CHAPTER 17

Tariffs and Power Factor Improvement

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17.1. TARIFFS

Tariff means the schedule of rates or charges. Tariff, in case of electric supply, means the schedule or rates framed for supply of electrical energy to different classes of consumers.

17.1.1. Objective of Tariff

The main objective of the tariff is to distribute equitably the cost of supplying energy among the various classification of use. Therefore, a tariff must cover the following items :

(*i*) Recovery of cost of capital investment in generating, transmitting and distributing equipment.

(*ii*) Recovery of cost of operation, supplies and maintenance of equipment.

(*iii*) Recovery of cost of metering equipment, billing, collection costs and miscellaneous services and

(*iv*) A satisfactory return on the total capital investment.

17.1.2. Principal Factors Affecting Framing of Tariff

The principal factors involved in fixing of a tariff are enumerated below :

1. Proper return is secured from each consumer. While fixing the tariff for different classes of consumers, it has to be taken into account whether the tariff will result in a revenue meeting all the expenditure of the supply authority. In addition, the tariff should bring forth sufficient money to enable future expansion to meet an anticipated load requirement.
2. The consumers are encouraged to make more extended use of electricity.
3. The tariff should be simple and capable of easy explanation to the public. A complicated tariff may cause an opposition from the public which is generally distrustful of the supply authorities.
4. The consumers are charged according to what the energy costs. The tariff should be such as to satisfy the consumers of all categories. A big consumer should be charged at a lower rate than a small consumer. This is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy.
5. The consumers are encouraged to use power during off-peak hours and penalised for high loads demanded at system peak by making a provision for higher demand charges.
6. The consumers are penalised for poor power factor.

The type of service rendered by the supply authority also determines the tariff that must be charged to a consumer. This is explained below by giving some examples. Electric supply to a domestic consumer, having usually light and fan points, makes the life of an ordinary citizen convenient and pleasant. But such a class of consumers cannot be charged at higher rates. This is because in a welfare state like India, the state has the responsibility to provide some basic necessities to its citizens. Similarly, the farmer for supply of electrical energy to agricultural loads cannot be charged at a higher rate because of the national concern for agricultural output. However, the consumers using electricity for extra comforts such as for air-conditioning and for commercial purposes can be charged at higher rates.

17.2. TYPES OF TARIFFS

Various types of tariffs, which are commonly used, are described below.

1. ***Flat Demand Tariff.*** This is one of the earliest form of tariffs used for charging the consumers for electrical energy consumption. In this case, the total demand and the energy consumption were fixed.

In early days, when the use of electricity was mainly restricted to very few applications such as for lamps etc. and the number of hours of use of the lamps were fixed, they were charged on the basis of number of lamps installed or total load connected in kW and fixed number of hours of use in a month or in a quarter of a year or in a year. Since the total demand and energy consumption were fixed and all the consumers were of alike class, so the rate could be expressed directly as certain amount per lamp or per unit of load installed. If x is the number of lamps or load connected in kW and a is the rate per lamp or per kW of connected load then

$$\text{Energy charges} = \text{Rs } ax$$

In this type of tariff the metering equipment, meter reading, billing and accounting costs are eliminated resulting in overall decrease of total cost. The main disadvantage of this tariff is that it does not differentiate between the consumers who use same appliance or equipment but for different duration of time. It encourages the consumers to keep their appliances connected to the supply mains even when not required. Nowadays the tariff of this type is restricted to use such as in street lighting, signal systems, sign lighting and other loads where the energy consumption in quantity could be readily predicted.

2. *Simple Tariff.* This is the simplest type of tariff according to which the cost of energy is charged on the basis of units consumed. The rate can be derived as

$$\text{Cost/kWh} = \frac{\text{Annual fixed cost + annual operating cost}}{\text{Total number of units supplied to the consumers per annum}}$$

Although this method of deriving the rate is simple and also the drawback of encouraging the consumers to keep their appliances connected to the supply mains even when not required is removed as they have to pay for all the energy consumed but suffers from the following drawbacks:

(i) There is no discrimination among the different types of consumers (domestic, industrial, bulk) having different load factor, diversity factor and power factor.

(ii) The cost per kWh delivered is higher.

The simple tariff can be made suitable by having the following modifications.

(i) A discount be allowed to the consumer who consumes more electricity than an average consumer.

(ii) Special tariffs be framed for the various types of consumers just as the domestic consumers using electricity for light and fans be charged at higher rates as compared to power consumers. The reason for it is that the load factor of light and fan load is low and the demand is during peak hours of the day.

(iii) The consumers be encouraged to use electricity during off-peak hours by giving a suitable discount. Such a tariff is called the *off-peak tariff*.

(iv) The consumers be encouraged to use electricity at high load factor and power factor by framing special types of tariffs such as maximum demand tariff and power factor tariff.

3. *Flat Rate Tariff.* This type of tariff differs from the former one in the sense that the different types of consumers are charged at different rates *i.e.*, the flat rate for light and fan loads is slightly higher than that for power load. The rate for each category of consumers is arrived at by taking into account its load factor and diversity factor.

The method is usually most popular with the public since it can easily be understood by the consumers and the calculations at the supplier's end are simple. If the energy consumed during the billing period is x units and the flat rate is Rs a per unit then charges are Rs ax.

The disadvantages of this tariff are:

(*i*) Separate meters are required for different types of supply.

(*ii*) Difficulty is experienced to derive the load factor and diversity factor for various types of loads to be employed in deciding the tariff.

(*iii*) The consumer is charged for the total quantity of energy consumed at the same rate irrespective of the magnitude of energy consumed while increased generation or consumption spread the fixed charges over a greater number of units and so the overall cost per unit decreases as the consumption increases.

4. *Step Rate Tariff.* The step rate tariff is a group of flat rate tariffs of decreasing unit charges for higher range of consumption, say for example

Rs 4.0 per unit if the consumption does not exceed 50 kWh

Rs 3.50 per unit if the consumption exceeds 50 kWh but does no exceed 200 kWh

Rs 3.0 per unit if the consumption exceed 200 kWh.

This type of tariff takes into account the fact of lower generation cost owing to higher energy consumption consequent to improvement of load factor and therefore promotes the use of electricity. The drawback of this tariff is however that by increasing the energy consumption so as just to enter the next range from the final stage of previous range, the total energy cost is reduced. Thus there is tendency with the consumer, just approaching the limit of the step to, anyhow cross the step and enter the next one in order to reduce the total energy cost. This drawback is removed in *block rate tariff* explained below.

5. *Block Rate Tariff.* In this type of tariff a given block of energy is charged at higher rate and succeeding blocks of energy are charged at progressively reduced rates, say for example

The first 25 units may be charged at the rate of Rs 4.0 paise/unit.

The next 40 units may be charged at the rate of Rs 3.50 per unit.

The consumption exceeding 65 units may be charged at the rate of Rs 3.0 per unit.

The advantage of such a tariff is that the consumer gets an incentive for consuming more electrical energy. This increases the load factor of the system and hence the generation cost is reduced. Its main drawback is that it lacks a measure of the consumer's demand. This tariff is most popular nowadays among domestic, commercial and small industrial consumers.

6. ***Hopkinson Demand Rate or Two Part Tariff.*** The total charge to be made to the consumer is split into two components namely fixed charge and running charge. Since fixed charge is independent of energy consumed and proportional to the maximum demand so the fixed charge is made at a certain amount per kW of maximum demand, which can be assessed on the basis of the rateable value of the premises or on the number of rooms excluding bath rooms, attics etc. or on the connected load or on the total combined kW capacity of all the consuming devices owned by a particular consumer. Running charge is made at a certain amount per kWh for the total energy consumed.

This type of tariff is expressed by the expression

Total energy charges, e = Rs $a \times$ kW + b kWh where Rs a is the charge per kW of maximum demand assessed and Rs b is the charge per kWh of energy consumed.

This tariff is mostly applicable to medium industrial consumers.

In this tariff charge made on maximum demand recovers the fixed charges such as interest and depreciation on the capital cost of building and equipment, taxes and insurance charges and operating cost which is independent of energy supplied by it and varies with variation of maximum demand. Charge made on total energy consumption recovers the operating cost, which varies with variation in energy supplied.

