed.

Example 50.38. *A customer is offered power at Rs. 80 per annum per kVA of maximum demand plus 8 paisa per unit metered. He proposes to install a motor to carry his estimated maximum demand of 300 b.h.p. (223.8 kW). The motor available has a power factor of 0.85 at full-load. How many units will he require at 20% load factor and what willl be his annual bill ?*

(Electric Power II Punjab Univ. 1992)

Solution. Assuming a motor efficiency of 90%, the full-load power intake of motor = 223.8/0.9 = 746/3 kW. This represents the max. demand.

$$\text{Now, load factor} = \frac{\text{average}}{\text{max.demand}}$$

∴ average power = max. demand × load factor = (746/3) × 0.2 = **149.2/3 kW**

∴ annual consumption = 149.2 × 8,760/3 = 435,700 kWh

Max. kVA of demand = 300 × 746/0.9 × 0.85 × 1000 = 292.5

∴ cost per kVA of maximum demand = 292.5 × 80 = Rs. 23,400

Cost of units consumed/annum = 435,700 × 8/100 = Rs. 34,856

∴ annual bill = Rs. 23,400 + Rs. 34,856 = **Rs. 58,256**

Example 50.39. *How two-part tariff is modified for penalising low p.f. consumers ?*

An industry consumes 4 million kWh/year with a maximum demand of 1000 kW at 0.8 p.f. What is its load factor ?

(a) *Calculate the annual energy charges if tariff in force is as under :*
Max. demand charge = Rs. 5 per kVA per month. Energy charges = Rs. 0.35 per kWh

(b) *Also calculate reduction in this bill if the maximum demand is reduced to 900 kW at 0.9 p.f. lagging.* **(Electrotechnics, Gujarat Univ.)**

Solution. Load factor $= 4 \times 10^6/1000 \times 8760 = 0.4566$ or 45.66%

(*a*) Max. kVA demand $= 1000/0.8 = 1250$

Annual M.D. charge/kVA $= 5 \times 12 =$ Rs. 60

M.D. charge for 1250 kVA $=$ Rs. $60 \times 1250 =$ Rs. 75×10^3

Annual energy charge $=$ Rs. $4 \times 10^6 \times 0.35 =$ Rs. 1400×10^3

Annual energy bill $=$ **Rs. 1475×10^3**

(*b*) Since load factor remains the same, annual average power $= 900 \times 0.4566$ kW

Units consumed annually $= 8760 \times 900 \times 0.4566 = 3.6 \times 10^6$

Max. kVA demand $= 900/0.9 = 1000$, M.D. charge for 1000 kVA $=$ Rs. $60 \times 1000 =$ Rs. 60×10^3

Energy charge $=$ Rs. $3.6 \times 10^6 \times 0.35 =$ Rs. 1260×10^3; Annual bill $=$ Rs.$1{,}320 \times 10^3$

Annual saving $=$ Rs. $(1475 - 1320) \times 10^3 =$ **Rs. 155×10^3**

Example 50.40. *A supply is offered on the basis of fixed charges of Rs. 30 per annum plus 3 paise per unit or alternatively, at the rate of 6 paisa per unit for the first 400 units per annum and 5 paise per unit for all the additional units. Find the number of units taken per annum for which the cost under these two tariffs becomes the same.* **(Electrical Technology-I, Bombay Univ.)**

Solution. Let x kWh be the annual consumption of the consumer for which the two tariffs are equally advantageous.

Cost according to the first tariff $=$ Rs. $30 + 3x / 100$

Charges according to the alternative tariff are

$=$ Rs. $6 \times 400/100 +$ Rs. $(x - 400) \times 5/100 =$ Rs. $[24 + (x - 400)/20]$

Since charges in both cases are to be equal

$$\therefore \quad 30 + \frac{3x}{100} = 24 + \frac{(x-400)}{20}$$

or $\quad x =$ **1300 kWh.**

Example. 50.41. *If power is charged for at the rate of Rs. 75 per kVA of maximum demand and 4 paisa per unit, what is the cost per unit at 25% yearly load factor **(a)** for unity power factor demand and **(b)** for 0.7 power factor demand.*

Solution. (*a*) At 25% load factor and unity power factor

Maximum demand charge *per unit* $= \dfrac{75 \times 100}{8760 \times 0.25} = 3.43$ paise

Energy charge per unit = 4 paisa ; Cost *per unit* $= 4 + 3.43 =$ **7.43 paise**

(*b*) At 25% load factor and 0.7 power factor

Maximum demand charge *per unit* $= \dfrac{75 \times 100}{0.7 \times 0.25 \times 8760} =$ **4.9 paise**

Energy charge per unit = 4 paise ; Cost per unit $= 4 + 4.9 =$ **8.9 paise**

Exmaple 50.42. *Explain different methods of tariff. A tariff in force is Rs. 50 per kVA of max. demand per year plus 10 p per kWh. A consumer has a max. demand of 10 kW with a load factor of 60% and p.f. 0.8 lag.*

(i) *Calculate saving in his annual bill if he improves p.f. to 0.9 lag.*

(ii) *Show the effect of improving load factor to 80% with the same max. demand and p.f. 0.8 lag on the total cost per kWh.* **(Electrical Engineering-III, Poona Univ.)**

Solution. *(i)* Max. kVA demand at 0.8 p.f. = 10/0.8 = 12.5

M.D. charges = Rs. 50 × 12.5 = Rs. 625

Max. kVA demand at 0.9 p.f. = 10/0.9 ; M.D. charge = Rs. 50 × 10/0.9 = Rs. 555.55

Since energy consumed remains constant, saving is due only to reduction in M.D. charges.

∴ saving = Rs. (625 – 555.55) = **Rs. 69.45**

(ii) With 60% load factor, average power = 10 × 0.6 = 6 kW. The number of units consumed annually = 6 × 8760 = 52,560 kWh. Also, annual M.D. charge = Rs. 50 × 12.5 = Rs. 625

M.D. charge/unit consumed = 625 × 100/52,560 = 1.19 paise

Total cost per unit = 10 + 1.19 = **11.19 paise**

With a laod p.f. of 80% average power = 10 × 0.8 = 8 kW

Number of units consumed annually = 8 × 8,760 = 70,080 kWh. The M.D. charge as before = Rs. 625.

∴ M.D. charge/unit consumed = 625 × 100/70,080 = 0.89 paise

∴ total cost/unit consumed = 10 + 0.89 = **10.89 paise**

Obviously, with improvement in load factor, total cost per unit is reduced.

Example 50.43. *A consumer has a maximum demand (M.D.) of 20 kW at 0.8 p.f. lagging and an annual load factor of 60%. There are two alternative tariffs* ***(i)*** *Rs. 200 per kVA of M.D. plus 3p per kWh consumed and* ***(ii)*** *Rs. 50 per kVA of M.D. plus 7p per kWh consumed. Determine which of the tariffs will be economical for him.* **(Electrical Engineering, Banaras Hindu Univ.)**

Solution. An M.D. of 20 kW at 0.8 p.f. = 20/0.8 = 25 kVA

Average power = M.D. × load factor = 20 × 0.6 = 12 kW

Energy consumed/year = 12 × 8760 = 105120 kWh

(a) M.D. charge = Rs. (200 × 25) = Rs. 5000

Energy charge = Rs. 3 × 105, 120/100 = Rs. 3153.60

Annual charges = Rs. 5000 + Rs. 3153.60 = **Rs. 8153.60**

(b) M.D. charge = Rs. (50 × 25) = Rs. 1250

Energy charge = Rs. $\dfrac{7 \times 105120}{100}$ = Rs. 7358.40

Annual charge = Rs. 1250 + Rs. 7358.40 = **Rs. 8608.40**

Obviously, tariff *(a)* is economical.

Example 50.44. *Determine the load factor at which the cost of supplying a unit of electricity from a Diesel station and from a steam station is the same if the respective annual fixed and running charges are as follows.*

Station	*Fixed charges*	*Running charges*
Diesel	*Rs. 300 per kW*	*25 paise/kWh*
Steam	*Rs. 1200 per kW*	*6.25 paise/kWh*

(Electrical Power-I, Gujarat Univ.)

Solution. *(i)* **Diesel Station**

Suppose that the energy supplied in one year is one unit *i.e.* one kWh.

∴ annual average power = 1 kWh/8760 *h* = 1/8760 kW

Now, annual load factor (L) $= \dfrac{\text{annual average power}}{\text{annual max. demand}}$

$\therefore$ max. demand $= \dfrac{\text{average power}}{L} = \dfrac{1}{8760\,L}$ kW

$\therefore$ fixed charge = Rs. 300 × 1/8760 L = 30,000 / 8760 L paise

Running charge = 1 × 25 = 25 paise

Hence, fixed and running charges per kWh supplied by Diesel station = $\left(\dfrac{30,000}{8760\text{ L}}\right)$ paise

***(ii)* Steam Station**

In the same way, fixed charge = Rs. 1200/8760 L = 120,000/8760 L paise

Running charge = 6.25 paise

$\therefore$ fixed plus running charges for supplying one kWh of energy are

= (120,000/8760 L) + 6.25 paise.

Since the two charges have to be the same

$$\therefore \quad \frac{120,000}{8760\,L} + 6.25 = \frac{30,000}{8760\,L} + 25\ ;\ L = \mathbf{0.55 \text{ or } 55\%.}$$

Example 50.45. *A factory has a maximum load of 300 kW at 0.72 p.f. with an annual consumption of 40,000 units, the tariff is Rs. 4.50 per kVA of maximum demand plus 2 paisa/unit. Find out the average price per unit. What will be the annual saving if the power factor be improved to units ?*

(Electrical Technology-I, Bombay Univ.)

Sulotion. kVA load at 0.72 p.f. = 300/0.72 = 1250/3

$\therefore$ max. kVA demand charge = Rs. 4.5 × 1250/3 = Rs. 1875

$\therefore$ M.D. charge per unit = Rs. 1875 / 40,000 = 4.69 paise

$\therefore$ total charge per unit = 2 + 4.69 = **6.69 paise**

Max. kVA demand at unity p.f. = 300

M.D. charge per unit = Rs. 300 × 4.5 = Rs. 1350

Annual saving = Rs. 1875 – Rs. 1350 = **Rs. 525.**

Example 50.46. *There is a choice of two lamps, one costs Rs. 1.2 and takes 100 W and the other costs Rs. 5.0 and takes 30 W ; each gives the same candle power and has the same useful life of 1000 hours. Which will prove more economical with electrical energy at Rs. 60 per annum per kW of maximum demand plus 3 paise per unit ? At what load factor would they be equally advantageous?*

Solution. (*i*) First Lamp

Initial cost of the first lamp per hour = Rs. 120/1000 = 0.12 paisa

Max. demand / hr. = 100/1000 = 0.1 kW

Max. demand charge/hr. = (60 × 100) × 0.1/8760 = 0.069 paisa

Energy charge/hr. = 3 × 0.1 = 0.3 paisa

$\therefore$ Total cost/hr. = 0.12 + 0.069 + 0.3 = **0.489 paisa**

***(ii)* Second Lamp**

Initial cost/hr. = 500/1000 = 0.5 paisa ; Max. demand /hr ; = 30/1000 = 0.03 kW

Max. demand charge/hr. = (60 × 100) × 0.03 / 8760 = 0.02 paisa

Energy charge/hr. = 3 × 0.03 = 0.09 paisa $\therefore$ total cost/hr. = 0.5 + 0.02 + 0.09 = **0.61 paisa**

Hence, the first lamp would be more economical.

It would be seen that the only charge which will vary with load factor is the max. demand charge. Moreover the maximum demand charge varies inversely as the load factor. Let x be the load factor at which both lamps are equally advantageous. Then

$$0.12 + \frac{0.069}{x} + 0.3 = 0.05 + \frac{0.02}{x} + 0.09 \quad \therefore \quad x = \mathbf{0.29}$$

Hence, both lamps would be equally advantageous at **29%** load factor.

Example 50.47. *The following data refers to a public undertaking which supplies electric energy to its consumers at a fixed tariff of 11.37 paise per unit.*

Total installed capacity = 344 MVA ; Total capital investment = Rs. 22.4 crores;

Annual recurring expenses = Rs. 9.4 crores ; Interest charge = 6% ; depreciation charge = 5%

Estimate the annual load factor at which the system should operate so that there is neither profit nor loss to the undertaking. Assume distribution losses at 7.84% and the average system p.f. at 0.86.

(Electrical Power-I, Bombay Univ.)

Solution. Yearly load factor (L) $= \dfrac{\text{No. of kWh supplied in a year}}{\text{Max. No. of kWh which can be supplied}}$ *

$$= \frac{\text{kWh supplied/year}}{\text{Max. output in kW} \times 8760}$$

$\therefore$ kWh supplied/year $= \text{Max. output in kW} \times 8760 \times L$

$$= (344{,}000 \times 0.86) \times 8760 \times L = L \times 25.92 \times 10^8$$

Considering distribution losses of 7.84%, the units actually supplied

$$= 92.16 \text{ per cent of } (L \times 25.92 \times 10^8) = L \times 23.89 \times 10^8$$

Amount collected @ of 11.37 paise / kWh = Rs. $L \times 23.89 \times 10^8 \times 11.37 / 100$

If there is to be no profit or gain, then this amount must just equal the fixed and running charges.

Annual interest and depreciation on capital investment

$$= 11\% \text{ of Rs. } 22.4 \times 10^7 = \text{Rs. } 2.46 \times 10^7$$

Total annual expenses $= \text{Rs. } 2.46 \times 10^7 + \text{Rs. } 9.4 \times 10^7 = \text{Rs. } 11.86 \times 10^7$

$\therefore$ $L \times 23.89 \times 10^8 \times 11.37 / 100 = 11.86 \times 10^7$; $L =$ **0.437 or 4.37%**

Example 50.48. *An area has a M.D. of 250 MW and a load factor of 45%. Calculate the overall cost per unit generated by* ***(i)*** *steam power station with 30 per cent reserve generating capacity and* ***(ii)*** *nuclear station with no reserve capacity.*

Steam station : Capital cost per kW = Rs. 1000 ; interest and depreciation on capital costs = 15% ; operating cost per unit = 5 paise.

Nucelar station : capital cost per kW = Rs. 2000 ; interest and depreciation on capital cost = 12% ; operating cost per unit = 2 paise.

For which load factor will the overall cost in the two cases become equal ?

(Electrical Power-I, Bombay Univ.)

Solution. (*i*) Steam Station

Taking into consideration the reserve generating capacity, the installed capacity of the steam station $= 250 + (30\% \text{ of } 250) = 325 \text{ MW} = 325 \times 10^3 \text{ kW}$

average power (annual) $= \text{M.D.} \times \text{load factor} = 325 \times 10^3 \times 0.45 = 146{,}250 \text{ kW}$

$\therefore$ No. of units produced/year $= 8760 \times 146{,}250 = 128 \times 10^7$

* In this case max. demand has been taken as equal to the installed capacity.

Capital investment = Rs. $325 \times 10^3 \times 1000$ = Rs. 325×10^6

Annual interest and depreciation = Rs. $325 \times 10^6 \times 0.15$ = Rs. 48.75×10^6

These fixed charges have to be spread over the total number of units produced by the station.

$\therefore$ fixed charges / unit = Rs. $48.75 \times 10^6 / 128 \times 10^7$ = 3.8 paise

$\therefore$ overall cost per unit generated = 3.8 + 5 = **8.8 paise**

(*ii*) Nuclear Station

Since there is no reserve capacity, installed capacity of the station equals the maximum demand of 250 MW = 25×10^4 kW.

Average power = $0.45 \times 25 \times 10^4$ = 112,500 kW

Units produced annually = $8760 \times 112{,}500 = 98.3 \times 10^7$

Capital investment = Rs. $2000 \times 250 \times 10^3$ = Rs. 5×10^8

Annual interest and depreciation = Rs. $0.12 \times 5 \times 10^8$ = Rs. 6×10^7

$\therefore$ fixed charges / unit = Rs. $6 \times 10^7 / 98.3 \times 10^7$ = 6.1 paise

Overall cost per unit generated = 6.1 + 2.2 = **8.3 paise**

Load Factor

Suppose L is the load factor at which the overall cost per unit generated is the same.

$$\text{Cost / unit for steam station} = \left(\frac{48.75 \times 10^8}{325 \times 10^3 \times 8760\, L} + 5\right) = \left(\frac{1.712}{L} + 5\right) \text{ paise.}$$

Similarly, overall cost/unit for nuclear station is

$$= \left(\frac{6 \times 10^7 \times 100}{250 \times 10^3 \times 8760\, L} + 2\right) = \left(\frac{2.74}{L} + 2\right) \text{ paise}$$

Equating the two, we get $[(1.712/L) + 5] = [2.74/L) + 2]$ $\therefore$ L = **0.34 or 34%**

Example 50.49. *The maximum demand of a customer is 25 amperes at 220 volt and his total energy consumption is 9750 kWh. If the energy is charged at the rate of 20 paise per kWh for 500 hours' use of the maximum demand plus 5 paise power unit for all additional units, estimate his annual bill and the equivalent flat rate.*

Solution. Charge at the max. demand rate.