The drawback of this tariff from the point of view of consumer is that he is to pay his fixed charge irrespective of the consumption. For example, if during any month any industry remains closed, the owner will be required to pay the fixed charges unnecessarily.

7. ***Maximum Demand Tariff or Wright Demand Rate.*** This tariff is similar to that of two part tariff except that in this case maximum demand is actually measured by a maximum demand indicator instead of merely assessing it on the basis of rateable value. In this tariff the drawback of the two part tariff is removed. This tariff is almost applicable to all bulk supplies and large industrial consumers, who have a control over their maximum demand.

Such a tariff induces the consumer to keep his maximum demand at a low value.

8. ***Power Factor Tariffs.*** Since the efficiency of plant and equipment depends upon the power factor, therefore, in order to increase the utility of plant and equipment to the maximum, the plant must be operated at the most economical power factor. That is why, sometimes consumers are penalised for poor power factor by applying the following types of power factor tariffs :

(*a*) **kVA Maximum Demand Tariff.** It is a modified form of two part tariff. In this case maximum demand is measured in kVA instead of in kW. This type of tariff encourages the consumers to operate their machines and other equipment at improved power factor, because low power factor will cause more demand charges.

(*b*) **kWh and kVARh Tariff.** In this type of tariff kWh and kVARh are measured and charged separately. Since kVARh decreases with the increase in power factor, therefore, the consumer tries to improve the power factor of his installation in order to decrease the charges on account of kVARh recorded.

(*c*) **Sliding Scale or Average Power Factor Tariff.** In this type of tariff, an average power factor, say 0.8 lagging may be taken as reference and a surcharge for each 0.01 by which the average power factor falls below this figure may be made. Similarly a discount may be allowed for each 0.01 by which the average power factor rises above this figure. Such tariffs are rarely used.

9. ***Three Part Tariff or Doherty Rate.*** In this tariff total charge is split into three elements namely fixed charge, semi-fixed charge and variable charge.

Constant or fixed charge recovers the cost on account of expenses in giving a supply (of any sort or of any magnitude) service connection (incurred once only but charged for either by a capital or an annum sum or charged each billing period), office and service expenses including accounting, metering and establishment charges.

Semi-fixed charge, which are levied on the basis of maximum demand in kW or kVA, recovers the plant initial cost as well as that operating cost which is independent of total energy supplied by it and varies with the variation in maximum demand.

Variable charge, which are levied on the basis of energy consumed, recovers the cost varying with the variation in energy supplied such as on account of fuels etc.

So the general expression for the recovery of the cost split into three sections mentioned above can be written as

Total charges = Rs a + b kW + c kWh

where a is a constant charge made each billing period.

b = Unit charge in Rs per kW of metered maximum demand in kW during billing period. In some cases it is also charged in Rs per kVA so that the consumers are penalised for poor power factor.

and c = Unit charge for energy in Rs per kWh of energy consumed.

This type of tariff is usually applicable to bulk supplies.

10. ***Off-Peak Tariff.*** The load on the power station usually has pronounced peak loads in the morning and early evening and a very low load during the night (from 10 PM to 6 AM). During the night, therefore, and other off-peak period which may occur, a large proportion of the generating and distribution equipment will be lying idle. In case the consumers are encouraged to use electricity during off peak hours by giving a special discount, the energy can be supplied without incurring an additional capital cost and should, therefore, prove very profitable.

This type of tariff is very advantageous for certain processes such as water heating by thermal storage, pumping, refrigeration etc.

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17.3. SPOT PRICING

The major concern of electric utilities all over the world is very large demand during peak load hours and surplus energy during off peak hours. This put the utilities in awkward situation of capacity shortages during peak load hours and large surplus during off peak hours. In spot pricing the consume is charged based on the time at which consumption occur. This is resorted to offset the imbalance caused because of large demand during peak load conditions and off peak conditions. The price is varied for reflecting the utility cost of providing the electrical energy at a given time. The spot pricing encourages the consumer to shift the maximum demand to off peak hours when the supply is abundant and prices are low. The spot pricing rate can be expressed as

Instantaneous spot rate
= Incremental operating cost + quality of supply component.

The quality of supply component is choosen so that the resultant price reflects the marginal value of unserved energy. Spot pricing rates are economically rational as they embody the principles of marginal cost theory and result in efficient location of resources. Spot pricing is also sometimes termed as 'load adaptive pricing', 'flexible pricing', 'homeostatic control pricing', 'real time pricing' or 'response pricing'. It is also known as 'Time of Day Tariff'.

Because of recent advancement in microcomputers and telecommunications and a drastic reduction in metering and communication costs, spot pricing has become feasible and many utilities in developed countries have adopted at least partial spot pricing in their industrial and commercial rate structures.

17.4. TYPES OF CONSUMERS AND THEIR TARIFFS

The main types of load on a system are domestic, commercial agricultural, industrial, municipal, traction etc. Accordingly the consumers may be categorised as domestic consumers, commercial consumers, agricultural consumers, industrial consumers (small, medium and large), bulk consumers etc.

17.4.1. Domestic Consumers

Residential load consists of lights, fans, and appliances such as radios, TVs, heaters, electric irons, refrigerators, electric water heaters, washing machines, coolers, air-conditioners, domestic pump sets etc. Domestic consumers are given single phase supply up to a load of 5 kW and a 3-phase supply for loads exceeding 5 kW.

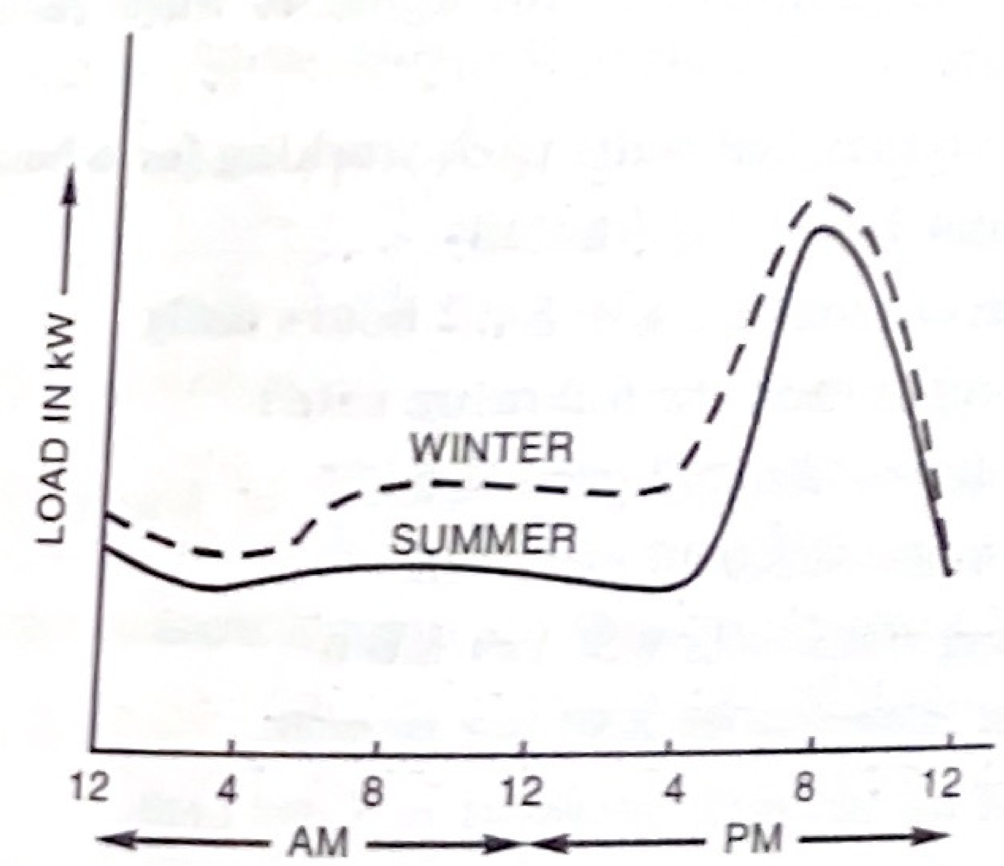

Fig. 17.1. *Typical Chronological Load Curve For Domestic Consumers*

The small consumers generally use all the light points simultaneously so their demand factor is high (almost unity). Big domestic consumers may have demand factor low (around 0.5). During summer the major part of domestic load may consist of fan load during day and light and fan load during evenings and early mornings and some air-conditioner load. During winter, the major load is light load during evenings and early mornings and some heater load. Typical chronological load curve for domestic consumers is given in Fig. 17.1. The tariffs applicable to domestic consumers are simple tariff, flat rate tariff or block rate tariff. In addition meter rent and electricity duty are also charged from the consumers.

17.4.2. Commercial Consumers

Non-residential premises, such as shops, business-houses, cinemas, hotels, public offices, clubs etc. fall under this category. The load mainly consists of lights, fans and small electric appliances. The load remains fairly constant from around morning 10 to evening 9 hours. During night the load may consist of some lighting load. The demand factor is fairly high. Such consumers are given single phase supply for loads up to 5 kW and three phase supply for loads exceeding 5 kW. Typical chronological load curve for commercial consumers is shown in Fig. 17.2. The tariffs applicable to commercial consumers are also simple tariff, flat rate tariff or block rate tariff but charges per unit are higher in comparison to those in case of domestic consumers. In addition, meter rent and electricity duty are also charged from the consumers. Sometimes there is also a provision for minimum charges in case the energy consumption remains below a certain prescribed limit.

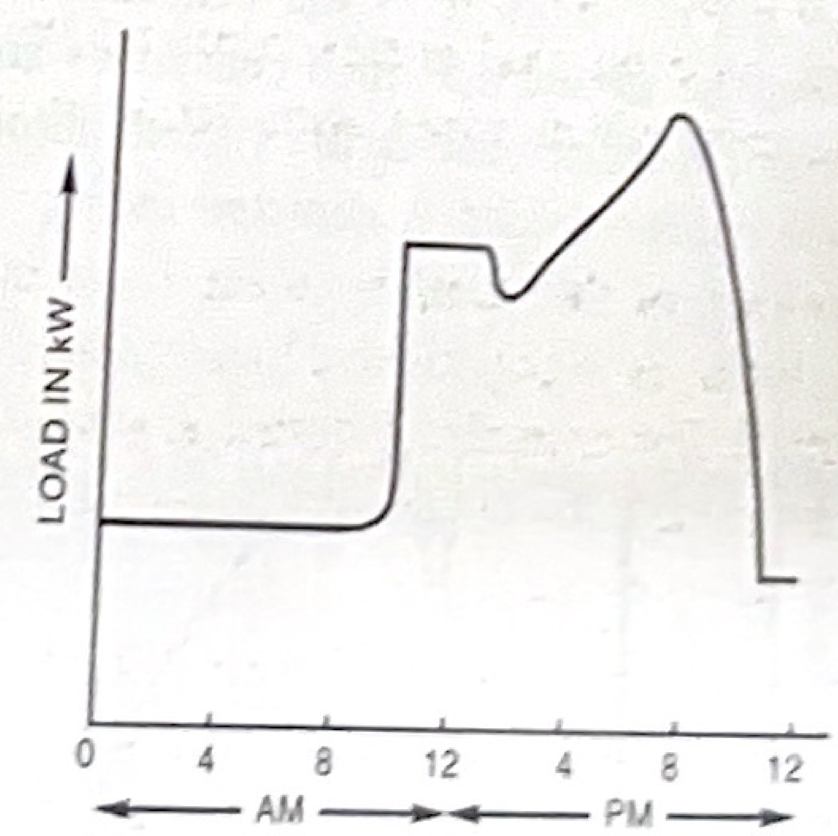

Fig. 17.2. *Typical Chronological Load Curve For Commercial Consumers*

17.4.3. Agricultural Consumers

Consumers drawing power up to 20 kW for irrigation pumping units are categorized as agricultural consumers. Such

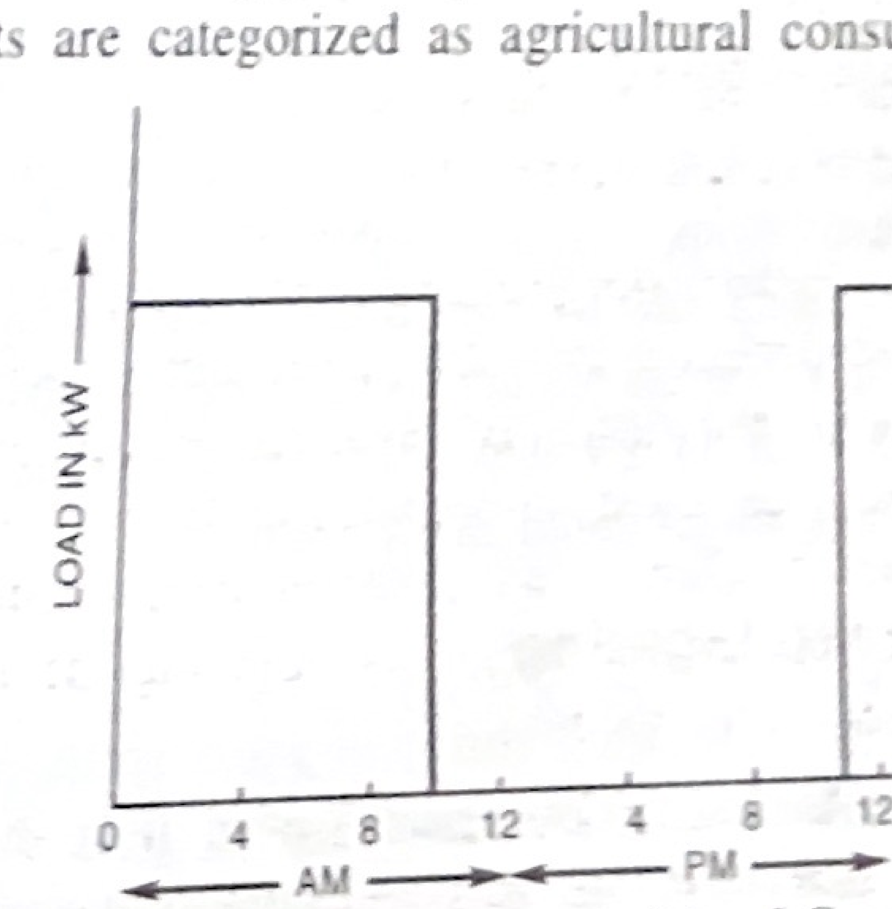

Fig. 17.3. *Typical Chronological Load Curve For Agricultural or Irrigation*

consumers are given a three phase supply. The loads of the tubewells used for irrigation constitute a substantial portion of the system load. The demand factor and diversity factor are both almost unity. Figure 17.3 depicts the typical chronological load curve for agricultural or irrigation load.

Agricultural consumers are charged at a flat rate tariff which may be either on the basis of a fixed charge per unit consumed or a fixed charge per kW or hp of connected load.

17.4.4. Industrial Consumers

Industrial consumers may further be categorised as small industrial consumers, medium industrial consumers and large industrial consumers according to the rating of loads.

Small industrial consumers are owners of small workshops, atta chakkis, wheat threshers, saw machines and other small manufacturing and repair shops with load not exceeding 20 kW. The demand factor depends on the nature of load but usually it is high (around 0.8). Such consumers are given 3-phase supply at 415 V. A block tariff is usually offered to such consumers.

Industrial consumers with loads exceeding 20 kW but not exceeding 100 kW fall under the category of *medium industrial consumers.* They are given three phase supply at 415 V and are usually charged on two part tariff.

Industrial consumers with loads exceeding 100 kW are categorized as *large industrial consumers.* They are supplied power at 11 or 33 kV, and in rare cases, at 415 V three phase depending on the requirement of the consumers. The demand factor may be around 0.5. Such consumers are usually charged kVA maximum demand tariff. Typical chronological load curve for industrial load is depicted in Fig. 17.4.