Max. demand = $25 \times 220/1{,}000$ = 5.5 kW

Units consumed at maximum demand rate = 5.5×500 = 2,750 kWh

Max. demand charge = $2{,}750 \times 20/100$ = **Rs. 550**

Energy Charge

Units to be charged at lower rate = 9,750 – 2,750 = 7,000

$$\text{Charge} = \frac{7{,}000 \times 5}{100} = \text{Rs. } 350$$

$\therefore$ annual bill = Rs. 550 + 350 = **Rs. 900**

Equivalent flat rate = $900 \times 100/9{,}750$ = **9.2 paise**

Example 50.50. *A workshop having a number of induction motors has a maximum demand of 750 kW with a power factor of 0.75 and a load factor of 35%. If the tariff is Rs. 75 per annum per kVA of maximum demand plus 3 paise per unit, estimate what expenditure would it pay to incur to raise the power factor of 0.9.*

Solution. Max. kVA demand at 0.75 p.f. = 750/0.75 = 1000

M.D. charge = 75×1000 = Rs. 75,000 ; Max. kVA demand at 0.9 p.f. = 750/0.9

M.D. charge = (7,500/9) × 75 = Rs. 62,500

Difference in one year = 75,000 – 62,500 = **Rs. 12,500**

If the annual interest on money borrowed for purchasing the p.f. improvement plant is assumed 10%, then an expenditure of Rs. 125,000 is justified.

Example 50.51. *The owner of a new factory is comparing a private oil-engine generating station with public supply. Calculate the average price per unit his supply would cost him in each case, using the following data :*

Max. demand, 600 kW; load factor, 30% ; supply tariff, Rs. 70 per kW of maximum demand plus 3 paise per unit; capital cost of plant required for public supply, Rs. 10^5; capital cost of plant required for private generating station, Rs. 4×10^5 ; cost of fuel, Rs. 80 per tonne ; consumption of fuel oil; 0.3 kg per unit generated. Other work costs for private plant are as follows : lubricating oil, stores and water = 0.35 paise per unit generated ; wages 1.1 paise ; repairs and maintenance 0.3 paise per unit.

Solution. Public Supply Charges

Running charge/unit = 3.0 paise ; Average power consumption = 600 × 0.3 = 180 kW

Annual energy consumption = 180 × 8,760 kWh

Fixed annual charges = Rs. 70 × 600 = Rs. 42,000

Let us assume a capital charge rate of 10%. Hence, further annual amount to be charged from the customer is 0.1×10^5 = Rs. 10,000

∴ total fixed charges/annum = Rs. 42,000 + Rs. 10,000 = Rs. 52,000

∴ fixed charge per unit generated = $\dfrac{52{,}000 \times 100}{180 \times 8760}$ = 3.3 paise

∴ fixed plus running charges per unit generated = 3.0 + 3.3 = **6.3 paise.**

Private Supply Charges

Annual capital charges = Rs. $4 \times 10^5 \times 0.1$=Rs. 40,000

No. of units generated annually = 180 × 8,760 kWh

∴ fixed charges per unit generated = $\dfrac{4{,}000 \times 100}{180 \times 8760}$ = 2.54 paise

Cost of oil per unit generated = $\dfrac{80 \times 100 \times 0.3}{1{,}000}$ = 2.4 paise

Running charges per unit generated are :

Lubricating oil, stores, water = 0.35 paise; Wages = 1.1 paise

Repairs and maintenance = 0.3 paisa; Total = 0.35 + 1.1 + 0.3 = 1.75 paise

Total running charges = 2.4 + 1.75 = **4.15 paise**

Fixed plus running charges per unit generated = 2.54 + 4.15 = **6.69 paise**

Example 50.52. *Calculate the minimum two-part tariff to be charged to the consumers of a supply undertaking from the following data :*

Generating cost per kWh; 3.6 paise ; Generating cost per kW of maximum demand, Rs. 50

Total energy generated per year ; $4{,}380 \times 10^4$ kWh

Load factor at the generating station, 50%

Annual charges for distribution Rs. 125,000

Diversity factor for the distribution network, 1.25

Total loss between station and consumer, 10%.

Solution. Average generating power $= 4{,}380 \times 10^4/8760 = 5{,}000$ kW

$\therefore$ maximum load on generator $= 5{,}000/\text{load factor} = 5{,}000 / 0.5 = 10{,}000$ kW

$\therefore$ annual fixed charges = Rs. $10{,}000 \times 50$ = Rs. 500,000

Fixed charges = Rs. 125,000 Total fixed charges = Rs. 625,000

Since diversity factor is known, consumer's max. demand $= 10{,}000 \times 1.25 = 12{,}500$ kW

Hence, Rs. 625,000 have to be equally distributed over the 12,500 kW maximum demand.

$\therefore$ cost per kW max, demand = 625,000/12,500 = Rs. 50

$\therefore$ monthly kW maximum charges is = Rs. 50/12 = Rs. 4.17

Since losses are 10%, consumer gets 0.9 kWh for every kWh generated at the station. Hence cost per kWh to the consumer is 3.6/0.9 = 4 paise.

Therefore, minimum charges are **Rs. 4.17 per kW** of max. demand per month and **4 paise per kWh** consumed.

Example 50.53. *Two systems of tariffs are available for a factory working 8 hours a day for 300 working days in a year.*

(a) High-voltage supply at 5 paise per unit plus Rs. 4.50 per month per kVA of maximum demand.

(b) Low-voltage supply at Rs. 5 per month per kVA of maximum demand plus 5.5 paise per unit.

The factory has an average load of 200 kW at 0.8 power factor and a maximum demand of 250 kW at the same p.f.

The high-voltage equipment costs Rs. 50 per kVA and losses can be taken as 4 per cent. Interest and depreciation charges are 12 per cent. Calculate the difference in the annual cost between the two systems.

Solution. First, let us find the annual cost according to rate (*a*).

(*a*) Capacity of h.v. switchgear = $(250/0.8) \times (100/96)$ kVA

Annual interest on capital investment and depreciation

$$= \left(\frac{250}{0.5} \times \frac{100}{96}\right) \times 50 \times 0.12 = \text{Rs. } 1953$$

Annual charge due to kVA max. demand is

$$= \frac{250}{0.5} \times \frac{100}{96} \times 12 \times 4.5 = \text{Rs. } 17{,}580$$

Annual charge due to kWh consumption

$$= 200 \times \frac{100}{96} \times \frac{5}{100} \times (8 \times 300) = \text{Rs. } 25{,}000$$

$\therefore$ total charges = Rs. (1953 + 17,580 + 25,000) = **Rs. 44,533**

(*b*) The total annual cost due to rate **(*b*)** would be as under.

Annual charge due to kVA max. demand is $= 250 \times 5 \times 12/0.8$ = Rs. 18,750

Annual charge due to kWh consumption is $= 200 \times \dfrac{5.5}{100} \times 2{,}400$ = Rs. 26,400

$\therefore$ total charges = Rs. 18,750 + Rs. 26,400 = Rs. 45,150

Hence, high-voltage supply is cheaper by 45,150 − 44,533 = **Rs. 617.**

Example 50.54. *Estimate what the consumption must be in order to justify the following maximum demand tariff in preference to the flat rate if the maximum demand is 6 kW.*

On Maximum Demand Tariff. A max. demand rate of 37 paise per unit for the first 200 hr. at the maximum demand rate plus 3 paisa for all units in excess.

Flat-rate tariff, 20 paise per unit.

Solution. Let x = the number of units to be consumed (within a specific period)

On Max. Demand Tariff

Units consumed at max. demand rate $= 6 \times 200 = 1200$ kWh

Units in excess of the max. demand units $= (x - 1200)$

Cost of max. demand units $= 1200 \times 37 = 44{,}400$ paise

Cost of excess units $= 3\,(x - 1200) = (3\,x - 3600)$ paise

$\therefore$ total cost on this tariff $= 44{,}400 + 3\,x - 3600 = 3\,x + 40{,}800$ paise

Flat-rate Tariff

Total cost of units on this rate $= 20\,x$ paise

$$\therefore \quad 20\,x = 3\,x + 40{,}800$$

$$\text{or} \quad 17x = 40{,}800 \qquad \therefore \quad x = \mathbf{2{,}400\ units}$$

Tutorial Problem No. 50.1

1. A plant costing Rs. 650,000 has a useful life of 15 years. Find the amount which should be saved annually to replace the equipment at the end of that time.

(*i*) by the straight line method and (*ii*) by the sinking fund method if the annual rate of compound interest is 15%.

Assume that the salvage value of equipment is Rs. 5000.

[(i) Rs. 4,000 (ii) Rs. 1,261] (*Elect. Generation, Punjab Univ.*)

2. A plant costs Rs. 7.56×10^5 and it is estimated that after 25 years, it will have to be replaced by a new one. At that instant, its salavage value will be Rs. 1.56×10^5. Calculate.

(*i*) the annual deposit to be made in order to replace the plant after 25 years and

(*ii*) value of the plant after 10 years on the 'reducing balance depreciation method'.

[(i) 0.0612 (ii) Rs. 4.02×10^5] (*Util. of Elect. Power, AMIE Sec. B,*)

3. From the following data, estimated the generating cost per unit delivered at the station.

Capacity of the generating plant = 10 MW; annual load factor = 0.4 ; capital cost = Rs. 5 million; annual cost of fuel, oil, wages, taxes and salaries = Rs. 2×10^5; Rate of interest = 5%; rate of depreciation = 5% of initial value. **[2 paisa/kWh]**

4. From the following data, find the cost of generation per unit delivered from the station.

Capacity of the plant installed = 100 MW; annual load factor = 35% ; capital cost of power plant = Rs. 1.25 crores ; Annual cost of fuel, oil, salaries and taxation = Rs. 0.15 crore; Interest and depreciation on capital = 12%.

If the annual load factor of the station is raised to 40%, find the percentage saving in cost per unit.

[1 paisa/kWh ; 12.2%]

5. The capital costs of steam and water power station are Rs. 1200 and Rs. 2100 per kW of the installed capacity. The corresponding running costs are 5 paise and 3.2 paise per kWh respectively.

The reserve-capacity in the case of the steam station is to be 25% and that for the water power station is to be 33.33% of the installed capacity.

At what load factor will the overall cost per kWh be the same in both cases ? Assume interest and depreciation charges on the capital to be 9% for the thermal and 7.5% for the hydroelectric station. What would be cost of generating 500 million kWh at this load factor ? **[47.5% ; Rs. 4.12 crores]**

6. In a particular area, both steam and hydro stations are equally possible. It has been estimated that capital costs and the running costs of these two types will be as follows :

	Capital cost /kW	*running cost/kW*	*interest*
Hydro	Rs. 2,200	1 paisa	5%
Steam	Rs. 1,200	5 paise	5%

If expected average load factor is only 10% which is economical to operate, steam or hydro ? If the load factor is 50%, would there be any changes in the choice ? If so, indicate with calculations.

[10% load factor ; hydro ; 13.5 paise / kWh ; Steam = 11.85 paise/ kWh50% load factor ; hydro ; 3.5 paise/kWh ; Steam = 6.35 paise/kWh]

7. A consumer takes a steady load of 200 kW at a power factor of 0.8 lagging for 10 hours per day and 300 days per annum. Estimate his annual payment under each of the following tariffs :

(*i*) 10 paisa per kWh plus Rs. 100 per annum per kVA

(*ii*) 10 paisa per kWh plus Rs. 100 per annum per kW plus 2 paisa per kVARh.

[(i) Rs. 85,000 (ii) Rs. 170,000.] (*Util. of Elect. Power, Punjab Univ.*)

8. A consumer requires one million units per year and his annual load factor is 50%. The tariff in force is Rs. 120 per kW per annum plus 5 paise per unit. Estimate the saving in his energy charges which would result if he improved his load factor to 100%.

[Rs. 13,698.60] (*Util. of Elect. Power, AMIE*)

9. A factory has a maximum demand of 1000 kW and a load factor of 40%. It buys power from a company at the rate of Rs. 45 per kW plus Rs. 0.025/kWh consumed. Calculate the annual electricity bill of the factory. Also work out the overall cost of one unit of electricity.

[Rs. 1,32,600, 3.78 paise] (*Util of Elect. Power, AMIE*)

10. A power station having a maximum demand of 100MW has a load factor of 30%. It is to be supplied by any of the following schemes :

(*a*) a steam power station in conjunction with a hydro station, the latter supplying 108 kWh/annum with a maximum output of 40 MW.

(*b*) a steam station capable of supplying whole load,

(*c*) a hydro station capable of supplying whole load.

	The following data may be assumed :	steam	hydro
(*i*)	Capital cost/kW installed capacity	Rs. 600	Rs. 1500
(*ii*)	Interest and depreciation on capital cost	12%	10%
(*iii*)	Operating cost/unit	5 p	1 p
(*iv*)	Transmission cost/unit negligible	0.25 p	

Neglect spares. Calculate the overall cost per unit generated in each case.

[(a) 7.5 P/ kWh (b) 7.74 P/kWh (c) 6.95 P/kWh]

11. An electricity undertaking having a maximum load of 100 MW generates 375 million kWh per annum and supplies consumers having an aggregate maximum demand of 165 MW.

The annual expenses including capital charges are : for fuel Rs. 30 lakhs, fixed charges concerning generation Rs. 40 lakhs. Fixed charges connected with transmission and distribution: Rs. 50 lakhs. Assume that 90% of the fuel cost is essential to running charges and with the losses in transmission and distribution as 15% of the kWh generated, deduce a two-part tariff to find the actual cost of supply to consumers. **[Rs. 56.3 per kW Max. demand ; 0.84 P/kWh]**

12. Obtain a tariff for the consumers of supply undertaking which generates 39×10^7 kWh/year and has maximum demand of 130 MW connected to it. The cost is distributed as follows :

Fuel : Rs. 37.5 lakhs : Generation : Rs. 18 lakhs ; Transmission : Rs. 37.5 lakhs ; Distribution : Rs.25.5 lakhs.

Of these items, 90%, 10% 5% and 7% respectively are allocated to running charges, the remainder being fixed charges. The total loss between the station and the consumers is 10% of the energy generated.

Find also the load factor and overall cost per unit.

[Rs. 61 per kW max. demand and 1.1 P/kWh ; 34.2% ; 3.38 P/kWh]

13. A generating station has got maximum demand of 80 kW. Calculate the cost per kWh delivered from the following data :

Capital cost = Rs. 16×10^6
Annual cost of fuel and oil = Rs. 14×10^5
Taxes, wages and salaries = Rs. 9×10^5
The rate of interest and depreciation is 12%; Annual load factor is 60%.

[10.036 paise] (*Utili. of Elect. Power. AMIE*)

14. A S/S supplies power by four feeders to its consumers. Feeder No. 1 supplies six consumers whose individual daily maximum demands are 70 kW, 90 kW, 20 kW, 50 kW, 10 kW and 20 kW, while the maximum demand on feeder is 200 kW. Feeder No. 2 supplies four consumers, whose daily max. demands are 60 kW, 40 kW, 70 kW, and 30 kW, while the maximum demand on feeder No. 2 is 160 kW. Feeders Nos. 3 and 4 have a daily maximum demand of 150 kW and 200 kW respectively, while the maximum demand on the station is 600 kW.

Determine the diversity factor for the consumers of feeder No. 1, feeder No. 2 and for the four feeders. **[1.3, 1.25, 1.18] (*AMIE*)**

15. A generating station has a M.D. of 75 MW and a yearly load factor of 40%. Generating costs inclusive of station capital cost are Rs. 60 per annum per kW demand plus 1 paisa/ kWh transmitted. The annual capital charge for the transmission system is Rs. 1.5 million, the respective diversity factors being 1.2 and 1.25 respectively. The efficiency of transmission system is 90% and that of the distribution system inclusive of substation losses 85%. Find the yearly cost per kW demand and the cost per kWh supplied (*a*) at the substation and (*b*) at the consumer's premises.

[(*a*) Rs. 72.2 per kW M.D. and 1.1. P/kWh (b) Rs. 71.1 per kW M.D. and 1.31 P/kWh]

50.21. Kelvin's Law

We will now consider the application of Kelvin's economy law to power transmission through feeder cables. Since, in feeders, voltage drop is not of vital importance, they can be designed on the basis of their current-carrying capacity and where feasible, of minimum financial losses.

The financial loss occuring in a current-carrying conductor is made up of two parts :

(*i*) interest on the capital cost of the conductor plus allowance for depreciation and

(*ii*) the cost of energy loss due to **(*a*)** ohmic resistance *i.e.*, I^2R loss, **(*b*)** losses in the metallic sheaths of sheathed cables and **(*c*)** in the case of high tension insulated cables, loss in the insulating material used.

For a given length of the cable, the weight and hence cost of copper required is directly proportional to the cable cross-section. The annual combined interest on capital cost and depreciation is also directly proportional to the cross-section of the cable and can be written as Rs. PA where P = a constant and A = cross-section of the cable.

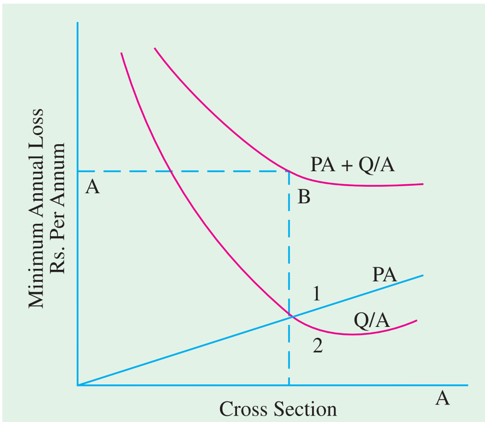


Fig. 50.11

Now, we will consider the cost of I^2R loss, neglecting at the moment losses other than ohmic. The ohmic resistance of the conductor is proportional to $1/A$. For a given annual load curve, the energy loss is proportional to resistance and so proportional to $1/A$. It can be written as Q/A where Q is another constant. If the load is variable, then current used in calculating I^2R loss will be the r.m.s. value of current reckoned over a period of one year.