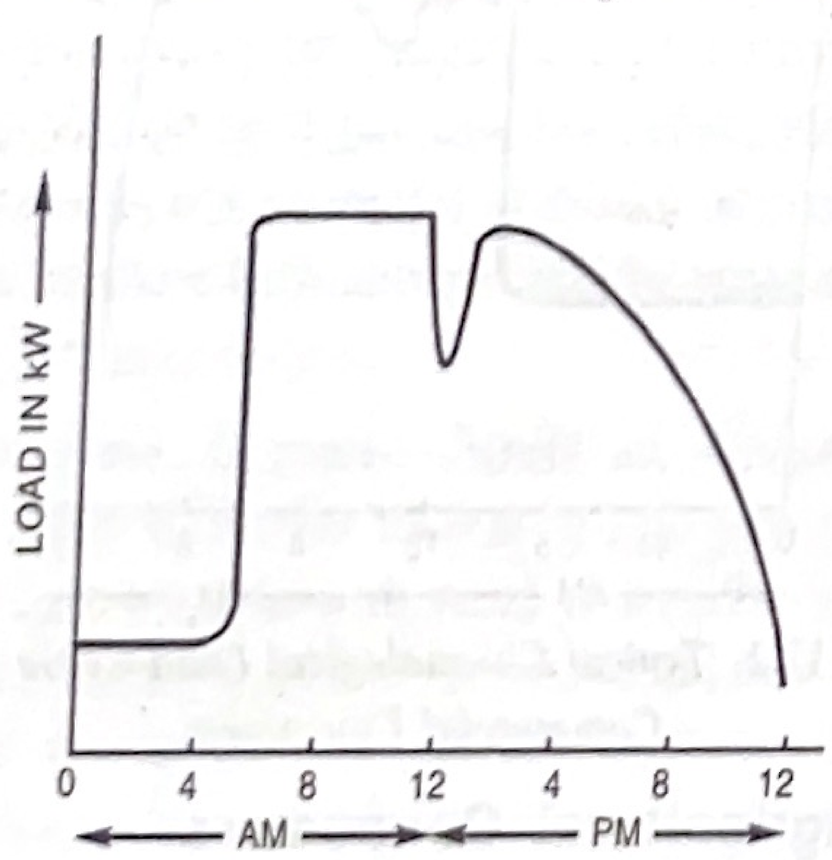

Fig. 17.4. *Typical Chronological Load Curve For Industrial Load*

17.4.5. Bulk Consumers

Power consumers such as railways, public work departments, educational institutions, military establishments, hospitals having loads exceeding 100 kW fall under the category of bulk consumers. Bulk consumers are usually supplied by 3-phase supply at 415 V or 11 kV depending on their requirements. Such consumers are charged at flat rate.

17.4.6. Street Lighting

Power supply given for the lighting of parks, roads and streets under the municipal committees, municipal boards or panchayats comes under this category. Supply for street lighting is given at 415 V three phase or 240 V single phase. Such a load has demand factor and diversity factor of unity. The switching on the lights and their switching off is synchronised with dusk and dawn respectively. Separate distributors are run for street lighting to enable their switching simultaneously. The tariff charged for street lighting is such that it recovers the cost of the energy consumed as well as the cost of replacement of lamps. Chronological load curve for street lighting is shown in Fig. 17.5.

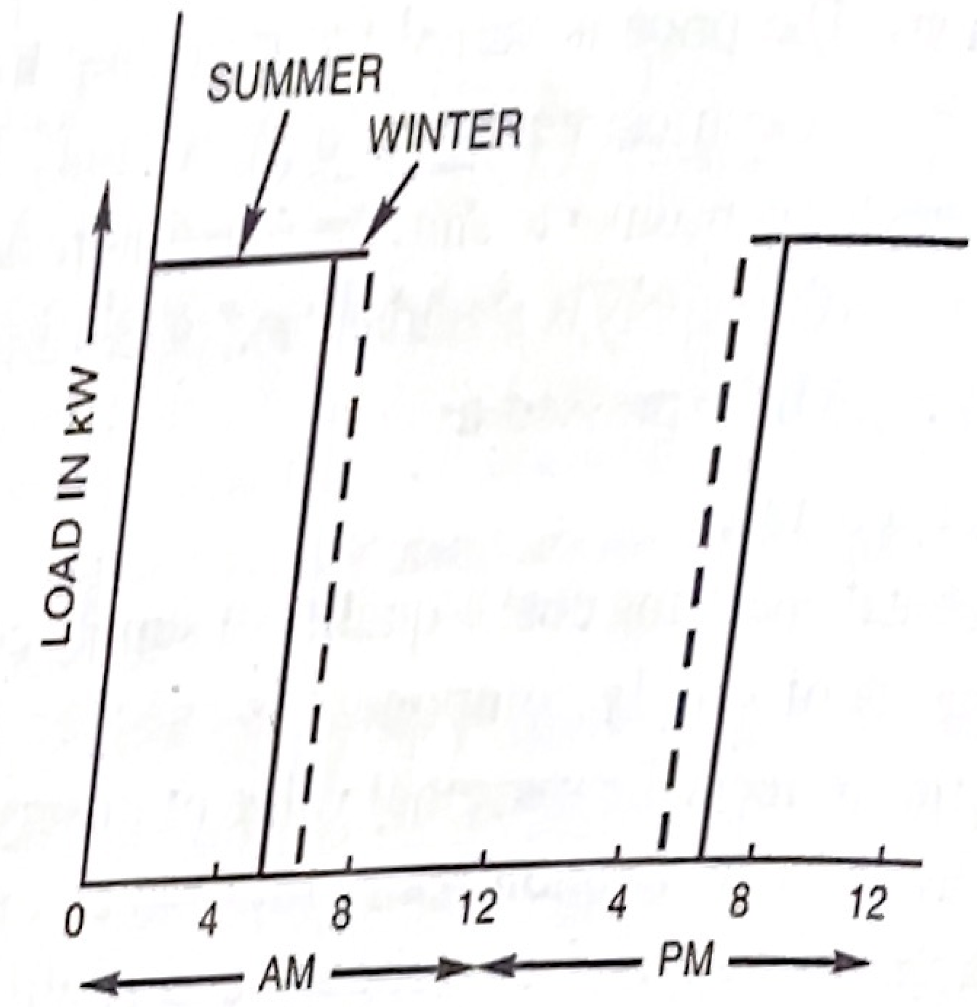

Fig. 17.5. *Typical Chronological Load Curve For Street Lighting*

17.4.7. Water Supply

The load for water supply is for pumping water to the overhead tanks. It is generally possible to fit this load during system off peak hours, usually during night hours.

Example 17.1. The daily load of an industrial consumer is as follows :

100 kW for 9 hours, 125 kW for 6 hours, 50 kW for 7 hours and 5 kW for 2 hours.

The tariff rate is Rs 800 per kW of maximum demand per year plus Rs 2.50 per kWh. Determine the energy consumption per year (365 days) and yearly bill. [*West Bengal Univ. of Technology 2009-10*]

Solution : Daily energy consumption

$= 100 \times 9 + 12.5 \times 6 + 50 \times 7 + 5 \times 2$

$= 900 + 750 + 350 + 10 = 2{,}010$ kWh

Annual energy consumption $= 2{,}010 \times 365 = 733{,}650$ kWh **Ans.**

Maximum demand = 125 kW

Demand charges per annum = Rs 800×125 = Rs 100,000

Energy charges per annum = Rs $2.50 \times 733{,}650$ = Rs 1,834,125

Yearly bill = Demand charges per annum + energy charges per annum

= Rs 100,000 + Rs 1,834,125 = Rs 2,834,125 **Ans.**

Example 17.2. Light load : 6 tube lights 40 watts each working for 4 hours daily

Fan load : 6 fans 100 watts each working for 6 hours daily

Refrigerator load : 2 kWh daily

Miscellaneous load : 2 kW for 2 hours daily

Find the monthly bill at the following rate :

First 20 units—Rs 0.50 per kWh

Next 30 units—Rs 0.40 per kWh

Remaining units—Rs 0.30 per kWh

Constant charge—Rs 2.50 per month

Discount for prompt payment = 5 per cent.