$\therefore$ total annual financial loss is $L =$ Rs. $\left(PA + \dfrac{Q}{A}\right)$

Now, it can be proved that this annual financial loss will be minimum when $PA = Q/A$ *i.e.*, ***when annual charge on the capital outlay is equal to the annual value of the energy loss***.* The most economical cross-section which will make the above cost equal is given by :

$$PA = \frac{Q}{A} \text{ or } A^2 = Q/P \therefore A = \sqrt{Q/P}$$

The most economical cross section can be also found graphically as shown in Fig. 50.11. It is seen that graph of PA is a straight line (curve 1) and that of Q/A is a rectangular hyperbola (curve 2). The graph for total annual loss is obtained by combining curves 1 and 2 and is found to exhibit a minimum for that value of 'A' which corresponds to the intersection of the two curves.

Since we have neglected the dielectric and sheath losses while deriving the above condition of minimum financial loss, it is obvious that it applies only to ***bare conductors.***

In practice, Kelvin's law may have to be modified because the most economical size so calculated may not always be the practical one because it may be too small to carry the current.

Example 50.55. *If the cost of an overhead line is Rs. 2000 A (where A is the cross-sectional area in cm^2) and if the interest and depreciation charges on the line are 8%, estimate the most economical current density to use for a transmission requiring full-load current for 60% of the year. The cost of generating electric energy is 5 paise/kWh. The resistance of a conductor one kilometre long and 1 cm^2 cross-section is 0.18 Ω.*

Solution. Take one kilometre of the overhead line and let I be the full-load current, then if R is the resistance of each line, the full-load power loss in the line is

$$= 2I^2R = 2I^2 \times 0.18 \times \frac{1}{A} \text{ watt} = \frac{0.36\, I^2}{A} \times 10^{-3} \text{ kW}$$

Since the line works for 60% of the year *i.e.* for $(0.6 \times 365 \times 24)$ hours, hence total annual loss is $= \dfrac{0.35\, I^2}{A} \times 10^{-3} \times 0.6 \times 365 \times 24$ kWh

$$\therefore \text{ annual cost of this loss} = \text{Rs.} \left(\frac{0.35\, I^2}{A} \times 10^{-3} \times 0.6 \times 365 \times 24 \times 0.05 \right) = 0.0946 \text{ I2/A}$$

The annual value of interest on capital outlay and depreciation = 8% of 2,000 A = Rs. 160 A

For minimum total financial loss : $160\, A = 0.0946\, I^2/A \quad I/A = \sqrt{(160/0.0946)}$ = **41.12 A/cm^2**

Example 50.56. *A 500-V, 2-core feeder cable 4 km long supplies a maximum current of 200 A and the demand is such that the copper loss per annum is such as would be produced by the full-load current flowiing for six months. The resistance of the conductor 1 km long and 1 sq cm. cross-sectional area is 0.17 Ω. The cost of cable including installation is Rs. (120 A + 24) per metre where A is the area of cross-section in sq. cm and interest and depreciation charges are 10%. The cost of energy is 4 paise per kWh. Find the most economical cross-section.*

(Electrical Technology, M.S. Univ. Baroda)

Solution. Let us consider one kilometer length of the feeder cable.**

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* For this expression to have minimum value $\dfrac{dL}{dA} = 0$

$$\frac{d}{dA}(P + Q/A) = 0 \quad \text{or} \quad P - \frac{Q}{A^2} = 0 \quad \therefore \quad P = \frac{Q}{A^2} \quad \text{or} \quad PA = \frac{Q}{A} \quad \text{or} \quad A = \sqrt{Q/P}$$

** Even through we are given 4 km length of the cable, so far as our calculations are concerned, any convenient unit of length can be taken.

Cable cost/metre $= \text{Rs. } (120\,A + 24)$

Cost of 1 km long cable $= \text{Rs. } 120\,A \times 1000 = \text{Rs. } 12 \times 10^4\,A$

Interest and depreciation per annum is $= 10\%$ of Rs. $12 \times 10^4\,A = \text{Rs. } 12 \times 10^3\,A$

Resistance of one km long cable is $R = 0.17/A$ ohm. —where A is in cm^2

Cu loss in the cable $= 2I^2R = 2 \times 200^2 \times 0.17/A\ W = 13.6 \times 10^3/AW = 13.6/A$ kW

Energy loss over six months $= (13.6/A) \times (8760/2)$ kWh $= 59{,}568/A$ kWh

Cost of this energy loss $= \text{Rs. } 59{,}568 \times 0.04/A = \text{Rs. } 2383/A$

For most economical cross-section ; $12 \times 10^3\ A = 2{,}383/A,\ A = \sqrt{0.1986} =$ **0.446 cm²**

Example 50.57. *A 2-core, 11-kV cable is to supply 1 MW at 0.8 p.f. lag for 3000 hours in a year. Capital cost of the cable is Rs. (20 + 400a) per metre where a is the cross-sectional area of core in cm². Interest and depreciation total 10% and cost per unit of energy is 15 paise. If the length of the cable is 1 km, calculate the most economical cross-section of the conductor. The specific resistance of copper is 1.75×10^{-6} ohm-cm.* **(Power Systems-I, AMIE, Sec. B, 1993)**

Solution. Cost of 1 km length of the cable = Rs. $(20 + 400a) \times 1000 = (20{,}000 + 400 \times 10^3 a)$

If a is the cross-sectional area of each core of the cable, then resistance of 1 km cable length is

$= 1.75 \times 10^{-6} \times 1000 \times 100/a = 0.175/a\ \Omega$.; F.L. current $= 1 \times 10^6/11 \times 10^3 \times 0.8 = 113.6$ A

Power loss in the cable $= 2I^2R = 2 \times 113.6^2 \times (0.175/a) = 4516.7/a$ W

Annual cost of energy loss $= \text{Rs. } (4516.7/a) \times 3000 \times 10^{-3} \times (15/100) = \text{Rs. } 2032.5/a$.

Interest and depreciation per annum $= 0.1 \times 400 \times 10^3 a = 40{,}000\,a$

As per Kelvin's law, the most economical cross-section would be given by

$$40{,}000\,a = 2032.5/a \qquad a = 0.2254 \text{ cm}^2 \text{ and}$$

$$d = \sqrt{0.2254 \times 4/\pi} = \mathbf{0.536\ cm.}$$

50.22. Effect of Cable Insulation

Let us now consider the effect of insulation in the case of an insulated cable. The cost of insulation would now be added to the annual value of interest and depreciation. Since for a given type of cable, a given type of armouring and for a given voltage of transmission, the insulation cost does not vary much with the cross-section of the cable, it is taken care of by merely adding a constant R to the term Rs. PA. Hence, the annual interest and depreciation, and insulation cost is represented by the term Rs. $(PA + R)$ where R is a constant representing insulation cost. The addition of term Rs. R results in merely raising the graph of Rs. PA vertically through a distance representing Rs. R, as shown in Fig. 50.12.

The total annual financial loss of insulated cable is thus represented by Rs. $(PA + R + Q/A)$. It should be noted that curve for Q/A is not disturbed at all. However, the graph for total loss *i.e.* $(PA + Q/A + R)$ is only shifted vertically through a distance equal to Rs.

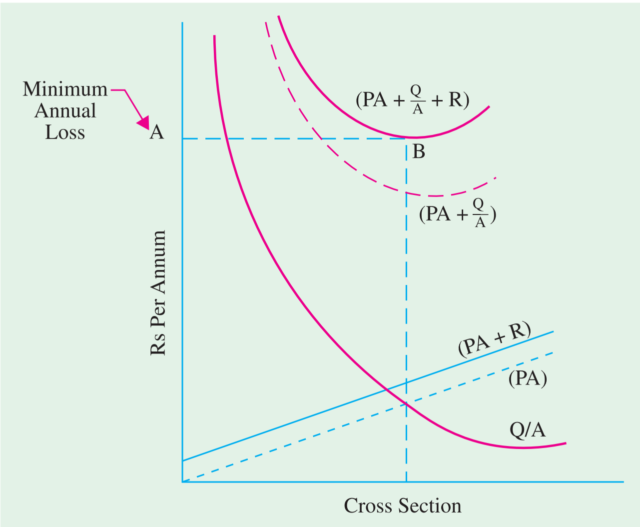

Fig. 50.12

R without any horizontal displacement of the point of minimum financial loss. In other words, the insulation cost does not affect the value of most economical cross-section. Hence, for an insulated cable, Kelvin's law is : *the most economical cross-section is that which makes the interest on the capital outlay plus depreciation due to the conductor in the cable equal to the annual cost of energy lost.*

Example 50.58. *The cost of a two-core feeder cable including insulation is Rs. (130 A + 24) per metre and the interest and depreciation charges 10% per annum. The cable is two km in length and the cost of energy is 4 paisa per unit. The maximum current in the feeder is 250 amperes and the demand is such that the copper loss is equal to that which would be produced by the full current flowing for six months. If the resistance of a conductor of 1 sq. cm cross-sectional area and one km in length be 0.18 Ω, find the most economical section of the same.*

Solution. Cable cost/m = Rs. $(130\,A + 24)$ where A is the cable cross-section in cm^2.

Cost of 1 km long conductor = Rs. $(130\,A \times 1000)$ = Rs. $(13 \times 10^4\,A)$

Interest and depreciation per annum = $0.1 \times 13 \times 10^4\,A$ = Rs. $(13 \times 10^3\,A)$

Resistance of one km long conductor = 0.18/A ohm

Cu loss in the cable $= 2I^2R = 2 \times 250^2 \times \dfrac{0.18}{A}\text{ W} = 2 \times 250^2 \times \dfrac{0.18}{A} \times 10^{-3}\text{ kW}$

Annual value of this energy loss = Rs. $\left(2 \times 250^2 \times \dfrac{0.18}{A} \times 10^{-3}\,\dfrac{4}{100}\right) \times \dfrac{8760}{2}$

= Rs. 3941/A

For most economical cross-section 13×10^3 A = 3,942/A $\therefore$ $A^2 = 3942/13 \times 10^3$

$\therefore$ A = **0.505 cm^2**

Example 50.59. *An 11-kV, 3-core cable is to supply a works with 500-kW at 0.9 p.f. lagging for 2,000 hours p.a. Capital cost of the cable per core when laid is Rs. (10,000 + 32,00 A) per km where A is the cross-sectional area of the core in sq. cm. The resistance per km of conductor of 1 cm^2 cross-section is 0.16 Ω.*

If the energy losses cost 5 paise per unit and the interest and sinking fund is recovered by a charge of 8% p.a., calculate the most economical current density and state the conductor diameter.

(Power Systems-I, AMIE-1994)

Solution. The annual charge on cost of conductors per km is = $0.08 \times 32{,}000\,A$ = Rs. 2,560 A

Current per conductor is = $500{,}000/\sqrt{3} \times 11{,}000 \times 0.9 = 29.2$ A

Losses in all the three cores $= 3I^2R = 3 \times 29.2^2 \times \dfrac{0.16}{A} = \dfrac{409.3}{A} \times 10^{-3}\text{ kW}$

Annual cost of this loss = Rs. $\dfrac{409.3 \times 10^{-3}}{A} \times \dfrac{5}{100} \times 200 = \text{Rs. } \dfrac{40.93}{A}$

Obviously, the values of the two constants per km are P = 2,560 and Q = 40.93

The most economical cross-section is given by $A = \sqrt{Q/P} = \sqrt{(40.93/2{,}560)} = 0.1265\text{ cm}^2$

The current density is 29.2/0.1265 = **231 A/cm^2** and the conductor diameter is

$d = \sqrt{4 \times 0.1256/\pi}$ = **0.4 cm.**

Example 50.60. *Discuss limitations of the application of Kelvin's law.*

An industrial load is supplied by a 3-phase cable from a sub-station at a distance of 6 km. The voltage at the load is 11 kV. The daily load cycle for six days in a week for the entire year is as given below :

(i) *700 kW at 0.8 p.f. for 7 hours,* *(ii)* *400 kW at 0.9 p.f. for 3 hours,*

(iii) *88 kW at unity p.f. for 14 hours.*

Compute the most economical cross-section of conductors for a cable whose cost is Rs. (5000 A + 1500) per km (including the cost of laying etc.). The tariff for the energy consumed at the load is Rs. 150 per annum per kVA of M.D. plus 5 paise per unit. Assume the rate of interest and depreciation as 15%. The resistance per km of the conductor is (0.173/A) Ω.

(Electrical Power-I ; Bombay Univ.)

Solution. Capital cost of the cable = 6 × Rs. (5000 A + 1500) = Rs. (30,000 A + 9000).

Annual cost of interest and depreciation = Rs. 0.15 (30,000 A + 9000) = Rs. (4500 A + 1350).

Resistance of each conductor = $6 \times 0.173/A = 1038/A$ ohm

Line currents due to different loads are :

(i) At 700 kW, 0.8 p.f.; $I = 700 \times 10^3/\sqrt{3} \times 11 \times 10^3 \times 0.8 =$ **45.9 A**

(ii) At 400 kW, 0.9 p.f.; $I = 400 \times 10^3/\sqrt{3} \times 11 \times 10^3 \times 0.9 =$ **23.3 A**

(iii) At 88 kW, u.p.f. $I = 88/ \times 11 =$ **4.62 A**

The corresponding energy losses per week in the cable are :

(i) loss $= 3 \times 45.9^2 \times (1.038/A) \times (6 \times 7)/1000 = (276/A)$ kWh

(ii) loss $= 3 \times 23.3^2 \times (1.038/A) \times (6 \times 3)/1000 = (30.4/A)$ kWh

(iii) loss $= 3 \times 4.62^2 \times (1.038/A) \times (6 \times 14) \times 10^{-3} = (5.6/A)$ kWh

Total weekly loss $= (276/A) + (30.4/A) + (5.6/A) = (312/A)$ kWh

Taking 52 weeks in one year, we have

Annual Cu loss $= \text{Rs. } \frac{5}{100} \cdot \frac{312}{A} \times 52 = \text{Rs. } \frac{811}{A}$

Max. voltage drop in each conductor = $45.9 \times 1.038/A = (47.64/A)$ volt

Max. kVA demand charge due to this drop for three conductors is

$= \text{Rs. } 3 \times (47.64/A) \times 45.9 \times 10^{-3} \times 150 = \text{Rs. } 984/A$

Total annual charges due to cable loss = Rs. (811/A) + Rs. (984/A) = Rs. (1795/A)

For the most economical size of the cable ; $4500\,A = 1795/A$; $A = 0.63$ cm^2.

Note. Though not given, it has been assumed that A appearing in Rs. (5000 A + 1500) is in cm^2.

Tutorial Problem No. 50.2

1. The daily load cycle of a 3-phase, 110-kV transmission line is as follows :
   (*a*) 6 hours–20 MW, (*b*) 12 hours–5 MW, (*c*) 10 hours – 6 MW. The load p.f. is 0.8 lag for all the three loads. Determine the most economical cross-section if the cost of the line including erection is Rs. (9,000 + 600 A) per km where A is the cross-section of each conductor in cm^2. The rate of interest and depreciation is 10% and energy cost is 6 paise/unit. The line is in use all the year. The resistance per km of each conductor is 0.176/A ohm. **[1.64 cm^2]**
2. Find the most economical cross-section of conductor for a system to transmit 120 A at 250 V all the year round with a cost of 10 paise per kWh for energy wasted. The two-core cable costs Rs. 20 A per metre where A is the cross-section of each core in cm^2. The length of feeder is one km. The interest and depreciation charges total 8% of total cost. One km of Cu wire 1 cm^2 in cross-section area has a resistance of 0.15 W.
   [1.52 cm^2]

50.23. Note on Power Factor

Irrespective of the nature of voltage and current, the power factor may be defined as the ratio of true power consumed to the apparent power (product of voltage and current).

$$\therefore \qquad \text{p.f.} = \frac{W}{VA} = \frac{kW}{kVA}$$

If voltage and current are both sinusoidal, then p.f. = kW/kVA = cos ϕ

where ϕ is the phase difference between voltage and current.

The power factor of all a.c. motors (except over-excited synchronous motors and certain types of commutator motors) and transformers is less than unity (lagging). Majority of industrial motors are induction motors which have a reasonable high power factor (0.9 or so) at full-load but very low power factor at light loads and at no-load as low a value as 0.1. Induction motor is, in fact, a simple resistance-inductance circuit. The current taken by such a circuit has two components ***(i)*** active or wattful component Iw which is in phase with the voltage. Its value is I cos ϕ where I is total circuit current. It is this component which represents the useful power in the circuit and ***(ii)*** reactive or wattless or idle component I_μ which lags behind the applied voltage by 90°. Its value is I sin ϕ and its purpose is to produce alternating magnetic flux. Hence, it is also known as wattless or magnetising current.

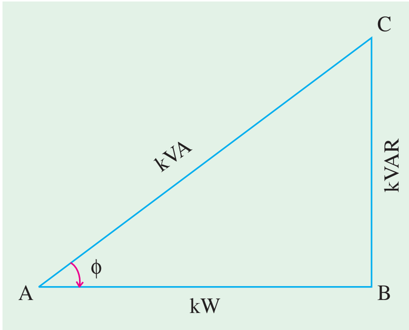

Fig. 50.13

Obviously $\qquad I^2 = I_w^{\,2} + I_\mu^{\,2}$

Multiplying both sides by V_2, we get

$$V^2I^2 = V^2I_w^{\,2} + V^2I_\mu^{\,2}$$

or $\qquad (VI)^2 = (VI_w)^2 + (VI_\mu)^2$

Now $\qquad VI$ = volt-amperes written as VA ; VI_w = wattage W

$\qquad VI_\mu$ = reactive volt-ampere written as $VA\,R$.

Hence, in any inductive circuit as shown in Fig. 50.13

$$\text{kVA}^2 = \text{kW}^2 + \text{kVA R}^2$$

For example, suppose an R-L circuit draws a current of 100 A from a supply of 250 V at a power factor of 0.8, then total kilo-voltampere of the circuit is 250 × 100/1000 = 25 kVA. The true power is 250 × 100 × 0.8/1000 = 20 kW and reactive voltampere is 250 × 100 × 0.6/1000 = 15 kVAR.

Obviously, $\qquad \text{kVA} = \sqrt{20^2 + 15^2} = 25$

50.24. Disadvantages of Low Power Factor

Suppose a 3-phase balanced system is supplying a load W at a voltage of V and p.f. cos ϕ, then current flowing through the conductor is $I = W/\sqrt{3}\,.\,V\,.\cos\phi$.

A lower power factor, obviously, means a higher current and this affects in the following three ways :

1. Line losses are proportional to I^2 which means proportional to $1/\cos^2\phi$. Thus losses at cos ϕ = 0.8 are 1/0.82 = 1.57 times those at unity power factor.
2. Ratings of generators and transformers etc. are proportional to current, hence to 1/cos ϕ, therefore, larger generators and transformers are required.
3. Low lagging power factor causes a large voltage drop, hence extra regulation equipment is required to keep voltage drop within prescribed limits.

Explanation

Low power factor means higher wattless current which presents a serious problem from supply viewpoint. Consider the following numerical example. Suppose an alternator (single-phase) is to have an output of 1500 kW at 10,000 V.

(*a*) Load at unity power factor $P = VI \times 1 = VI$ watt and $I = \dfrac{P}{V} = \dfrac{1,500,000}{10,000} = 150$ A

In this case $\quad$ kVA $=$ kW $= 1500$

(*b*) If the load has a lagging p.f. of 0.6, then

$$I = \frac{P}{V\cos\phi} = \frac{1,500,000}{10,000 \times 0.6} = 250 \text{ A and kVA} = \mathbf{2500}$$

It is obvious that in case **(*b*)**, the current-carrying capacity of alternator winding will have to be (250-150)/150 = 0.67 or 67% greater. Now, the size and hence cost of a given type of alternator is decided by kVA output and not by kW.

In case **(*a*)**, kVA = kW1500. In case **(*b*)** kVA = 1500/0.6 = 2500.

It is seen that with a load p.f. of 0.6, the cost of an alternator to give the same power output and hence the earning capacity, is about 67% greater than when p.f. is unity. Moreover, the switchgear will have to carry 250 A instead of 150 A and so, will be correspondingly larger and more costly. Since transformers are almost always used in the line, they too will be more expensive.

The cables connecting the alternator with the load will also have to carry more current. If current density is the same, then cable cross-section and hence the weight of copper required will be increased.

Therefore, it is seen that a low power factor leads to a high capital cost for the alternator, switchgear, transformers and cables etc. Since the value of power factor is decided by the consuming devices like motors etc., the electric supply undertakings encourage the consumers to make their power factor as high as possible. As an inducement, they offer cheaper tariffs in different ways discussed in Art. 50.25.

The disadvantages of low power factor are summarized below :

In a transmission line (supplying an inductive load) it is only the in-phase component of line current which is active in the transmission of power. When power factor is low, then in-phase (or active) component is small, but reactive component is large hence unnecessarily large current is required to transmit a given amount of power. Large reactive component means large voltage drop and hence greater Cu losses with the result that the regulation is increased and efficiency is decreased.

Lighting and heating loads, being mainly resistive, have unity p.f. but electromagnetic machinery has a low p.f. especially on no-load or light loads.

A low power factor (lagging) system has the following disadvantages as compared to a system carrying the same power but at higher p.f.

1. As current is large and at a large lagging angle, it cause greater losses and requires higher excitation in the generators, thereby reducing the efficiency of generation.

2. Increased Cu losses are incurred in the cables and machinery because of large current. Both these factors raise the running cost of the system.

3. The ratings of the generators, transformers, switchgears and cables etc., have to be increased, which means additional capital charges with increased depreciation and interest.

4. Due to voltage drop in generators, transformers and cables etc. the regulation becomes poor. As supply authorities are usually bound to maintain the voltage at consumer's terminals within prescribed limits, they have to incur additional capital cost of tap-changing gear on transformers to compensate for the voltage drop. Hence, the supply authorities penalise industrial consumers for their low power factor by charging increased tariff for kVA maximum demand in addition to usual kWh charge. Obviously, it is advantageous for the consumer to improve his load p.f. with the help of phase-advancing equipment (*i.e.* synchronous capacitors) or static capacitors.

50.25. Economics of Power Factor

In order to induce the customers to keep their load p.f. as high as possible, tariff rates for a.c. power are such that the overall charge per kWh of the energy consumed depends, in some way or the other, on the load p.f. of the consumer. Some of the ways in which it is done are given below :

(i) The total bill for consumption is so adjusted as to make it depend on the deviation of the load p.f. from a standard value,say 0.9. The bill is increased by a constant percentage for each unit p.f. deviation from 0.9, say, for every decrease of 0.01 from 0.9. Similarly, there would be bonus for each increase of unit p.f. value.

(ii) The total power bill is adjusted in some way on the total reactive kilo-volt ampere-hour *i.e.* kVARh instead of kWh. Special meters are installed for measuring kVARh.

(iii) But the most commonly-used tariff is the two-part tariff (Art. 50.20). The fixed charges instead of being based on kW maximum demand are based on kVA maximum demand so that they become inversely proportional to the power factor (because kVA = kW/cos ϕ)

Explanation

Consider a single-phase, 1500-kW, 10,000-V alternator already discussed in Art. 50.24. Suppose whole of its output is taken up by one consumer and the two-part tariff is Rs. 60 per annum per kVA max. demand plus 2 paise per kWh. Let the load factor be 30%. Then,

Average power throughout the year = $0.3 \times 1500 = 450$ kW

$\therefore$ annual consumption = $450 \times 8{,}760$ kWh

Annual cost at 2 paise per kWh = Rs. $450 \times 8{,}760 \times 0.02$ = Rs. 78,840

For the fixed kVA charge, we have

Annual charge at unit p.f. = Rs. 60×1500 = Rs. 90,000

Annual charge at of 0.6 p.f. = Rs. $60 \times (1500/0.6)$ = Rs. 150,000

Total charges at unity p.f. = Rs. 90,000 + 78,840 = Rs. 168,840

Total charges of 0.6 p.f. = Rs. 150,000 + 78,840 = Rs. 228,840

It is seen that annual saving for unity p.f. is Rs. 60,000. Of course, this may not represent the net total saving when p.f. correction has been done either by phase-advancing equipment or static capacitors because the cost and maintenance of p.f. correcting apparatus has still to be taken into account. The cost will be by way of interest on capital required to install the p.f. improvement apparatus plus depreciation, maintenance expenses etc.

Consider the undergiven case. To illustrate how two-part tariff operates for different cases, suppose that rate of charging power to a large factory is Rs. 90 per annum per kVA maximum demand and 2 paise per kWh consumed. Also, suppose that the factory has 450 kW maximum load demand and an annual consumption of 10,000,000 kWh.

(i) If load p.f. were 0.9, then 450 kW max. demand is equal to 450/0.9 = 500 kVA max. demand.

(ii) If load p.f. were 0.7, then 450 kW max. demand is equal to 450/0.7 = 643 kVA max. demand.

Cost on kWh consumed will be the same for both power factors, it is only the maximum demand charge which will vary with the power factor.

At 0.7, the annual fixed charge for 643 kVA at Rs. 90 is Rs. 90×643 = Rs. 57,870

At 0.9, the annual fixed charge for 500 kVA = Rs. 90×500 = Rs. 45,000

$\therefore$ extra charge = Rs. 12,870

Now, let us assume that phase advancing equipment required to improve the power factor from 0.7 to 0.9 costs Rs. 50,000. Then, taking combined interest and depreciation at 12%, the annual charge will be Rs. $50{,}000 \times 0.12$ = Rs. 6,000.

Hence, the net annual saving comes to Rs. 12,870 – Rs. 6,000 = Rs. 6,870.

If, suppose, the p.f. correcting plant had cost Rs. 107,250, then interest and depreciation allowance on it would be = Rs. 107,250 × 0.12 = Rs. 12,870. In that case, there would be no point in installing such an apparatus because there would be no net saving.

It can be seen from the above example that higher the desired power factor improvement *i.e.* greater the kVAR reduction, the more costly the p.f. improvement plant and hence greater the charge on interest on capital outlay and depreciation. A point is reached, in practice, when any further improvement in power factor costs more than the saving in the power bill. Hence, it is necessary for the consumer to find out the value of power factor at which his net saving will be maximum. The value can be found if ***(i)*** annual charge per kVA maximum demand and ***(ii)*** the cost per kVA rating of phase advancing equipment are known.

50.26. Economical Limit of Power Factor Correction

Suppose a consumer is charged at Rs. A per kVA maximum demand plus a flat rate per kWh. Further, suppose that he is taking power of P kW at a power factor of cos ϕ_1. As shown in Fig. 50.14, his kVA$_1$ is $P/\cos\phi_1$ and his kVAR$_1$ is $P\tan\phi_1$. Suppose by installing static capacitors or synchronous capacitors, he improves his power factor to cos ϕ_2 (his power consumption P remaining the same). In that case, his kVA$_2$ is $P/\cos\phi_2$ and kVAR$_2$ is $P\tan\phi_2$.

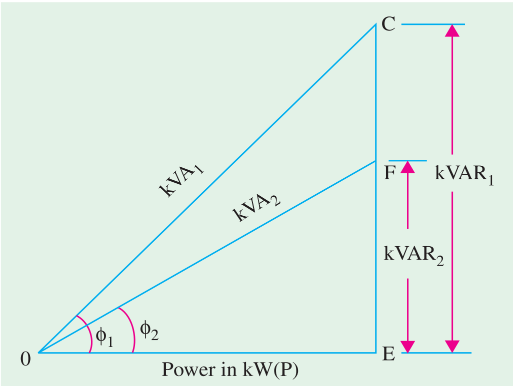

Fig. 50.14

Reduction in his kVA maximum demand is = (kVA$_1$ – kVA$_2$) = ($P/\cos\phi_1 - P/\cos\phi_2$). Since charge is Rs. A per kVA maximum demand, his annual saving on this account is

$$= A\,(P/\cos\phi_1 - P/\cos\phi_2).$$

His kVAR is reduced from kVAR$_1$ to kVAR$_2$, the difference (kVAR$_1$ – kVAR$_2$) = ($P\tan\phi_1 - P\tan\phi_2$) being neutralized by the leading kVAR supplied by the phase advancer.

∴ Leading kVAR supplied by phase advancer is = ($P\tan\phi_1 - P\tan\phi_2$).

If the cost per kVAR of advancing plant is Rs. B and the rate of interest and depreciation is p percent per year, then its cost per annum is

$$= \frac{BP}{100}(P\tan\phi_1 - P\tan\phi_2)$$

$$= C\,(P\tan\phi_1 - P\tan\phi_2) \text{ where } C = BP/100$$

∴ Net annual saving $S = A\,(P/\cos\phi_1 - P/\cos\phi_2) - C(P\tan\phi_1 - P\tan\phi_2)$

This net saving is maximum when $dS/d\phi_2 = 0$

$$\therefore \quad \frac{dS}{d\phi_2} = \frac{d}{d\phi_2}[A\,(P/\cos\phi_1 - P/\cos\phi_2) - C\,(P\tan\phi_1 - P\tan\phi_2)]$$

$$= -AP\sec\phi_2\tan\phi_2 + CP\sec^2\phi_2$$

For maximum saving, $dS/d\phi_2 = 0$

$$\therefore \quad -AP\sec\phi_2\tan\phi_2 + CP\sec^2\phi_2 = 0 \quad \text{or} \quad \sin\phi_2 = C/A = BP/A$$

From this expression, ϕ_2 and hence cos ϕ_2 can be found. It is interesting to note that the most economical angle of lag ϕ_2 is independent of the original value ϕ_1.

Obviously, most economical p.f. is

$$\cos\phi_2 = \sqrt{1-\sin^2\phi_2} = \sqrt{1-(C/A)^2} = \sqrt{1-(BP/100\,A)^2}$$

Example 50.61. *A 3-phase, 50-Hz, 3,000-V motor develops 600 h.p. (447.6 kW), the power factor being 0.75 lagging and the efficiency 0.93. A bank of capacitors is connected in delta across the supply terminals and power factor raised to 0.95 lagging. Each of the capacitance units is built of five similar 600-V capacitors. Determine capacitance of each capacitor.* **(London Univ.)**

Solution. Power input $P = 447,600/0.93 = 480,000$ W

$\cos\phi_1 = 0.75 ; \phi_1 = \cos^{-1}(0.75) = 41°24', \cos\phi_2 = \cos^{-1}(0.95) = 18°12'.$

$\therefore \quad \tan\phi_1 = \tan 41°24' = 0.8816, \tan\phi_2 = \tan 18°12' = 0.3288$

As shown in Fig. 50.14, leading VAR supplied by capacitor bank is

$= P(\tan\phi_1 - \tan\phi_2) = 480,000\,(0.8816 - 0.3288) = 48 \times 5,528$

Leading VAR supplied by each of the three sets $= 48 \times 5,528/3 = 16 \times 5,528$ ...(*i*)

Phase current of capacitor is $I_{CP} = \dfrac{V}{X_C} = \dfrac{3,000}{X_C} = \dfrac{3,000}{1/\omega C} = 3,000 \times 314\, C$

where C is the total capacitance in each phase.

$\therefore \quad$ VAR of each phase $= VI_{cap} = 3,000 \times 3,000 \times 314\, C$ ...(*ii*)

Equating (*i*) and (*ii*) we get, $3,000 \times 3,000 \times 314\, C = 16 \times 5,528 \quad \therefore \quad C = 31.22\ \mu F$

Since it is the combined capacitance of five equal capacitors joined in series, the capacitance of each $= 5 \times 31.22 =$ **156 μF**.

Example 50.62. *A synchronous motor having a power consumption of 50 kW is connected in parallel with a load of 200 kW having a lagging power factor of 0.8. If the combined load has a p.f. of 0.9, what is the value of leading reactive kVA supplied by the motor and at what p.f. is it working?* **(I.E.E. London)**

Solution. Let ϕ_1 = p.f. angle of motor ; ϕ_2 = p.f. angle of load

ϕ_t = combined p.f. angle ; $\phi_2 = \cos^{-1}(0.8) = 36°52'$

$\tan\phi_2 = \tan 36°52' = 0.75 ; \phi_t = \cos^{-1}(0.9) = 25°51'$

$\tan\phi_t = \tan 25°51' = 0.4854$

Combined power $P = 200 + 50 = 250$ kW

Total kVAR $= P\tan\phi_t = 250 \times 0.4854 = 121.1$

Load kVAR $= 200 \times \tan\phi_2 = 200 \times 0.75 = 150$

$\therefore$ leading kVAR supplied by synchronous motor $= 150 - 121.1 =$ **28.9**

$\tan\phi_1 = 28.9/50 ; \phi_1 = 30.1°, \quad \cos\phi_1 =$ **0.86 (lead)**

Example 50.63. *A generating station supplies power to the following, lighting load 100-kW ; an induction motor 400 h.p. (298.4 kW), power factor 0.8, efficiency, 0.92 ; a rotary converter giving 100 A at 500 V at an efficiency of 0.94. What must be the power factor of the rotary converter in order that the power factor of the supply station may be unity.*

Solution. Since, lighting load has no kVAR (unity p.f. assumed), the lagging kVAR of induction motor are neutralized by the leading kVAR of rotary converter only,

(*i*) Motor input $= 298.4/0.92 = 324.4$ kW

motor p.f. angle $\phi_m = \cos^{-1}(0.8) = 36°52' \quad \therefore \quad \tan\phi_m = \tan 36°52' = 0.75$

$\therefore$ lagging motor kVAR $= 324.4 \times \tan\phi_m = 324.4 \times 0.75 = 243.3$

$\therefore$ leading kVAR to be supplied by rotary converter = 243.3

Rotary converter intake $= 500 \times 100/0.94 \times 1000 = 53.2$ kW

$$\tan\phi = \frac{\text{kVAR}}{\text{kW}} = \frac{243.3}{53.2} = 4.573$$

$\therefore \quad \phi = 77°40'$ or $\cos\phi =$ **0.214 (leading)**

Example 50.64. *A factory has an average annual demand of 50 kW and an annual load factor of 0.5. The power factor is 0.75 lagging. The tariff is Rs. 100 per kVA maximum demand per annum plus five paise per kWh. If loss-free capacitors costing Rs. 600 per kVAR are to be utilized, find the value of the power factor at which maximum saving will result. The interest and depreciation together amount to ten per cent. Also, determine the saving affected by improving the power factor to this value.* **(Electrical Technology ; M.S. Univ. Baroda)**

Solution. The most economical power factor angle is given by $\sin\phi = C/A$

C = 10% of Rs. 600 = Rs. 60, A = Rs. 100 $\quad\therefore \sin\phi = 60/100 = 0.6$

$\phi = \sin^{-1}(0.6) = 36°52'$; New p.f. = $\cos 36°52'$ = **0.8**

The net annual saving due to improving in power factor can be found as follows :

Max. demand = 50/0.5 = 100 kW

At load p.f. of 0.75, maximum demand of 100 kW represents 100/0.75 = 400/3 kVA maximum demand.