[*Rajasthan Technical Univ. Generation of Electrical Power 2008, 2009*]

Solution : Daily energy consumption

$$= \frac{(6 \times 40 \times 4) + (6 \times 100 \times 6)}{1{,}000} + 2 + 2 \times 2 = 10.56 \text{ kWh}$$

Monthly (30 days) consumption

$= 10.56 \times 30 = 316.8$ kWh or units

Monthly bill = (Energy charges + constant charge) (1 – discount)

$= \text{Rs } [20 \times 0.5 + 30 \times 0.4 + (316.8 - 50) \times 0.3 + 2.5]\,(1 - 0.05)$

$= \text{Rs } (10 + 12 + 80.04 + 2.5)\,(0.95) = \text{Rs } 99.31$ **Ans.**

Example 17.3. A consumer has an annual consumption of 70,080 kWh. The charge is Rs 100 per kW of maximum demand plus 5 paise per kWh. Find the annual bill and the overall costs per kWh, if the load factor is 40%.

[U.P. Technical Univ. Power Station Practice 2003-04]

Solution : Annual energy consumption = 70,080 kWh

Annual load factor, LF = 40% or 0.4

$$\text{Average load} = \frac{\text{Annual energy consumption}}{8{,}760} = \frac{70{,}080}{8{,}760} = 8 \text{ kW}$$

$$\text{Maximum demand, MD} = \frac{\text{Average load}}{\text{LF}} = \frac{8}{0.4} = 20 \text{ kW}$$

Annual energy consumption bill

= Demand charges/annum + energy charges/annum

$= \text{Rs } 100 \times 20 + \text{Rs } 0.05 \times 70{,}080$

$= \text{Rs } 2{,}000 + \text{Rs } 3{,}504 = \text{Rs } 5{,}504$ **Ans.**

Example 17.4. An industrial undertaking has connected load of 200 kW. The maximum demand is 150 kW. On average each machine works for 70% of time. Find yearly expenditure on electricity if the tariff is Rs 3,000 + Rs 700 per kW of maximum demand per year + Rs 0.60 per kWh.

[Rajasthan Univ. Generation of Electrical Power 2003]

Solution : Yearly energy consumption

$= 200 \times 0.7 \times 365 \times 24 = 1{,}226{,}400$ kWh

Fixed charges/annum = Rs 3,000

Demand charges/annum $= \text{Rs } 700 \times 150 = \text{Rs } 105{,}000$

Energy charges/annum $= \text{Rs } 0.60 \times 1{,}226{,}400 = \text{Rs } 735{,}840$

Yearly expenditure on electricity

$= \text{Rs } 3{,}000 + \text{Rs } 105{,}000 + \text{Rs } 735{,}840 = \text{Rs } 843{,}840$ **Ans.**

Example 17.5. The annual consumption of domestic customer is $1{,}500 \times 10^3$ units and the annual load factor is 40%. What will be the saving in the average unit cost if the load factor improves to 100%? The two part tariff is Rs 500 per kW of maximum demand per year + 40 paise per kWh.

[Rajasthan Univ. Generation of Electrical Power 2000]

Solution : Annual energy consumption = $1{,}500 \times 10^3$ kWh

$$\text{Average load} = \frac{\text{Annual energy consumption}}{365}$$

$$= \frac{1{,}500 \times 10^3}{365 \times 24} = 171.233 \text{ kW}$$

Load factor = 40% = 0.4

$$\text{Maximum demand} = \frac{\text{Average load}}{\text{Load factor}} = \frac{171.233}{0.4} = 428 \text{ kW}$$

In case the consumer improves the load factor to 100 per cent, his maximum demand will be reduced to $\frac{171.233}{1}$ *i.e.* 171.233 kW

Annual energy bill with 40% load factor

$= \text{Rs } 500 \times 428 + \text{Rs } 0.40 \times 1{,}500 \times 10^3 = \text{Rs } 814{,}000$

$$\text{Unit cost} = \text{Rs } \frac{814{,}000}{1{,}500 \times 10^3} = \text{Re } 0.5427 \text{ or paise } 54.27$$

Annual energy bill with 100% load factor

$= \text{Rs } 500 \times 171.233 + \text{Rs } 0.40 \times 1{,}500 \times 10^3 = \text{Rs } 685{,}616.50$

$$\text{Unit cost} = \text{Rs } \frac{685{,}616.50}{1{,}500 \times 10^3} = \text{Re } 0.4571 \text{ or paise } 45.71$$

Saving in the average unit cost

= Paise 54.27 – paise 45.71 = Paise 8.56/kWh **Ans.**

Example 17.6. An industrial consumer has single phase 230V supply. His monthly energy consumption is 2,020 kWh. A maximum demand indicator installed at his premises indicates 40 A which is charged at unity power factor for 2 hours daily at Rs 3.50 per kWh. The remaining units are charged at Rs 1.80 per kWh. Find the monthly bill for 30 days and average tariff per kWh.

[Generation of Electrical Power, Pb. Technical Univ. May 2008; Rajasthan Univ. 2001, 2004, 2005, Rajasthan Technical Univ. 2008]

Solution : Monthly energy consumption corresponding to maximum demand

$$= \frac{\text{Voltage} \times \text{maximum demand of current} \times \text{pf} \times \text{working hour} \times 30}{1{,}000}$$

$$= \frac{230 \times 40 \times 1 \times 2 \times 30}{1{,}000} = 552 \text{ kWh}$$

Cost of energy corresponding to maximum demand

$= \text{Rs } 3.50 \times 552 = \text{Rs } 1{,}932$

Energy cost for remaining energy consumption

$= \text{Rs } 1.80 \times (2{,}020 - 552) = \text{Rs } 2{,}642.40$

Total monthly bill $= \text{Rs } 1{,}932 + \text{Rs } 2{,}642.40 = \text{Rs } 4{,}514.40$ **Ans.**

$$\text{Average tariff} = \frac{\text{Monthly energy cost}}{\text{Monthly energy consumption}}$$

$$= \text{Rs } \frac{4{,}514.40}{2{,}020} = \text{Rs } 2.265 \text{ per kWh}$$ **Ans.**

Example 17.7. An industrial consumer having a maximum demand of 100 kW, maintains a load factor of 60%. The tariff rates are Rs 900 per kVA of maximum demand per annum plus Rs 1.80 per kWh of energy consumed. If the average power factor is 0.8 lagging, calculate the total energy consumed per annum and the annual electricity bill. Also workout the overall cost per kWh consumed.

Solution : Maximum demand = 100 kW

Average power factor = 0.8

$$\text{Maximum demand in kVA} = \frac{\text{Maximum demand in kW}}{\text{Average power factor}} = \frac{100}{0.8} = 125$$

Load factor = 60% or 0.6

Total energy consumed per annum

= Maximum demand in kW × load factor × 8,760

$= 100 \times 0.6 \times 8{,}760 = 525{,}600$ kWh **Ans.**

Annual demand charges $= \text{Rs } 900 \times 125 = \text{Rs } 112{,}500$

Annual energy charges $= \text{Rs } 1.80 \times 525{,}600 = \text{Rs } 946{,}080$

Annual electricity charges = Rs (112,500 + 946,080)

= Rs 1,058,580 **Ans.**

$$\text{Overall cost per kWh supplied} = \text{Rs } \frac{1{,}058{,}580}{525{,}600} = \text{Rs } 2.02$$ **Ans.**

Example 17.8. A consumer takes a steady load of 250 kW at a power factor of 0.8 lagging for 10 hours per day and 300 days per annum. Estimate the annual payment under each of the following tariffs

(*i*) Rs 1.20 per kWh + Rs 1,200 per kVA per annum.

(*ii*) Rs 1.20 per kWh + Rs 1,200 per kW per annum + 25 paise per kVARh.

Solution : Maximum demand = 250 kW

Annual energy consumption

= Steady load in kW × working hours per day × working days per annum

= 250 × 10 × 300 = 750,000 kWh

$$\text{Maximum demand in kVA} = \frac{\text{kW}}{\text{PF}} = \frac{250}{0.8} = 312.5$$

kVARh consumed per annum

$= \text{kWh} \times \tan(\cos^{-1} \text{pf})$

$= 750{,}000 \times \tan(\cos^{-1} 0.8) = 750{,}000 \times 0.75 = 562{,}500$

(*i*) Annual payment under tariff (*i*)

= Rs 1.20 × 750,000 + Rs 1,200 × 312.5

= Rs 1,275,000.00 **Ans.**

(*ii*) Annual payment under tariff (*ii*)

= Rs 1.20 × 750,000 + Rs 1,200 × 250 + Rs 0.25 × 562,500

= Rs (900,000 + 300,000 + 140,625) = Rs 1,340,625.00 **Ans.**

Example 17.9. Calculate the number of units to be consumed so that the annual bill on the basis of two part tariff is same from the following data :

Maximum demand = 10 kW

Two part tariff—Rs 1,200 per annum per kW of maximum demand plus Rs 1.80 per unit consumed.