At load p.f. of 0.8, 100 kW represent 100/0.8=125 kVA maximum demand.

Max. kVA demand charge

At 0.75 p.f. = Rs. $100 \times 400/3$ = Rs. 13,333.3

At 0.8 p.f. = Rs. 100×125 = Rs. 12,500

Annual saving = Rs. (13,333.3 – 12,500) = **Rs. 838.3**

Example 50.65. *For increasing the kW capacity of a plant working at 0.7 lag p.f. the necessary increase of power can be obtained by raising the p.f. to 0.85 or by installing additional plant. What is the maximum cost per kVA of p.f. correction apparatus to make its use more economical than additional plant at Rs. 500 kVA ?* **(Gen. Protect. and Switchgear, Madras Univ.)**

Solution. Let kVA_1 be the initial capacity of the plant and kVA_2 its increased capacity with extra or additional plant. As seen from Fig. 50.15.

$$KVA_1 \cos\phi_2 = kVA_2 \cos\phi_1$$

$$\therefore \quad kVA_2 = kVA_1 \times \cos\phi_2/\cos\phi_1$$

$$= kVA_1 \times 0.85/0.7 = (17/14)\, kVA_1$$

kVA of the additional plant $= kVA_2 - kVA_1 = (17/14)\,kVA_1 - kVA_1 = (3/14)\,kVA_1$

Capital cost of additional plant = Rs. $(500 \times 3/14)\,kVA_1$ = Rs. $(750/7)\,kVA_1$

Now, $\cos\phi_1 = 0.7,\ \phi_1 = 45°34'$; $\sin\phi_1 = 0.714$

$\cos\phi_2 = 0.85,\ \phi_2 = 31.8°$; $\sin\phi_2 = 0.527$

$\therefore$ kVAR supplied by p.f. correction apparatus

$$= (kVA_2 \sin\phi_1 - kVA1 \sin\phi_s) = \left(\frac{7}{14} \times 0.714\, kVA_1 - kVA_1 \times 0.527\right) = 0.34\, kVA_1$$

If the capital cost of the p.f. correction apparatus be Rs. x per kVAR, the total cost is = $0.34x$ kVA_1.

If the annual cost of the additional plant is to be the same as that of the p.f. correction apparatus (assuming same annual interest and depreciation), then

$$(750/7)\, kVA_1 = 0.34\, x\ kVA_1\ x = \text{Rs. } 315.2$$

If p.f. correction apparatus is loss-free, then its kVAR = kVA. Hence, the maximum cost per kVA of p.f. correction apparatus that can be paid is **Rs. 315.2.**

Example 50.66. *A consumer taking a steady load of 160 kW at a p.f. of 0.8 lag is charged at Rs. 80 per annum per kVA of maximum demand plus 5 paise per kWh consumed. Calculate the value to which he should improve the p.f. in order to affect the maximum saving if the leading kVA cost Rs.100 per kVA and interest and depreciation be at 12% per annum.*

Calculate also the saving.

(Electrical Technology ; Gujarat Univ.)

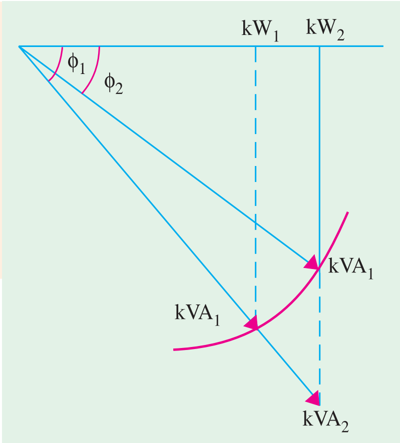

Fig. 50.15

Solution. With reference to Art. 50.26, $C = BP/100 = 12 \times 100/100 = 12$, $A = 80$

$$\text{Most economical p.f. } \cos\phi_2 = \sqrt{1-(BP/100A)^2}$$
$$= \sqrt{1-(12/80)^2}$$
$$= \mathbf{0.9887\ (lag)}$$

Since load remains steady, maximum load is also 160 kW.

At load p.f. of 0.8, maximum load of 160 kW represents 160/0.8 = 200 kVA.

Similarly, at 0.9887 p.f., it represents 160/0.9887 = 162 kVA.

Max. kVA demand charge at 0.8 p.f. = Rs. 80 × 200 = Rs. 16000

Max. kVA demand charge at 0.9887 p.f. = Rs. 80 × 162 = Rs. 12,960

∴ annual saving = Rs. (16,000 – 12,960) = **Rs. 3,040.**

Example 50.67. *A consumer takes a steady load of 1500 kW at a p.f. of 0.71 lagging and pays Rs. 50 per annum per kVA of maximum demand. Phase advancing plant costs Rs. 80 per kVA. Determine the capacity of the phase advancing plant required for minimum overall annual expenditure. Interest and depreciation total 10%. What will be the value of the new power factor of the supply?*

(Electrical Power-III, Bangalore Univ.)

Solution. Minimum overall annual expenditure corresponds to most economical power factor given by $\cos\phi_2 = \sqrt{1-(BP/100A)^2}$ as shown in Art. 50.26.

Now, $B = 80,\ P = 10,\ A = 50\ \cos\phi_2 = \sqrt{1-(80\times 10/100\times 50)^2} = \mathbf{0.987}$

Now, $\cos\phi_1 = 0.71,\ \phi_1 = 44.7°$

tan $\phi_1 = 0.9896$; $\cos\phi_2 = 0.987.\ \phi_2 = 9.2°,\ \tan\phi_2 = 0.162$

kVA supplied by phase advancing plant = $P(\tan\phi_1 - \tan\phi_2)$ = 1500 (0.9896 – 0.162) = **1240.**

Example 50.68. *A factory takes a load of 200 kW at 0.85 p.f. (lagging) for 2,500 hours per annum and buys energy on tariff of Rs. 150 per kVA plus 6 paise per kWh consumed. If the power factor is improved to 0.9 lagging by means of capacitors costing Rs. 525 per kVA and having a power loss of 100 W per kVA, calculate the annual saving affected by their use. Allow 8% per annum for interest and depreciation on the capacitors.*

Solution. Factory load = 200 kW

$\cos\phi_1 = 0.85$ (lagging)

∴ $\phi_1 = \cos^{-1}(0.85) = 31°48'$ $\tan\phi_1 = 0.62$

∴ lagging kVAR of factory load = 0.62 × 200 = 124

(or first find total kVA = 200/0.85 and then multiply it by $\sin\phi_1$ to get kVAR)

Suppose, x = capacitor's kVAR (leading), Total kVAR = 124 – x

Because loss per kVA is 100 W *i.e.*, 1/10 kW per kVA

$\therefore$ capacitor's loss $= x/10$ kW

$\therefore$ Total kW $= 200 + (x/10)$

Now, overall p.f. $= \cos\phi = 0.9 \quad \therefore \quad \phi = 25°51' \quad \therefore \tan 25'51' = 0.4845$

Now $\tan\phi = \dfrac{\text{total kVAR}}{\text{total kW}} = \dfrac{124 - x}{200 + (x/10)} \quad \therefore \quad x = 25.9$ kVAR

Cost per annum before improvement

kVA = 200/0.85 = 235.3 Units consumed per annum = $200 \times 2500 = 5 \times 10^5$ kWh

$\therefore$ annual cost = Rs. $(235.3 \times 150 + 5 \times 105 \times 6/100)$ = Rs. 65,295

Cost per annum after improvement

kVA = 200/0.9 = 222.2, Cost = Rs. 222.2×150 = Rs. 33,330

Cost of energy = Rs. $5 \times 10^5 \times 6/100$ = Rs. 30,000 (as before)

Cost of losses occuring in capacitors = Rs. $\dfrac{25.9 \times 100 \times 2500 \times 6}{1000 \times 100}$ = Rs. 389

Annual interest and depreciation cost on capacitors =Rs. $525 \times 25.9 \times 8/100$ = Rs. 1088

$\therefore$ total annual cost is = Rs. (33,330 + 30,000 + 389 + 1088) = Rs. 64,807

$\therefore$ annual saving = Rs. (65,295 – 64,807) = **Rs. 488.**

Example 50.69. *A 30 h.p. (22.38 kW) induction motor is supplied with energy on a two-part tariff of Rs. 60 per kVA of maximum demand per annum plus 5 paise per unit. Motor (A) has an efficiency of 89% and a power factor of 0.83. Motor (B) with an efficiency of 90% and a p.f. of 0.91 costs Rs. 160 more. With motor (A) the p.f. would be raised to 0.91 (lagging) by installing capacitors at a cost Rs. 50 per kVA.*

If the service required from the motor is equivalent to 2,280 hr. per annum at full load, compare the annual charges in the two cases. Assume interest and depreciation charges to be % per annum for the motor and 8% per annum for the capacitors.

Solution. For Motor A

Full-load motor input $= 22.38 \times 10^3/0.89 = 25.14$ kW ; kVA = 25.14/0.83 = 30.29

Now, when p.f. is raised to 0.91, then kVA demand of motor = 25.14/0.91 = 27.6

Annual cost of energy supplied to motor $= 27.6 \times 60 + (25.14 \times 2{,}280 \times 5/100)$

= 1,656 + 2,866 = Rs. 4,522

By using capacitors, the phase angle of load is decreased from ϕ_1 ($\cos\phi_1 = 0.83$) to ϕ_2 ($\cos\phi_2 = 0.91$).

kVAR necessary for this improvement = load kW $(\tan\phi_1 - \tan\phi_2)$

= 25.14 (0.672 – 0.4557) = 5.439

Annual charges on capacitors = Rs. $50 \times 5.439 \times 8/100$ = Rs. 21.8

Total charges per annum including interest and depreciation on motor

= Rs. (4,522 + 21.8) = Rs. 4,544.

For Motor B

F.L. motor input = 22.38/0.9 = 24.86 kW ; kVA = 24.86/0.91 = 27.32

Annual cost of energy supplied to motor $= 27.32 \times 60 + (24.86 \times 2280 \times 5/100)$ = Rs. 4,473

If we do not include the interest and depreciation on the motor itself, then *B* is cheaper than *A* by Rs. (4544 – 4473) i.e., by Rs. 71. But *B* cost Rs. 160 more than *A*. Hence, additional annual charges on *B* are % of Rs. 160 *i.e.*, Rs. 20. Hence, B is cheaper than *A* by Rs. (71 – 20) = Rs. 51 per annum.

Example 50.70. *The motor of a 22.5 kW condensate pump has been burnt beyond economical repairs. Two alternatives have been proposed to replace it by*

Motor A. Cost = Rs. 6000 ; η at full-load=90% ; at half-load = 86%.

Motor B. Cost = Rs. 4000 ; η at full-load=85% ; at half-load= 82%.

The life of each motor 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 of motor A is Rs. 420 and that of motor B is Rs. 240. The energy rate is 10 paise per kWh.

Which motor will you recommend ? **(Power Plant Engg., AMIE)**

Solution. Motor A

Annual interest on capital cost = Rs. 6000 × 5/100 = Rs. 300

$$\text{Annual depreciation charges} = \frac{\text{original cost-salvage value}}{\text{life of motor in years}}$$

$$= \text{Rs. } \frac{6000 - (6000 \times 10/100)}{20} = \text{Rs. } 270$$

Annual maintenance cost = Rs. 420

$$\text{Energy input per annum} = \frac{22.5 \times 0.25 \times 8760}{0.9} + \frac{11.25 \times 0.75 \times 8760}{0.86} = 1,40,695 \text{ kWh}$$

Annual energy cost = Rs. 0.1 × 1,40,695 = Rs. 14,069

Total annual cost = Rs. (300 + 270 + 420 + 14,069) = Rs. 15,059

Motor B

Annual interest on capital cost = Rs. 4000 × 5/100 = Rs. 200

$$\text{Annual depreciation charges} = \text{Rs. } \frac{4000 - (4000 \times 10/100)}{20} = \text{Rs. } 180$$

Annual maintenance charges = Rs. 240

$$\text{Energy input per annum} = \frac{22.5 \times 0.25 \times 8760}{0.85} + \frac{11.25 \times 0.75 \times 8760}{0.82} = 1,48,108 \text{ kWh}$$

Annual energy cost = Rs. 0.1 × 1,48,108 = Rs. 14,811

Total annual cost = Rs. (200 + 180 + 240 + 14,811) = Rs. 15,431

Since the annual cost of Motor *B* is Rs. (15431 – 15059) = Rs. 372 more than that of Motor *A*, hence **motor A would be recommended.**

Example 50.71. *An industrial load takes 10^6 kWh a year, the power factor being 0.707 lagging. The maximum demand is 500 kVA. The tariff is Rs. 75 per annum per kVA maximum demand plus 3 paise per unit. Calculate the yearly cost of supply and find the annual saving in cost by installing phase advancing plant costing Rs. 45 per kVA which raises the plant power factor from 0.707 to 0.9 lagging. Allow 10% per annum on the cost of the phase advancing plant to cover all additional costs.*

Solution. Max. demand charge per annum = Rs. 500 × 75 = Rs. 37,500

Annual energy charges = Rs. 10^6 × 3/100 = Rs. 30,000

∴ yearly cost of supply = Rs. (37,500 + 30,000) = **Rs. 67,500**

Now, when p.f. is increased from 0.707 to 0.9, then maximum kVA demand is reduced to 500 × 0.707/0.9 = 392.8.

Now, annual cost of the supply = Rs. 75 × 392.8 + Rs. 30,000

= 29,460 + 30,000 = Rs. 59,460

kVAR to be supplied by the phase-advancing plant for improving the p.f. from 0.707 to 0.9 = kW demand ($\tan \phi_1 - \tan \phi_2$) where $\phi_1 = \cos^{-1}(0.707)$ and $\phi_2 = \cos^{-1}(0.9)$.

∴ kVAR = 500 × 0.707 × 0.516 = 182.4

Annual cost by way of interest and depreciation etc. on the phase advancing plant

= Rs. 182.4 × 45 × 0.1 = Rs. 821

The annual saving would be due to reduction in the maximum demand charge only because units consumed remain the same throughout.

∴ yearly saving = initial charges for kVA – (new charges for kVA + annual cost of phase advancer) = 67,500 – (59,460 + 821) = **Rs. 7,219.**

Example 50.72. *It is necessary to choose a transformer to supply a load which varies over 24 hour period in the manner given below :*

500 kVA for 4 hours, 1000 kVA for 6 hours, 1500 kVA for 12 hours and 2000 kVA for the rest of the period.

Two transformers each rated at 1500 kVA have been quoted. Transformer I has iron loss of 2.7 kW and full-load copper loss of 8.1 kW while transformer II has an iron loss and full-load copper loss of 5.4 kW each.

(i) *Calculate the annual cost of supplying losses for each transformer if electrical energy costs 10 paise per kWh.*

(ii) *Determine which transformer should be chosen if the capital cost of the transformer I is Rs. 1000 more than that of the transformer II and annual charges of interest and depreciation are 10%.*

(iii) *What difference in capital cost will reverse the decision made in (ii) above ?*

(Utilisation of Elect. Power AMIE)

Solution. (i) Transformer No. 1

Iron loss/day = $2.7 \times 24 = 64.8$ kW

Cu loss/day = $8.1\,(500/1500)^2 \times 4 + 8.1 \times (1000/1500)^2 \times 6 + 8.1 \times (1500/1500)^2 \times 12 + 8.1 \times (2000/1500)^2 \times 2 = 151.2$ kWh

Annual energy loss = 365 (64.8 + 151.2) = 78,840 kWh

Annual cost of both losses = Rs. $0.1 \times 78{,}840$ = **Rs. 7884**

Transformer No. 2

Iron loss/day = $5.4 \times 24 = 129.6$ kWh

Cu loss/day = $5.4\,(500/1500)^2 \times 4 + 5.4\,(1000/1500)^2 \times 6 + 5.4\,(1500/1500)^2 \times 12 + 5.4\,(2000/1500)^2 \times 2 = 100.8$ kWh

Annual energy loss = 365 (129.6 + 100.8) = 84,096 kWh

Annual cost of both losses = Rs. $0.1 \times 84{,}096$ = **Rs. 8410**

(ii) Since the cost of transformer No. 1 is Rs. 1000 more than that of transformer No. 2, extra annual charge in case transformer No. 1 is selected = Rs. $1000 \times 10/100$ = Rs. 100

Annual saving in energy cost due to losses = Rs. (8410 – 7884) = Rs. 526

Since the annual saving in the energy cost of supplying losses is much than the extra annual charges due to the higher cost of the transformer No. 1, therefore transformer No. 1 will be selected.

(iii) Transformer No. 2 would be chosen in case annual charges due to extra capital cost of transformer No. 1 exceed the annual saving on the energy cost of supplying losses.

If x is the extra capital cost of transformer No. 1, then transformer No. 2 could be selected if

$x \times 10/100 > 526$ or $x >$ **Rs. 5260**

Example 50.73. *Three-phase 50-Hz power is supplied to a mill, the voltage being stepped down to 460-V before use.*

The monthly power rate is 7.50 per kVA. It is found that the average power factor is 0.745 while the monthly demand is 611 kVA.

To improve power factor, 210 kVA capacitors are installed in which there is negligible power loss. The installed cost of the equipment is Rs. 11,600 and fixed charges are estimated at 15% per year. What is the yearly saving introduced by the capacitors.

Solution. Monthly demand $= 611$ kVA ; p.f. $= 0.745$

$\phi = \cos^{-1}(0.745) = 41°5'$ $\therefore$ $\sin\phi = \sin 41°5' = 0.667$

$\therefore$ kW component $=$ kVA $\cos\phi = 611 \times 0.745 = 455$

kVAR component $=$ kVA $\sin\phi = 611 \times 0.667 = 408$ (lagging)

leading kVAR supplied by capacitor $= 210$

Hence, kVAR after p.f. improvement $= 408 - 210 = 198$

$\therefore$ kVA after p.f. improvement $= \sqrt{455^2 + 198^2} = 491$

Reduction in kVA $= 611 - 491 = 120$

Hence, monthly saving on kVA charge $=$ Rs. $120 \times 7.5 =$ Rs. 900

Yearly saving on kVA charge $=$ Rs. $12 \times 900 =$ Rs. 10,800

Capital cost on capacitors $=$ Rs. 11,600

Fixed charge per annum $=$ Rs. $0.15 \times 11{,}600 =$ Rs, 1,740

Hence, net saving per annum $=$ Rs. (10,800 – 1,740) $=$ **Rs. 9,060**

Example 50.74. *A supply undertaking is offering the following two tariffs to prospective customers :*

Tariff A : Lighting : 20 paise per unit; domestic power: 5 paise per unit, meter rent: 30 paise per meter per month.

Tariff B : 12 per cent on the rateable value of the customer's premises plus 3 paise per unit for all purposes.

If the annual rateable value of the customer's premises is Rs. 2,500 and his normal consumption for lighting per month is 40 units, determine what amount of domestic power consumption will make both the tariffs equally advantageous.

Solution. Let $x =$ minimum number of power units consumed per month.

Tariff A

Total cost per month $=$ meter rent + lighting charges + power charges

$= (2 \times 30) + (40 \times 20) + 5x = 860 + 5x$ paise

Tariff B

Total cost per month $=$ 12% of 2500 + energy charges for all purposes

$= 0.12 \times 2500 \times 100/12 + 3(40 + x)$

$\therefore$ $860 + 5x = 2500 + 120 + 3x$ $\therefore$ $2x = 1760$ $\therefore$ $x =$ **880 units**

Example 50.75. *Transformers and low-tension motors of a certain size can be purchased at Rs. 12 per kVA of full output and Rs. 24 per kW output respectively. If their respective efficiencies are 98% and 90%, what price per kW output could be paid for high-tension motors of the same size but of average efficiency only 89%? Assume an annual load factor of 30%, the cost of energy per unit as 7 paise and interest and depreciation at the rate of 8% for low-tension motors.*

Solution. Let $S =$ the price of h.t. motors per output kW in rupees.

Low-tension Motors with Transformers

(*a*) Interest and depreciation on the motor input kW $=$ Rs. $\dfrac{24 \times 0.08}{0.9} =$ Rs. 2.13

(*b*) Let ∞ a p.f.or the mers and calculate their standing charges on the basis of their input expressed in kW.

$\therefore$ interest and depreciation on transformers per input kW = Rs. $\dfrac{12 \times 0.9}{0.99} \times 0.08$ = Rs. 0.88

(c) Running charges $= \dfrac{(8,760 \times 0.3) \times 7}{(0.98 \times 0.9) \times 100}$ = Rs. 208.6

Hence, total cost of transformers and low-tension motors per input kW

= 2.13 + 0.88 + 208.6 = Rs. 211.6

High Tension Motors

Standing charges/output kW = Rs. $\dfrac{S}{.89} \times .12$ = Rs. $\dfrac{12S}{89}$

Running cost $= \dfrac{(1 \times 8,760 \times 0.3) \times 7}{0.89 \times 100}$ = Rs. 206.7

Total cost of h.t. motors = (12 S/89) + 206.7.

$\therefore$ 12 S/89 + 206.7 = 211.6 $\therefore$ S = **Rs. 36.34 kW output.**

Example 50.76. *An industrial load can be supplied on the following alternative tariffs **(a)** high-voltage supply at Rs. 45 per kVA per annum plus 1.5 paise per kWh or **(b)** low-voltage supply at Rs. 50 per annum plus 1.8 paise per kWh. Transformers and switchgear etc. for the H.V. supply cost Rs. 35 per kVA, the full-load transformer losses being 2%. The fixed charges on the capital cost of the high-voltage plant are 25% and the installation works at full-load. If there are 50 working weeks in a year, find the number of working hours per week above which the H.V. supply is cheaper.*

Solution. Let x be the number or working hours per week above which H.V. supply is cheaper than the L.V. supply. Also, suppose that the load = 100 kW.

Rating of transformers and switchgear = 100/0.98=10,000/98 kW, because transformer losses are 2%.

Cost of switchgear and transformer = (10,000/98) × 35 = Rs. 3,571.5

Annual fixed charges = 3,571.5 × 0.25 = Rs. 892.9

Annual energy consumption = 100 × x × 50 = 5,000 x kWh

On the H.V., the total kWh which will have to be paid for is 5,000 x/0.98.

(a) H.V. Supply

Total annual cost = 45 × kVA + energy charges + charge on H.V. plant

$= 45 \times \dfrac{100}{0.98} + \dfrac{1.5 \times 5,000\, x}{100 \times 0.98} + \text{Rs. } 892.9$

= Rs. 4,592 + Rs. 76.54 x + Rs. 892.9 = **Rs. (5,485 + 76.54 x)**

(b) L.V. Supply

Total annual cost = Rs. 50 × kVA + energy charges = 50 × 100 + $\dfrac{1.8 \times 5,000\, x}{100}$

= **Rs. (5,000 + 90 x)**

If the two annual costs are to be equal, then

5,485 + 76.54 x = 5,000 + 90 x

$\therefore$ 13.46 x = 485 or x = **36 hr.**

Hence, above 36 hours per week, the H.V. supply would be cheaper.

Example 50.77. *For a particular drive in a factory requiring 10 h.p. (7.46 kW) motors, following tenders have been received. Which one will you select ?*

	cost	*efficiency*
Motor X	*Rs. 1,150*	*86%*
Motor Y	*Rs. 1,000*	*85%*

Electrical tariff is Rs. 50 per kW + 5 paise per kWh. Assume interest and depreciation as 10% and that the factory works for 10 hours a day for 300 days a year.

(Electrical Engineering, Bombay Univ.)

Solution. ***(i)* Motor X**

F.L. power input	= 7.46/0.86	= 8.674 kW
Units consumed/year	= 8760 × 8.674	= 75,980 kWh
kW charges	= Rs. 50 × 8.674	= Rs. 433.7
kWh charges	= Rs. 5 × 75,980/100	= Rs. 3,799
Fixed charges	= Rs. 0.1 × 1150	= Rs. 115
Total annual charges	= (3,799 + 433.7 + 115)	= **Rs. 4,347.7**

***(ii)* Motor Y**

F.L. power input	= 7.46/0.85	= 8.776 kW
units consumed/year	= 8760 × 8.766	= 76,880 kWh
kW charges	= Rs. 50 × 8.766	= Rs. 438.8
kWh charges	= Rs. 5 × 76,880/100	= Rs. 3,844
Fixed charges	= Rs. 0.1 × 1000	= Rs. 100
Total annual charges	= (438.8 + 3,844 + 100)	= Rs. 4,382.8

Obviously, motor *X* is cheaper by Rs. (4,382.8 × 4,347.7) = **Rs. 35.1**

Example 50.78. *A 200-h p. (149.2 kW) motor is required to operate at full-load for 1500 hr, at half-load for 3000 hr per year and to be shut down for the remainder of the time. Two motors are available.*

Motor A : efficiency at full load = 90% ; *at half-load = 88%*

Motor B : efficiency at full load = 90% ; *at half-load = 89%*

The unit of energy is 5 paise/kWh and interest and depreciation may be taken as 12 per cent per year. If motor A cost Rs. 9,000 ; what is the maximum price which could economically be paid for motor B ? **(Electrical Power-II, Bombay Univ.)**

Solution. **(*a*) Motor A**

F.L. power input	= 149.2/0.9	= 165.8 kW
Half-load power input	= (149.2/2)/0.88	= 84.7 kW
Total energy consumed per year	= (1500 × 165.8) + (3000 × 84.7) = 502,800 kWh	
Cost of energy	= Rs. 5 × 502,800/100	= Rs. 25,140
Interest and depreciation on motor	= Rs. 0.12 × 9000	= Rs. 1,080
Total charge	= Rs. 25,140 + Rs. 1,080 = **Rs. 26,220**	

(*b*) Motor B

F.L. input = 149.2/0.9 = 165.8 kW : Half-load input = (149.2/2)/0.89 = 83.8 kW

Total energy consumed per year = (1500 × 165.8) + (3000 × 83.8) = 497,100 kWh

Cost of energy consumed = Rs. 5 × 497,100/100 = Rs. 24,855

Let x be the maximum price which could be paid for motor B.

Annual interest and depreciation = Rs. $0.12\,x$

annual charges = Rs. (24,855 + 0.12x)

For the two charges to be equal = $24{,}855 + 0.12x = 26{,}220$; x = Rs. 11,375

Example 50.79. *Two tenders A and B for a 1000-kVA, 0.8 power factor transformer are : A, full-load efficiency = 98.5% and iron loss = 6 kW at rated voltage ; B, 98.8% and iron loss 4 kW but costs Rs. 1,500 more than A. The load cycle is 2000 hours per annum at full-load, 600 hours at half-load and 400 hours at 25 kVA. Annual charges for interest and depreciation are 12.5% of capital cost and energy costs 3 paise per kWh. Which tender is better and what would be the annual saving.*

Solution. Tender A Transformer full-load output = $1000 \times 0.8 = 800$ kW

Efficiency = 98.5% Input = 800/0.985

Total losses = (800/0.985) – 800 = 12.2 kW ; F.L. Cu losses = 12.2 – 6 = 6.2 kW

Total losses per year for a running period of 3000 hr. are—

(i) Iron loss = $3{,}000 \times 6 = 18{,}000$ kWh

(ii) F.L. Cu losses for 2000 hours = $2{,}000 \times 6.2 = 12{,}400$ kWh

(iii) Cu loss at half-load for 600 hours = $\frac{1}{4} \times 6.2 \times 600 = 930$ kWh

(iv) Cu loss at 25 kVA load for 400 hours = $\left(\frac{25}{1000}\right)^2 \times 6.2 \times 400 = 1.5$ kWh

Total energy loss per year = 18,000 + 12,400 + 930 + 1.5 = 31,332 kWh

Cost = Rs. $31{,}332 \times 3/100$ = Rs. 939.96

Tender B.

Total loss of transformer = (800/0.988) – 800 = 9.7 kW

Iron loss = 4 kW ; Full-load Cu loss = 9.7 – 4 = 5.7 kW

Total losses for 3,000 hours per year are as follows :

(i) Iron loss = $3{,}000 \times 4 = 12{,}000$ kWh

(ii) F.L. Cu loss for 2000 hours = $5.7 \times 2000 = 11{,}400$ kWh

(iii) Cu loss at half-load for 600 hours = $(5.7/4) \times 600 = 855$ kWh

(iv) Cu loss at 25 kVA for 400 hours = $(25/1000)^2 \times 5.7 \times 400 = 1.4$ kWh

Total yearly loss = 12,000 + 11,400 + 855 + 1.4 = 24,256 kWh

Cost = Rs. $24{,}256 \times 3/100$ = Rs. 727.68 ; Extra cost of B = Rs. 1500

Annual interest and depreciation etc. = 12.5% or 1500 = Rs. 187.50

$\therefore$ yearly cost of B = Rs. 727.68 + Rs. 187.50 = Rs. 915.18

Obviously, tender B is cheaper by Rs. (939.96 – 915.18) = **Rs. 24.78 annually.**

Example 50.80. *Transformer A has iron loss of 150 kWh and load loss of 140 kWh daily while the corresponding losses of transformer B are 75 kWh and 235 kWh. If annual charges are 12.5% of the capital costs and energy costs 5 paise per kWh, what should be the difference in the cost of the two transformers so as to make them equally economical ?*

Solution. Transformer A

Yearly loss = $365 \times (150 + 140) = 365 \times 290$ kWh

Transformer B

Yearly loss = $365 \times (75 + 235) = 365 \times 310$ kWh

Difference in yearly loss	=	365 (310 – 290) = 7,300 kWh
Value of this loss	=	Rs. 7,300 × 5/100 = Rs. 365

Hence, transformer *B* has greater losses per year and so is costlier by Rs. 365. If it is to be equally advantageous, then let it cost Rs. *x* less than *A*. Annual interest and depreciation on it is Rs. 0.125 *x*.

$$\therefore \quad 0.125x = 365$$

$$\text{or} \quad x = \text{Rs. } 2{,}920$$

Hence, transformer *B* should cost Rs. 2,920 less than *A*.

Example 50.81. *Quotations received from three sources for transformers are :*

	Price	*No-load loss*	*Full-load loss*
A	*Rs. 41,000*	*16 kW*	*50 kW*
B	*Rs. 45,000*	*14 kW*	*45 kW*
C	*Rs. 38,000*	*19 kW*	*60 kW*

If the transformers are kept energized for the whole of day (24 hours), but will be on load for 12 hours per day, the remaining period on no-load, the electricity cost being 5 paise per kWh and fixed charges Rs. 125 per kW of loss per annum and if depreciation is 10% of the initial cost, which of the transformers would be most economical to purchase ?

Solution. Transformer A

F.L. loss	=	50 kW
No-load losses	=	16 kW (this represents iron loss)
∴ F.L. Cu loss	=	50 – 16 = 34 kW
F.L. Cu loss for 12 hours*	=	12 × 34 = 408 kWh
Iron losses for 24 hours	=	24 × 16 = 384 kWh
Total loss per day	=	408 + 384 = 792 kWh
Annual loss	=	792 × 365 kWh
Cost of this loss	=	Rs. 792 × 365 × 5/100 = Rs. 14,454
Annual fixed charges	=	Rs. 125 × 50 = Rs. 6,250
Annual depreciation	=	Rs. 0.1 × 41,000 = Rs. 4,100

Total annual charges for transformer

A = Rs. 14,454 + Rs. 6,250 + Rs. 4,100 = Rs. 24,804

Transformer B

F.L. loss	=	45 kW ; Iron or no-load loss = 14 kW
F.L. Cu loss	=	45 – 14 = 31 kW; Iron loss/day = 24 × 14 = 336 kWh
F.L. Cu losss for 12 hours*	=	12 × 31 = 372 kWh
Total loss/day	=	708 kWh ; Annual loss = 708 × 365 kWh
Cost of this loss	=	708 × 365 × 5/100 = Rs. 12,921
Fixed charges	=	Rs. 125 × 45 = Rs. 5,625
Annual depreciation	=	Rs. 0.1 × 45,000 = Rs. 4,500

Total annual charges for transformer *B*

= Rs. 12,921 + Rs. 5,625 + Rs. 4,500 = Rs. 23,046

Transformer C

F.L. loss	=	60 kW ; Iron or N.L. loss = 19 kW
F.L. Cu loss	=	60 – 19 = 41 kW

* Cu loss is proportional to $(\text{kVA})^2$

Iron loss for 24 hr. $= 24 \times 19 = 456$ kWh

F.L. Cu loss for 12 hr $= 12 \times 41 = 492$ kWh

Total losses per day $= 948$ kWh ; Annual losses $= 948 \times 365$ kWh

Cost of these losses $=$ Rs. $948 \times 365 \times 5/100 =$ Rs. 17,301

Fixed charges $=$ Rs. $125 \times 60 =$ Rs. 7,500 ;

Annual depreciation $=$ Rs. $0.1 \times 38{,}000 =$ Rs. 3,800

Total annual charges on transformer $C =$ Rs. 17,301 + Rs. 7,500 + Rs. 3,800 = Rs. 28,601

Obviously, transformer B is cheaper and should be purchased.

Example. 50.82. *A 37.3 kW induction motor has power factor 0.9 and efficiency 0.9 at full-load, power factor 0.6 and efficiency 0.7 at half-load. At no-load, the current is 25% of the full-load current and power factor 0.1. Capacitors are supplied to make the line power factor 0.8 at half-load. With these capacitors in circuit, find the line power factor at* ***(i)*** *full-load and* ***(ii)*** *no-load.*

(Utilisation of Elect. Power, AMIE)

Solution. Full-load motor input, $P_1 = 37.3/0.9 = 40.86$ kW

Lagging kVAR drawn by the motor at full-load, $\text{kVAR}_1 = P_1 \tan\phi_1 = 40.86 \tan(\cos^{-1} 0.9) =$ 19.79.