Flat rate tariff—Rs 2.40 per unit.

Solution : Maximum demand = 10 kW

Let the consumption be x units so that the annual bill on the basis of two part tariff and flat rate tariff is the same.

Annual bill under two part tariff

= Rs 1,200 × 10 + Rs 1.80 × x = Rs $(1.8x + 12{,}000)$

Annual bill under flat rate tariff

= Rs 2.40 × x = Rs $2.4x$

Annual bill will be same if $(1.8x + 12{,}000) = 2.4x$

$$\text{or } x = \frac{12{,}000}{(2.4 - 1.8)} = 20{,}000 \text{ units } \textbf{Ans.}$$

Example 17.10. The monthly reading of a consumer's meter are as follows :

Maximum demand = 50 kW

Energy consumed = 36,000 kWh

Reactive energy = 23,400 kVARh

If the tariff is Rs 80 per kW of maximum demand plus 8 paise per unit plus 0.5 paise per unit for each 1% of power factor below 86%, calculate the monthly bill of the consumer.

[*Generation of Electrical Power Rajasthan Univ. 2003, 2004, 2005, 2006; Rajasthan Technical Univ. 2011*]

Solution : Average load

$$= \frac{\text{Monthly energy consumption}}{24 \times 30} = \frac{36{,}000}{24 \times 30} = 50 \text{ kW}$$

$$\text{Power factor angle } \phi = \text{Tan}^{-1}\frac{\text{kVA hr}}{\text{kWh}} = \text{Tan}^{-1}\frac{23{,}400}{36{,}000} = 33.024°$$

Power factor = Cos ϕ = Cos 33.024° = 0.838444 or 83.444%.

Power factor surcharge = Rs 0.005 × 36,000 (86 – 83.8444) = Rs 388

Monthly bill = Rs (80 × 50 + 0.08 × 36,000 + 388) = Rs 7,268 **Ans.**

Example 17.11. A factory works for 16 hours a day for 300 days in a year. The following two systems of tariff are available :

High voltage supply at Re 1 per unit plus Rs 50 per month per kVA of maximum demand. Low voltage supply at Rs 60 per month per kVA of maximum demand plus Rs 1.10 per unit.

The factory has an average load of 250 kW at 0.8 power factor and a maximum demand of 300 kW at the same power factor.

The high voltage equipment costs Rs 500 per kVA and losses can be taken as 5%. Interest and depreciation charges are 12%. Calculate the difference in the annual cost between the two systems. [*A.M.I.E. Sec. B. Power Plant Engineering Summer 1998*]

Solution : *Average load = 250 kW*

Working hours per annum

= Number of working hours/day × number of working days in a year

= 16 × 300 = 4,800

Number of units consumed on low voltage supply

= 250 × 4,800 = 1,200,000

$$\textit{Maximum demand on low voltage supply} = \frac{300}{0.8} = 375 \text{ kVA}$$

Annual cost under low voltage supply tariff

= Rs 60 × 12 × 375 + Rs 1.10 × 1,200,000 = Rs 1,590,000.00

High voltage equipment losses = 5% or 0.05

Rating of high voltage equipment

$$= \frac{\text{Maximum demand in kW}}{\text{Power factor} \times (1 - \text{losses})} = \frac{300}{0.8 \times 0.95} = 395 \text{ kVA}$$

Number of units consumed on high voltage supply

$$= \frac{1{,}200{,}000}{0.95} = 1{,}263{,}158$$

Annual cost of high voltage equipment

= Rs 500 × 395 = Rs 197,500

Annual interest and depreciation charges

$$= \text{Rs } 197{,}500 \times \frac{12}{100} = \text{Rs } 23{,}700.00$$

Annual cost under high voltage supply tariff

= Annual interest and depreciation charges on hv equipment + annual maximum demand charges + annual energy charges

= Rs 23,700.00 + Rs 50 × 12 × 395 + Rs 1.0 × 1,263,158

= Rs 1,523,858.00 **Ans.**

Thus high voltage supply will be cheaper and saving per annum

= Rs 1,590,000.00 – Rs 1,523,858 = Rs 66,142.00

17.5. POWER FACTOR

The cosine of the angle between voltage and current in an ac circuit is known as *power factor.*

In an ac circuit, there is generally a phase difference between voltage and current. In an inductive circuit, the current lags behind the applied voltage and the power factor of the circuit is referred to as lagging. In a capacitive circuit the current leads the applied voltage and therefore, the power factor of the circuit is said to be leading.

Consider an inductive circuit, which draws a current I from the supply mains lagging behind the supply voltage V by an angle ϕ, known as phase angle, the phasor diagram is shown in Fig. 17.6.

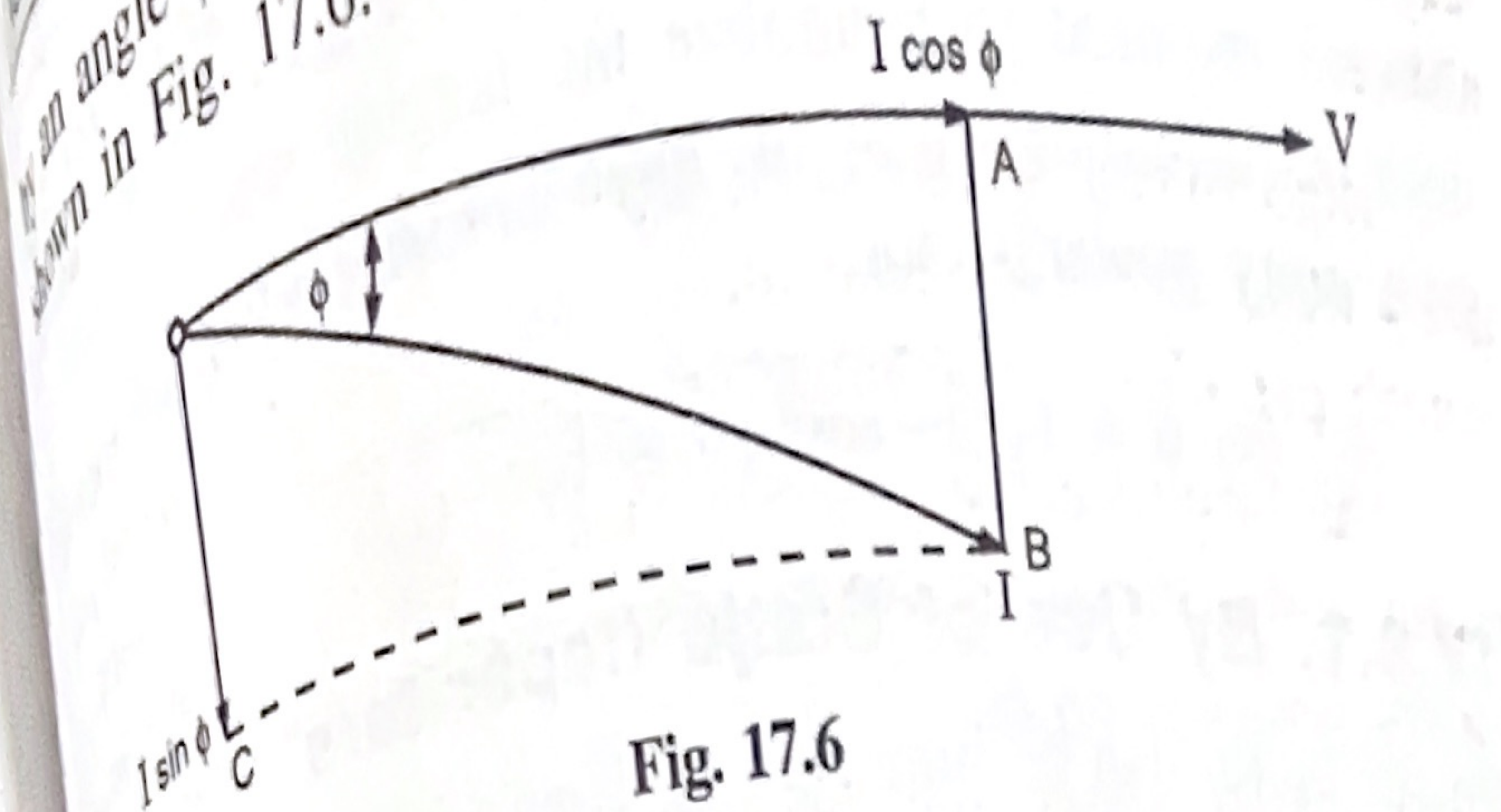

Fig. 17.6

The current I can be resolved into two components, one along the voltage phasor and the other perpendicular to it. The component along the voltage phasor, I cos ϕ is called the *in-phase* or *active* component of current, and the one perpendicular to the voltage phasor, I sin ϕ is called the *out of phase* or *wattless* or *reactive* component of current.

If all these components are multiplied by voltage V, the product of voltage V and in-phase component of current I cos ϕ *i.e.*, VI cos ϕ will represent the true power of the circuit in watts or kW, whereas the product of voltage V and the quadrature component of current I sin ϕ *i.e.*, VI sin ϕ will represent the reactive power in VARs or kVARs and the product of voltage V and current I *i.e.*, VI will represent the apparent power in volt-amperes or kVA. Thus we get a power triangle, as shown in Fig. 17.7.

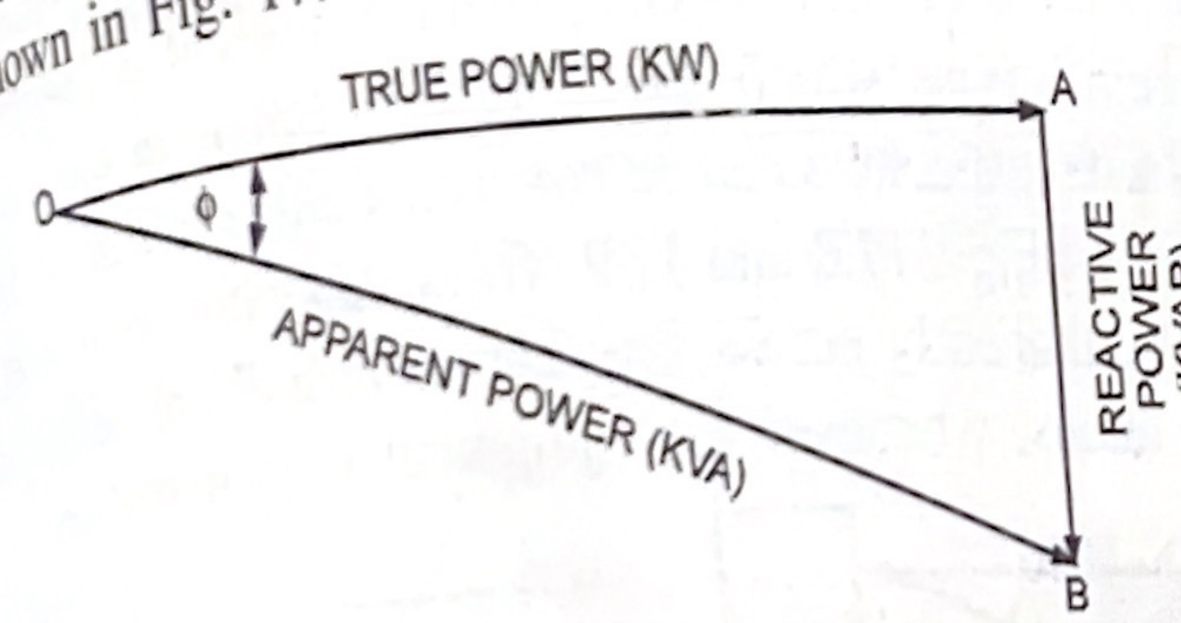

Fig. 17.7

From power triangle OAB shown in Fig. 17.7.

OA = kW component of power

AB = kVAR component of power

$$\cos \phi = \frac{OA}{OB} = \frac{kW}{kVA}, \text{ the ratio of true power and apparent power} \quad ...(17.1)$$

$$\text{Reactive power in kVAR} = \text{Apparent power} \times \sin \phi$$

$$= \text{kVA} \sin \phi$$

$$= (\text{kVA} \cos \phi) \times \frac{\sin \phi}{\cos \phi} = \text{kW} \tan \phi$$

i.e., smaller the reactive component of power, the smaller is the phase angle and the higher is the power factor.

For leading currents the triangle becomes reversed. This fact provides a key to the power factor improvement. If a device drawing leading reactive power is connected in parallel with the inductive load, then the lagging reactive power of the load will be partly neutralised, resulting in improvement of the power factor of the system.

17.6. DISADVANTAGES OF LOW POWER FACTOR

The current for a given load supplied at constant voltage will be higher at a lower power factor and lower at higher power factor. For example if load P is to be supplied at terminal voltage V and at power factor cos ϕ by a 3-phase balanced system then load current is given by

$$I_L = \frac{P}{\sqrt{3}\, V \cos\phi}$$

If P and V are constant, the load current, I_L is inversely proportional to power factor, cos ϕ *i.e.*, lower the power factor, higher the current and vice versa. The higher current due to poor power factor affects the system and results in following disadvantages.

(*i*) Rating of generators and transformers are proportional to their output current hence inversely proportional to power factor, therefore, large generators and transformers are required to deliver same load but at low power factor.

(*ii*) The cross-sectional area of the bus-bar, and the contact surface of the switchgear is required to be enlarged for the same power to be delivered but at low power factor.

(*iii*) For the same power to be transmitted but at low power factor, the transmission line or distributor or cable have to carry more current. The size of the conductor will have to be increased if current density in the line is to be kept constant. Thus more conductor material is required for transmission lines, distributors and cables to deliver the same load but at low power factor.

(*iv*) Energy losses are proportional to the square of the current hence inversely proportional to the square of the power factor *i.e.*, more energy losses incur at low power factor, which results in poor efficiency.

(*v*) Low lagging power factor results in large voltage drop in generators, transformers, transmission lines and distributors which results in poor regulation. Hence extra regulating equipment is required to keep the voltage drop within permissible limits.

(*vi*) Low lagging power factor reduces the handling capacity of all the elements of the system.

Thus we see that the low power factor leads to a high capital cost for the alternators, switchgears, transformers, transmission lines, distributors and cables etc.

Keeping in view the various drawbacks associated with the low power factor, the power suppliers insist on a power factor of 0.8 or above for industrial establishments. The power tariffs are devised to penalize the consumers with low lagging power factor and to encourage them to instal power factor correction devices or equipment.

17.7. CAUSES OF LOW POWER FACTOR

(*i*) All ac motors (except overexcited synchronous motors and certain type of commutator motors) and transformers operate at lagging power factor. The power factor falls with the decrease in load. For example an induction motor has a reasonable higher power of 0.85 at full load, 0.8 at 75% of full load, 0.7 at half-full load, 0.5 at 25% of full load and as low as 0.1 on no load.

(ii) Arc lamps and electric discharge lamps operate at low lagging power factor.

(iii) Due to increased supply mains voltage, which usually occurs during low-load periods such as lunch hours, night hours etc, the magnetizing current of inductive reactances increase and power factor of the electrical plant as a whole comes down.

(iv) The power factor at which motors operate falls due to improper maintenance and repairs of motors. In repaired motors, less wire is sometimes used than originally wound motors, therefore, in such motors leakage of magnetic flux increases and power factor of the motor decreases.

In case of heavily worn-out bearings, the rotor may catch at the stator.

Some metal is sometimes removed from the rotor by turning instead of replacing the defective bearings. In doing so, the length of air gap between stator and rotor increase, due to which greater magnetising current is required and, therefore, power factor drops.

(v) Industrial heating furnaces such as arc and induction furnaces operate on very lagging power factor.