Half-load motor input, $P_2 = (0.5 \times 37.3)/0.7 = 26.27$ kW

Lagging kVAR drawn by the motor at half-load,

$$\text{kVAR}_2 = P_2 \tan\phi_2 = 26.27 \tan(\cos^{-1} 0.6) = 35.02$$

Full-load current, $I_1 = 37.3 \times 10^3/\sqrt{3}\, V_L \times 0.9 \times 0.9 = 26,\,212/V_L$

Current at no-load, $I_0 = 0.25\, I_1 = 0.25 \times 26{,}212/V_L = 6553/V_L$

Motor input at no-load, $P_0 = \sqrt{3} V_L I_0 \cos\phi_0 = \sqrt{3} \times 6553 \times V_L \times 0.1/V_L = 1135 \text{ W} = 1.135$ kW

Lagging kVAR drawn by the motor at no-load, $\text{kVAR}_0 = 1.135 \tan(\cos^{-1} 0.1) = 11.293$

Lagging kVAR drawn from the mains at half-load with capacitors,

$$\text{kVAR}_{2C} = 26.27 \tan(\cos^{-1} 0.8) = 19.7$$

kVAR supplied by capacitors, $\text{kVAR}_C = \text{kVAR}_2 - \text{kVAR}_{2C} = 35.02 - 19.7 = 15.32$

kVAR drawn from the main at full-load with capacitors $\text{kVAR}_{1C} = \text{kVAR}_K - \text{kVAR}_C =$ $19.79 - 15.32 = 4.47$.

(*i*) Line power factor at full-load $= \cos(\tan^{-1} \text{kVAR}_{1C}/P_1) = \cos(\tan^{-1} 4.47/40.86) =$ **0.994 lagging**

(*ii*) kVAR drawn from mains at no-load with capacitors $= 11.293 - 15.32 = -4.027$

Line power factor at no-load $= \cos(\tan^{-1} - 4.027/1.135) = \cos(-74.26^\circ)$

$=$ **0.271 leading.**

Tutorial Problem No. 50.3

1. A power plant is working at its maximum kVA capacity with a lagging p.f. of 0.7. It is now required to increase its kW capacity to meet the demand of additional load. This can be done by raising the p.f. to 0.85 by correction apparatus or by installing extra generating plant which costs Rs. 800 per kVA. Find the minimum cost per kVA of p.f. apparatus to make its use more economical than the additional generating plant. **[Rs. 502 per kVAR]**

2. An industrial load of 4 MW is supplied at 11 kV, the p.f. being 0.8 lag. A synchronous motor is required to meet additional load of 1500 h.p. (1,119 kW) and at the same time to raise the resultant p.f. to 0.95 lag. Find the kVA capacity of the motor and the p.f. at which it must operate. The efficiency of the motor is 80%. **[1875 kVA ; 0.7466 (lead)]**

3. A factory takes a load of 300 kW at 0.8 p.f. lag for 4800 hours per annum and buys energy at a tariff of Rs. 100 per kVA plus 3 p/kWh consumed. If p.f. is improved to 0.9 (lag) by means of capacitors costing Rs. 200 per kVA and having a power loss of 50 W per kVA, calculate the annual saving affected by their use. Allow 10% per annum for interest and depreciation of the capacitors.
[Rs. 693 per year]

4. The following two tenders are received in connection with the purchase of 1000-kVA transformer.

Transformer A : full-load efficiency = 98% ; core loss = 8 kW

Transformer B : full-load efficiency = 91.5% ; core loss = 6 kW

The service needed per year is 200 hours as 1000 kVA, 1000 hours at 500 kVA and 1000 hours at 200 kVA. If the transformer A is costing Rs. 25,000, estimate the maximum price that could be paid for transformer *B*. Take interest and depreciation at 10 per cent per annum and cost of energy 5 paise per kWh. Assume working at unity power factor. **[Max. Price for B = Rs. 21,425]**

5. Tenders *A* and *B* for a 1000-kVA, 0.8 p.f. transformer are :

A : full-load η = 98.3% ; core loss = 7 kW at rated voltage
B : full-load η = 98.7% ; core loss = 4 kW but costs Rs. 5000 more than *A*.

The service needed is 1800 hours per annum at 1000 kVA, 600 hours at 600 kVA, 400 hours at 25 kVA and remaining period shut down. Take the annual charges for interest and depreciation at 12.5 per cent of capital cost and energy costs at 8 paise/kWh ; which is the better tender and what will be annual saving ? **[Tender B is cheaper by Rs. 211]**

6. A 440-V, 50-Hz induction motor takes a line current of 45 A at a power factor of 0.8 (lagging). Three D-connected capacitors are installed to improve the power factor to 0.95 (lagging). Calculate the kVA of the capacitor bank and the capacitance of each capacitor.
[11.45 kVA ; 2.7 μ F] (*I.E.E. London*)

7. A generator station supplies power to the following : lighting 100 kW; an induction motor 400 h.p. (298.4 kW) power factor 0.8, efficiency 0.92, a rotary converter giving 100 A at 800 V at an efficiency of 0.94. What must be the p.f. of the rotary converter in order that the p.f. of the supply station may be unity. **[0.214 leading] (*C. & G. London*)**

8. A substation which is fed by a single feeder cable supplies the following loads : 1,000 kW at p.f. 0.85 lagging, 1,500 kW at 0.8 lagging, 2,000 kW at 0.75 lagging : 500 kW at 0.9 leading. Find the p.f. of the supply to the substation and the load the feeder cable could carry at unity p.f. with the same cable heating. **[0.84 ; 5,960 kW] (*I.E.E. London*)**

9. A 3-phase synchronous motor is connected in parallel with a load of 200 kW at 0.8 p.f. (lagging) and its excitation is adjusted until it raises the total p.f. to 0.9 (lagging). If the mechanical load on the motor, including losses, takes 50 kW, calculate the kVA input to the motor.
[57.8 kVA] (*I.E.E. London*)

10. A 3-phase, 3,000-V, 50-Hz motor develops 375 h.p. (223.8 kW), the p.f. being 0.75 lagging and the efficiency 92%. A bank of capacitors is star-connected in parallel with the motor and the total p.f. raised to 0.9 lagging. Each phase of the capacitor bank is made up of 3 capacitors joined in series. Determine the capacitance of each. **[118 μF] (*London Univ.*)**

11. For increasing the kW capacity of a power plant working at 0.7 lagging power factor, the necessary increase in power can be obtained by raising the power factor to 0.9 or by installing additional plant. What is the maximum cost per kVA of power factor correction apparatus to make its use more economical than additional plant at Rs. 800 per kVA?
[Rs. 525] (*Utili. of Elect. Power, AMIE*)

12. A 340-kW, 3300-V, 50-Hz, 3f star-connected induction motor has full-load efficiency of 85% and power factor of 0.8 lagging. It is desired to improve power factor to 0.96 lagging by using a bank of three capacitors. Calculate (*i*) the kVA rating of the capacitor bank,

(*ii*) the capacitance of each limb of the capacitor bank connected in delta,

(*iii*) the capacitance of each capacitor, if each one of the limbs of the delta-connected capacitor bank is formed by using 6 similar 3300-V capacitors.

[(*i*) 183.33 kVAR (*ii*) 17,86 μF (*iii*) 2.977 μF] (*Util. of Elect. Power, AMIE*)

13. A system is working at its maximum kVA capacity with a lagging power factor of 0.71. An anticipated increase of load could be met by

(*i*) raising the power factor of the system to 0.87 by the installation of phase advancers,

(*ii*) installing extra generating plant, cables etc. to meet the increased power demand.

Estimate the limiting cost per kVA of phase advancing plant which would justify its use if the cost for generating plant is Rs. 60 per kVA. Interest and depreciation charges may be assumed to be 1% in each case. **[Rs. 36.5] (*Util. of Elect. Power, AMIE*)**

14. A consumer requires an induction motor of 36.775 kW. He is offered two motors of the following specifications :

Motor *A* : efficiency 88% and p.f. = 0.9 Motor *B* : efficiency 90% and p.f. = 0.81

The consumer is being charged on a two-part tariff of Rs. 70 per kVA of the maximum demand plus 5 paise per unit. The motor (*B*) power factor is raised to 0.89 by installing capacitors. The motor *B* costs Rs. 150 less than *A*.

The cost of capacitor is Rs.60 per kVAR. Determine which motor is more economical and by how much. Assume rate of interest and depreciation as 10% and working hours of motors as 2400 hours in a year. **[Motor B, Rs. 111.10] (*Power Systems-II, AMIE*)**

15. A 250-V, 7.46 kW motor is to be selected for a workshop from two motors *A* and *B*. The cost of each motor is same but the losses at full load are different as given below :

	Motor A	Motor B
Stray loss	1000 W	900 W
Shunt field loss	250 W	200 W
Armature copper loss	300 W	450 W

The motor has to work on full-load for 8 hours, half-load for 4 hours and quarter load for 4 hours each day. Which motor should be selected ? **[Motor B] (*Util. of Elect. Power AMIE*)**

16. What is load duration curve? *(Anna University, April 2002)*

17. How will you classify loads? *(Anna University, April 2002)*

18. Why should there be diversity? *(Anna University, April 2002)*

19. Define load factor. *(Anna University, April 2002)*

20. What is M.D.? *(Anna University, April 2002)*

21. Distinguish between a base load plant and a peak load plant. *(Anna University, April 2002)*

OBJECTIVE TESTS – 50

1. While calculating the cost of electric power generation, which of the following is NOT considered a fixed cost ?

(*a*) interest on capital investment

(*b*) taxes and insurance

(*c*) most of the salaries and wages

(*d*) repair and maintenance.

2. Maximum demand of an installation is given by its

(*a*) instantaneous maximum demand

(*b*) greatest average power demand

(*c*) average maximum demand over a definite interval of time during a certain period.

(*d*) average power demand during an interval of 1-minute.

3. A diversity factor of 2.5 gives a saving of .... percent in the generating equipment.

(*a*) 60

(*b*) 50

(*c*) 40

(*d*) 25.

4. Mark the WRONG statement.

High load factor of a generating equipment

(*a*) leads to lesser charges per kWh

(*b*) implies lower diversity in demand

(*c*) gives more profit to the owner

(*d*) can be obtained by accepting off-peak loads.

5. In a generating station, fixed, charges at 100% load factor are 6 paise/kWh. With 25% load factor, the charges would become .... paise/kWh.

(*a*) 1.5

(*b*) 10

(*c*) 24

(*d*) 3

6. When considering the economics of power transmission, Kelvin's law is used for finding the

(*a*) cost of energy loss in bare conductors

(*b*) most economical cross-section of the con ductors

(*c*) interest on capital cost of the con- ductor

(*d*) the maximum voltage drop in feeders.

7. A 3-phase balanced system working at 0.9 lagging power factor has a line loss of 3600 kW. If p.f. is reduced to 0.6, the line loss would become .... kW.

(*a*) 8100

(*b*) 1600

(*c*) 5400

(*d*) 2400.

8. Mark the WRONG statement.

While considering power factor improve- ment, the most economical angle of lag depends on the

(*a*) cost/kVA rating of phase advancer

(*b*) rate of interest on capital outlay

(*c*) rate of depreciation

(*d*) value of original lagging p.f. angle.

9. Load factor of a power station is defined as

(*a*) maximum demand / average load

(*b*) average load × maximum demand

(*c*) average load / maximum demand

(*d*) (average load × maximum demand)$^{1/2}$

10. Load factor of a power station is generally

(*a*) equal to unity

(*b*) less than unity

(*c*) more than unity

(*d*) equal to zero

11. Diversity factor is always

(*a*) equal to unity

(*b*) less than unity

(*c*) more than unity

(*e*) more than twenty

12. Load factor for heavy industries may be taken as

(*a*) 10 to 20%

(*b*) 25 to 40%

(*c*) 50 to 70%

(*d*) 70 to 80%

13. The load factor of domestic load is usually

(*a*) 10 to 15%

(*b*) 30 to 40%

(*c*) 50 to 60%

(*d*) 60 to 70%

14. Annual depreciation cost is calculated by

(*a*) sinking fund method

(*b*) straight line method

(*c*) both (*a*) and (*b*)

(*d*) none of the above

15. Depreciation charges are high in case of

(*a*) thermal plant

(*b*) diesel plant

(*c*) hydroelectric plant

16. Demand factor is defined as

(*a*) average load/maximum load

(*b*) maximum demand/connected load

(*c*) connected load/maximum demand

(*d*) average load × maximum load

17. High load factor indicates

(*a*) cost of generation per unit power is increased

(*b*) total plant capacity is utilised for most of the time

(*c*) total plant capacity is not properly utilised for most of the time

(*d*) none of the above

18. A load curve indicates

(*a*) average power used during the period

(*b*) average kWh (kW) energy consumption during the period

(*c*) either of the above

(*d*) none of the above

19. Approximate estimation of power demand can be made by

(*a*) load survey method

(*b*) statistical methods

(*c*) mathematical method

(*d*) economic parameters

(*e*) all of the above

20. Annual depreciation as per straight line method, is calculated by
(*a*) the capital cost divided by number of year of life
(*b*) the capital cost minus the salvage value, is divided by the number of years of life
(*c*) increasing a uniform sum of money per annum at stipulated rate of interest
(*d*) none of the above

21. A consumer has to pay lesser fixed charges in
(*a*) flat rate tariff
(*b*) two part tariff
(*c*) maximum demand tariff
(*d*) any of the above

22. In two part tariff, variation in load factor will affect
(*a*) fixed charges
(*b*) operating or running charges
(*c*) both (*a*) and (*b*)
(*d*) either (*a*) & (*b*)

23. In Hopkinson demand rate or two part tariff the demand rate for fixed charges are
(*a*) dependent upon the energy consumed
(*b*) dependent upon the maximum demand of the consumer
(*c*) both (*a*) and (*b*)
(*d*) neither (*a*) and (*b*)

24. Which plant can never have 100 percent load factor?
(*a*) Peak load plant
(*b*) Base load plant
(*c*) Nuclear power plant
(*d*) Hydro electric plant

25. The area under a load curve gives
(*a*) average demand
(*b*) energy consumed
(*c*) maximum demand
(*d*) none of the above

26. Different generating stations use following prime movers
(*a*) diesel engine
(*b*) hydraulic turbine
(*c*) gas turbine
(*d*) steam turbine
(*e*) any of the above

27. Diversity factor has direct effect on the
(*a*) fixed cost of unit generated
(*b*) running cost of unit generated
(*c*) both (*a*) and (*b*)
(*d*) neither (*a*) nor (*b*)

28. Following power plant has instant starting
(*a*) nuclear power plant
(*b*) hydro power plant
(*c*) both (*a*) and (*b*)
(*d*) none of the above

29. Which of the following generating station has minimum running cost?
(*a*) Nuclear
(*b*) Hydro
(*c*) Thermal
(*d*) Diesel

30. Power plant having maximum demand more than the installed rated capacity will have utilisation factor
(*a*) equal to unity
(*b*) less than unity
(*c*) more than unity
(*d*) none of the above

31. Load curve is useful in deciding the
(*a*) operating schedule of generating units
(*b*) sizes of generating units
(*c*) total installed capacity of the plant
(*d*) all of the above

32. Load curve of a power plant has always
(*a*) zero slope
(*b*) positive slope
(*c*) negative slope
(*d*) any combination of (*a*), (*b*) and (*c*)

33. Annual operating expenditure of a power plant consists of
(*a*) fixed charges
(*b*) semi-fixed charges
(*c*) running charges
(*d*) all of the above

34. Maximum demand on a power plant is
(*a*) the greatest of all "short time interval averaged" demand during a period
(*b*) instantaneous maximum value of kVA supplied during a period
(*c*) both (*a*) or (*b*)
(*d*) none of the above

35. Annual instalment towards depreciation reduces as rate of interest increases with
(*a*) sinking fund depreciation
(*b*) straight line depreciation
(*c*) reducing balances depreciation
(*d*) none of the above

36. Annual depreciation of the plant is proportional to the earning capacity of the plant vide

(*a*) sinking fund depreaciation
(*b*) straight line depreciation
(*c*) reducing balances depreciation
(*d*) none of the above

37. For high value of diversity factor, a power station of given installed capacity will be in a position to supply
(*a*) less number of consumers
(b) more number of consumers
(*c*) neither (*a*) nor (*b*)
(*d*) either (*a*) or (*b*)

38. Salvage value of the plant is always
(*a*) positive
(*b*) negative
(*c*) zero
(*d*) any of the above

39. Load curve helps in deciding
(a) total installed capacity of the plant
(b) size of the generating units
(c) operating schedule of generating units
(d) all of the above

40. .... can generate power at unpredictable or uncontrolled times.
(*a*) Solar power plant
(*b*) Tidal power plant
(*c*) Wind power plant
(*d*) Any of the above

41. Direct conversion of heat into electric power is possible through
(*a*) fuel cell
(*b*) batteries
(*c*) thermionic converter
(*d*) all of the above

42. A low utilization factor for a plant indicates that
(*a*) plant is used for stand by purpose only
(*b*) plant is under maintenance
(*c*) plant is used for base load only
(*d*) plant is used for peak load as well as base load

43. Which of the following is not a source of power?
(*a*) Thermocouple
(*b*) Photovoltaic cell
(*c*) Solar cell
(*d*) Photoelectric cell

44. Which of the following should be used for extinguishing electrical fires?
(*a*) Water
(*b*) Carbon tetrachloride fire extinguisher
(*c*) Foam type fire extinguisher
(*d*) CO_2 fire extinguisher

45. Low power factor is usually not due to
(*a*) arc lamps
(*b*) induction motors
(*c*) fluorescent tubes
(*d*) incandescent lamp

46. Ships are generally powered by
(*a*) unclear power plants
(*b*) hydraulic turbines
(*c*) diesel engines
(*d*) steam accumulators
(*e*) none of the above

47. Direct conversion of heat into electrical energy is possible through
(*a*) fuel cells
(*b*) solar cells
(*c*) MHD generators
(*d*) none of the above

48. Which of the following place is not associated with nuclear power plants in India?
(*a*) Narora
(*b*) Tarapur
(*c*) Kota
(*d*) Benglore

49. During load shedding
(*a*) system power factor is changed
(*b*) some loads are switched off
(*c*) system voltage is reduced
(*d*) system frequency is reduced

50. Efficiency is the secondary consideration in which of the following plants?
(*a*) Base load plants
(*b*) Peak load plants
(*c*) Both (*a*) and (*b*)
(*d*) none of the above

51. Air will not be the working substance in which of the following?
(*a*) Closed cycle gas turbine
(*b*) Open cycle gas turbine
(*c*) Diesel engine
(*d*) Petrol engine

52. A nuclear power plant is invariably used as a
(*a*) peak load plant
(*b*) base load plant
(*c*) stand-by plant
(*d*) espinning reserve plant
(*e*) any of the above

53. ....power plant is expected to have the longest life.

(a) Steam
(b) Diesel
(c) Hydroelectric
(d) Any of the above

54. .... power plant cannot have single unit of 100 MW.
(a) Hydroelectric
(b) Nuclear
(c) Steam
(d) Diseal
(e) Any of the above

55. Which of the following, in a thermal power plant, is not a fixed cost?
(a) Fuel cost
(b) Interest on capital
(c) Depreciation
(d) Insurance charges

56. .... will offer the least load.
(a) Vacuum cleaner
(b) Television
(c) Hair dryer
(d) Electric shaver

57. In .... fuel transportation cost is least.
(a) nuclear power plants
(b) diesel generating plants
(c) steam power stations

58. Which of the following equipment provides fluctuating load?
(a) Exhaust fan
(b) Lathe machine
(c) Welding transformer
(d) All of the above

59. The increased load during summer months is due to
(a) increased business activity
(b) increased water supply
(c) increased use of fans and air conditioners
(d) none of the above

60. .... is the reserved generating capacity available for service under emergency conditions which is not kept in operation but in working order.
(a) Hot reserve
(b) Cold reserve
(c) Spinning reserve
(d) Firm power

61. Generating capacity onnected to the bus bars and ready to take load when switched on is known as ....
(a) firm power
(b) cold reserve
(c) hot reserve
(d) spinning reserve

62. .... offers the highest electric load.
(a) Television set
(b) Toaster
(c) Vacuum cleaner
(d) Washing machine

63. .... industry has the least power consumption per tonne of product.
(a) Soap
(b) Sugar
(c) Vegetable oil
(d) Caustic soda

64. With reference to a power station which of the following is not a fixed cost?
(a) Fuel cost
(b) Interest on capital
(c) Insurance changes
(d) Depreciation

65. .... is invariably used as base load plant.
(a) Diesel engine plant
(b) Nuclear power plant
(c) Gas turbine plant
(d) Pumped storage plant

66. In a power plant if the maximum demand on the plant is equal to the plant capacity, then
(a) plant reserve capacity will be zero
(b) diversity factor will be unity
(c) load factor will be unity
(d) load factor will be nearly 60%

67. In case of .... fuel transportation is the major problem.
(a) diesel power plants
(b) nuclear power plants
(c) hydro-electric power plants
(d) thermal power plants

68. Which of the following power plants need the least period for installation?
(a) Thermal power plant
(b) Diesel power plant
(c) Nuclear power plant
(d) Hydro-electric power plant

69. For which of the following power plants highly skilled engineers are required for running the plants?
(a) Nuclear power plants
(b) Gas turbine power plants
(c) Solar power plants
(d) Hydro-electric power plants

70. In which of the following power plants the maintenance cost is usually high?
(*a*) Nuclear power plant
(*b*) Hydro-electric power plants
(*c*) Thermal power plants
(*d*) Diesel engine power plants

71. .... is inveriably used for peak load
(*a*) Nuclear power lant
(*b*) Steam turbine plant
(*c*) Pumped storage plant
(*d*) None of the above

72. Which of the following is not an operating cost?
(*a*) Maintenance cost
(*b*) Fuel cost
(*c*) Salaries of high officials
(*d*) Salaries of operating stall

73. Which of the following is the essential requirement of peak load plant?
(*a*) It should run at high speed
(*b*) It should produce high voltage
(*c*) It should be small in size
(*d*) It should be capable of starting quickly

74. Large capacity generators are invariably
(*a*) water cooled
(*b*) natural air cooled
(*c*) forced air cooled
(*d*) hydrogen cooled

75. By the use of which of the following power factor can be improved?
(*a*) Phase advancers
(*b*) Synchronous compensators
(*c*) Static capacitors
(*d*) Any of the above

76. An induction motor has relatively high power factor at
(*a*) rated r.p.m.
(*b*) no load
(*c*) 20 percent load
(*d*) near full load
(*e*) none of the above

77. Which of the following is the disadvantage due to low power factor?
(*a*) Poor voltage regulation
(*b*) Increased transmission losses
(*c*) High cost of equipment for a given load
(*d*) All of the above

78. In a distribution system, in order to improve power factor, the synchronous capacitors are installed
(*a*) at the receiving end
(*b*) at the sending end
(*c*) either (*a*) or (*b*)
(*d*) none of the above

79. Satic capacitors are rated in terms of
(*a*) kW
(*b*) kWh
(*c*) kVAR
(*d*) none of the above

80. Base load plants usually have .... capital cost, ... operating cost and .... load factor.
(*a*) high, high, high
(*b*) high, low, high
(*c*) low, low, low
(*d*) low, high, low

81. Which of the following is the disadvantage of a synchronous condenser?
(*a*) High maintenance cost
(*b*) Continuous losses in motor
(*c*) Noise
(*d*) All of the above

82. For a consumer the most economical power factor is generally
(*a*) 0.5 lagging
(*b*) 0.5 leading
(*c*) 0.95 lagging
(*d*) 0.95 leading

83. A synchronous condenser is virtually which of the following?
(*a*) Induction motor
(*b*) Underexcited synchronous motor
(*c*) Over excited synchronous motor
(*d*) D.C. generator
(*e*) None of the above

84. For a power plant which of the following constitutes running cost?
(*a*) Cost of wages
(*b*) Cost of fuel
(*c*) Cost of lubricants
(*d*) All of the above

85. In an interconnected system, the diversity factor of the whole system
(*a*) remains unchanged
(*b*) decreases
(*c*) increases
(*d*) none of the above

86. Generators for peak load plants are usually designed for maximum efficiency at
(*a*) 25 to 50 percent full load
(*b*) 50 to 75 percent full load
(*c*) full load
(*d*) 25 percent overload

87. .... will be least affected due to charge in supply voltage frequency.
(*a*) Electric clock
(*b*) Mixer grinder
(*c*) Ceiling fan
(*d*) Room heater

88. For the same maximum demand, if load factor is decreased, the cost generation will
(*a*) remain unchanged
(*b*) decrease
(*c*) increase

89. The connected load of a domestic consumer is around
(*a*) 5 kW
(*b*) 40 kW
(*c*) 80 kW
(*d*) 120 kW

90. Which of the following is not necessarily an advantage of interconnecting various power stations?
(*a*) Improved frequency of power supplied
(*b*) Reduction in total installed capacity
(*c*) Increased reliability
(*d*) Economy in operation of plants

91. A power transformer is usually rated in
(*a*) kW
(*b*) kVAR
(*c*) kWh
(*d*) kVA

92. .... public sector undertaking is associated with erection and sometimes running of thermal power plants
(*a*) NTPC
(*b*) SAIL
(*c*) BEL
(*d*) BHEL

93. Most efficient plants are normally used as
(*a*) peak load plants
(*b*) base load plants
(*c*) either (*a*) or (*b*)
(*d*) none of the above

94. For a diesel generating station the useful life is expected to be around
(*a*) 15 to 20 years
(*b*) 20 to 50years
(*c*) 50 to 75 years
(*d*) 75 to 100 years

95. Which of the following is not a method for estimating depreciation charges?
(*a*) Sinking fund method
(*b*) Straight line method
(*c*) Diminishin value method
(*d*) Halsey's 50–50 formula

96. The expected useful life of an hydroelectric power station is around
(*a*) 15 years
(*b*) 30 years
(*c*) 60 years
(*d*) 100 years

97. In a load curve the highest point represents
(*a*) peak demand
(*b*) average demand
(*c*) diversified demand
(*d*) none of the above

98. Which of the following source of power is least reliable?
(*a*) Solar energy
(*b*) Geothermal power
(*c*) Wind power
(*d*) MHD

99. In Indial production and distribution of electrical energy is confined to
(*a*) private sector
(*b*) public sector
(*c*) government sectors
(*d*) joint sector
(*e*) none of the above

100. A pilot exciter is provided on generators for which of the following reasons?
(*a*) To excite the poles of main exciter
(*b*) To provide requisite starting torque to main exciter

(c) To provide requisit starting torque to generator
(d) None of the above

101. The primary reason for low power factor is supply system is due to installation of
(a) induction motors
(b) synchronous motors
(c) single phase motors
(d) d.c. motors

102. an over excited synchronous motor on no-load is known as
(a) syachronous condenser
(b) generator
(c) induction motor
(d) alternator

103. Which of the following is an advantage of static capacitor for power factor improvement?
(a) Little maintenance cost
(b) Ease in installation
(c) Low losses
(d) All of the above

104. For any type of consumer the ideal tariff is
(a) two part tariff
(b) three part tariff
(c) block rate tariff
(d) any of the above

105. The efficiency of a plant is of least concern when it is selected as
(a) peak load plant
(b) casual run plant
(c) either (a) or (b)
(d) base load plant

106. Power generation cost reduces as
(a) diversity factor increases and load factor decreases
(b) diversity factor decreases and load factor increases
(c) both diversity factor as well as load factor decrease
(d) both diversity factor as well as load factor increase

107. The depreciation charges in diminishing value method are
(a) light in early years
(b) heavy in early years
(c) heavy in later years
(d) same in all years

108. The area under daily load curve divided by 24 hours gives
(a) average load
(b) least load
(c) peak demand
(d) total kWh generated

109. Maximum demand tariff is generally not applied to domestic consumers because
(a) they consume less power
(b) their load factor is low
(c) their maximum demand is low
(d) none of the above

110. A 130 MW generator is usually .... cooled
(a) air
(b) oxygen
(c) nitrogen
(d) hydrogen

111. For cooling of large size generators hydrogen is used because
(a) it is light
(b) it offers reduced fire risk
(c) it has high thermal conductivity
(d) all of the above

112. Major share of power produced in India is through
(a) diesel power plants
(b) hydroelectric power plants
(c) thermal power plants
(d) nuclear power plants

113. Which of the following may not be the effect of low plant operating power factor?
(a) Improved illumination from lighting
(b) Reduced voltage level
(c) Over loaded transformers
(d) Overloaded cables

114. Which of the following plants is almost inevitably used as base load plant?
(a) Diesel engine plant
(b) Gas turbine plant
(c) Nuclear power plant
(d) Pumped storage plant

115. Which of the following component, in a steam power plant, needs maximum maintenance attention?
(a) Steam turbine
(b) Condenser
(c) Water treatment plant
(d) Bioler

116. For the same cylinder dimensions and speed, which of the following engine will produce least power?
(a) Supercharged engine
(b) Diesel engine

(*c*) Petrol engine
(*d*) All of the above engines will equal power

117. The least share of power is provided in India, by which of the following power plants?
(*a*) Diesel power plants
(*b*) Thermal power plants
(*c*) Hydro-electric power plants
(*d*) Nuclear power plants

118. Submarines for under water movement, are powered by which of the following?
(*a*) Steam accumulators
(*b*) Air motors
(*c*) Diesel engines
(*d*) Batteries

119. An alternator coupled to a .... runs at slow speed, as compared to as compared to others.
(*a*) diesel engine
(*b*) hydraulic turbine
(*c*) steam turbine
(*d*) gas turbine

120. The effect of electric shock on human body depends on which of the following
(*a*) current
(*b*) voltage
(*c*) duration of cantact
(*d*) all of the above

121. Which lightening stroke is most dangerous?
(*a*) Direct stroke on line conductor
(*b*) Indirect stroke on conductor
(*c*) Direct stroke on tower top
(*d*) Direct stroke on ground wire

122. Which of the following devices may be used to provide protection against lightening over voltages?
(*a*) Horn gaps
(*b*) Rod gaps
(*c*) Surge absorbers
(*d*) All of the above

123. When the demand of consumers is not met by a power plant, it will resort to which of the following?
(*a*) Load shedding
(*b*) Power factor improvement at the generators
(*c*) Penalising high load consumers by increasing the charges for electricity
(*d*) Efficient plant operation.

124. Load shedding is possible through which of the following?
(*a*) Switching of the loads
(*b*) Frequency reduction
(*c*) Voltage reducteion
(*d*) Any of the above

125. In power plants insurance cover is provided for which of the following?
(*a*) Unskilled workers only
(*b*) Skilled workers only
(*c*) Equipment only
(*d*) All of the above

126. A company can raise funds through
(*a*) fixed deposits
(*b*) shares
(*c*) bonds
(*d*) any of the above

127. Which of the following are not repayable after a stipulated period?
(*a*) Shares
(*b*) Fixed deposits
(*c*) Cash certificates
(*d*) Bonds

128. The knowledge of diversity factor helps in determining
(*a*) plant capacity
(*b*) average load
(*c*) peak load
(*d*) kWh generated
(*e*) none of the above

129. Load shedding is done to
(*a*) improve power factor
(*b*) run the equipment efficiently
(*c*) repair the machine
(*d*) reduce peak demand

130. when a plant resorts to load shedding it can be concluted that
(*a*) peak demand is more than the installed capacity
(*b*) daily load factor is unity
(*c*) diversity factor is zero
(*d*) plant is under repairs

131. Which of the following is the disadvantage of static capacitor for power factor improvement?
(*a*) Easily damaged by high voltage
(*b*) Cannot be repaired
(*c*) Short service life
(*d*) All of the above

132. If the tariff for electrical energy charages provides incentive by way of reduced charges for higher consumption, then it can be concluede that
(*a*) Load factor is unity

(*b*) power is generated through hydroelectric plant
(*c*) plant has sufficient reserve capacity
(*d*) station has more than two generators

133. Anything having some heat value can be used as fuel in case of
(*a*) open cycle gas turbines
(*b*) closed cycle gas turbines
(*c*) petrol engines
(*d*) diesel engines

ANSWERS

1. (*d*)	**2.** (*c*)	**3.** (*a*)	**4.** (*b*)	**5.** (*c*)	**6.** (*b*)	**7.** (*a*)
8. (*d*)	**9.** (*c*)	**10.** (*b*)	**11.** (*c*)	**12.** (*d*)	**13.** (*a*)	**14.** (*c*)
15. (*a*)	**16.** (b)	**17.** (*b*)	**18.** (*b*)	**19.** (*e*)	**20.** (*b*)	**21.** (*c*)
22. (*b*)	**23.** (*b*)	**24.** (*a*)	**25.** (*b*)	**26.** (*e*)	**27.** (*a*)	**28.** (*d*)
29. (*b*)	**30.** (*c*)	**31.** (*d*)	**32.** (*d*)	**33.** (*d*)	**34.** (*a*)	**35.** (*a*)
36. (*c*)	**37.** (*b*)	**38.** (*d*)	**39.** (*d*)	**40.** (*d*)	**41.** (*c*)	**42.** (*a*)
43. (*a*)	**44.** (*b*)	**45.** (*d*)	**46.** (*c*)	**47.** (*c*)	**48.** (*d*)	**49.** (*b*)
50. (*b*)	**51.** (*a*)	**52.** (*b*)	**53.** (*c*)	**54.** (*d*)	**55.** (*a*)	**56.** (*d*)
57. (*a*)	**58.** (*c*)	**59.** (*c*)	**60.** (*b*)	**61.** (*d*)	**62.** (*b*)	**63.** (*c*)
64. (*a*)	**65.** (*b*)	**66.** (*a*)	**67.** (*d*)	**68.** (*b*)	**69.** (*a*)	**70.** (*c*)
71. (*c*)	**72.** (*c*)	**73.** (*d*)	**74.** (*d*)	**75.** (*d*)	**76.** (*d*)	**77.** (*d*)
78. (*a*)	**79.** (*c*)	**80.** (*b*)	**81.** (*d*)	**82.** (*c*)	**83.** (*c*)	**84.** (*d*)
85. (*c*)	**86.** (*b*)	**87.** (*f*)	**88.** (*c*)	**89.** (*a*)	**90.** (*a*)	**91.** (*d*)
92. (*a*)	**93.** (*b*)	**94.** (*a*)	**95.** (*d*)	**96.** (*d*)	**97.** (*a*)	**98.** (*c*)
99. (*b*)	**100.** (*a*)	**101.** (*a*)	**102.** (*a*)	**103.** (*d*)	**104.** (*b*)	**105.** (*c*)
106. (*d*)	**107.** (*b*)	**108.** (*a*)	**109.** (*c*)	**110.** (*d*)	**111.** (*d*)	**112.** (*c*)
113. (*a*)	**114.** (*c*)	**115.** (*d*)	**116.** (*d*)	**117.** (*a*)	**118.** (*d*)	**119.** (*b*)
120. (*d*)	**121.** (*a*)	**122.** (*d*)	**123.** (*a*)	**124.** (*d*)	**125.** (*c*)	**126.** (*d*)
127. (*d*)	**128.** (a)	**129.** (*d*)	**130.** (*a*)	**131.** (*d*)	**132.** (*c*)	**133.** (*b*)

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