The average power factors of some of the common appliances are given below :

Type of Load	Power Factor
Incandescent lamps	0.98 – 1.0
Fluorescent lamps	0.6 – 0.8
Neon lamps used for advertisements	0.4 – 0.5
Arc lamps used in cinemas	0.3 – 0.7
Fans	0.5 – 0.8
Induction motors	0.5 – 0.85
Fractional kW motors	0.4 – 0.75
Induction heaters	0.85
Resistance furnaces	0.6 – 0.9
Arc furnaces	0.85
Induction furnaces	0.6
Arc welders	0.3 – 0.4
Resistance welders	0.4 – 0.75

17.8. METHODS OF POWER FACTOR IMPROVEMENT

As we have already indicated, the low power factor is almost invariably due to inductive nature of load and, therefore, the logical corrective is to connect such devices across the load, which take leading reactive power such as static capacitors, synchronous machines or synchronous condensers. The leading reactive component of current drawn by power factor correcting device neutralises the lagging reactive component of current drawn by the load partly or completely. Power factor of the system will become unity when lagging reactive component of load current is completely neutralised by the leading reactive component of current drawn by power factor correcting device.

Let the current drawn by an inductive circuit be I lagging behind the applied voltage by an angle ϕ. The leading current required to neutralize the lagging reactive component of current drawn by the inductive circuit (equipment) to give unity power factor.

$$= I \sin\phi = I\sqrt{(1-\cos^2\phi)} = I\sqrt{1-(pf)^2} \quad ...(17.2)$$

17.8.1. By Use of Static Capacitors

Power factor can be improved by connecting the capacitors* in parallel with the equipment operating at lagging power factor such as induction motors, fluorescent tubes. Static capacitors have the advantages of small losses (less than $\frac{1}{2}$ per cent) or higher efficiency (say 99.6%), low initial cost, little maintenance owing to absence of rotating parts, easy installation being lighter in weight and capability to operate under ordinary atmospheric conditions. However, they have drawbacks of short service life (8 to 10 years), getting damaged on overvoltages and uneconomical repair. The current drawn by induction motors or fluorescent tubes can be resolved into two components ; the active component, which is in phase with the supply voltage and the quadrature or wattless component of constant magnitude. The capacitors draw current leading the supply voltage by 90° approximately and neutralise the quadrature or wattless component of current drawn by the equipment across which these are connected. In case of 3-phase loads, capacitors can be connected either in star or delta, as shown in Figs. 17.8 and 17.9. These capacitors remain connected permanently across the equipment and are across the supply mains, whenever the equipment is switched on.

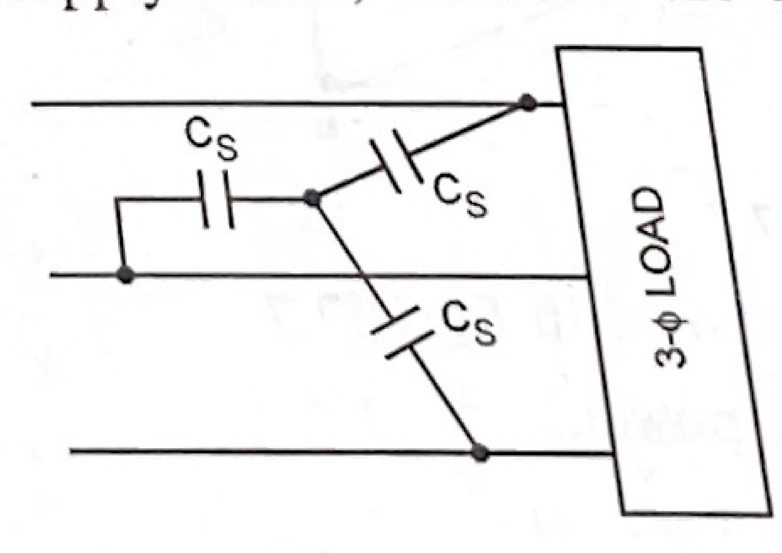

Fig. 17.8. ***Star-Connected Capacitors***

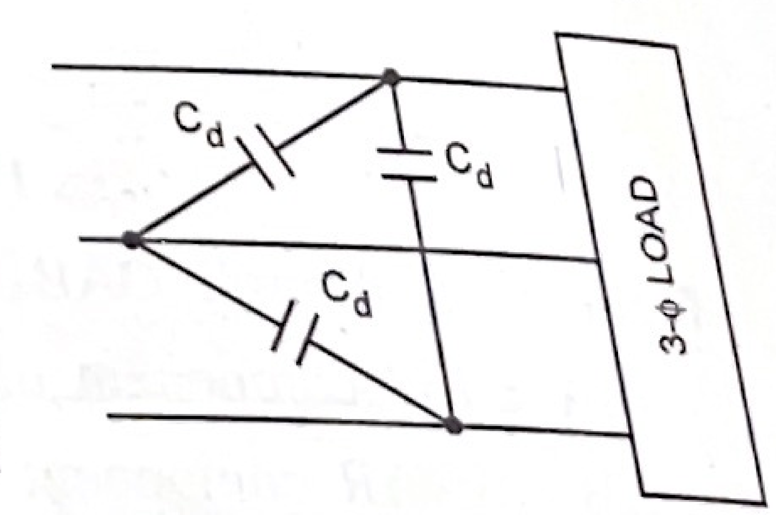

Fig. 17.9. ***Delta-Connected Capacitors***

The value of the static capacitors for the improvement of the power factor can be determined as follows :

The leading current required to neutralise the lagging reactive component of the current drawn by the equipment to give unity power factor is expressed as

$$I_C = I_L = I\sin\phi = I\sqrt{(1-\cos^2\phi)} = I\sqrt{1-(pf)^2}$$

The value of capacitance in star bank is given by

$$C_S = \frac{I_C}{2\pi f V} = \frac{I}{2\pi f V}\sqrt{1-(pf)^2} \quad ...(17.3)$$

where V is the phase voltage, I is the phase current and f is supply frequency.

For given kVAR and line voltage the delta value will be one-third of star value.

* The capacitors are generally designated as static capacitors to distinguish from the so called synchronous condensers which are synchronous motors operating under no-load condition and taking leading current.

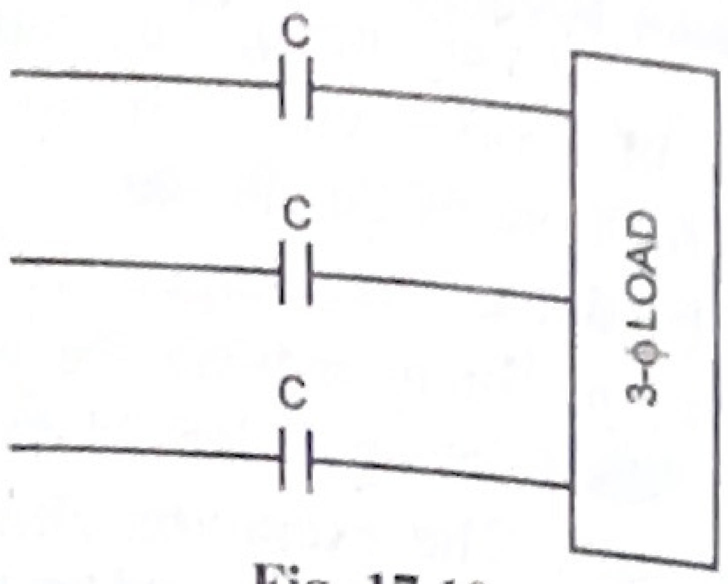

Fig. 17.10

Power factor can also be improved by connecting static capacitors in series with the line, as shown in Fig. 17.10. Capacitors connected in series with the line neutralize the line reactance. The capacitors, when connected in series with the line, are called the *series capacitors*, and when connected in parallel with the equipment, are called the *shunt capacitors*.

Shunt capacitors are used in factories, plants and also on transmission lines.

Series capacitors are used on long transmission lines as they provide automatic compensation with the variations in load. The capacity of the capacitors to neutralize the line reactance is given by

$$C = \frac{1}{(2\pi f)^2 L}$$

where f is the supply frequency and L is the inductance of the line per phase.

The value of reactance required is usually very large but reduced to reasonable value by use of a transformer, as shown in Fig. 17.11.

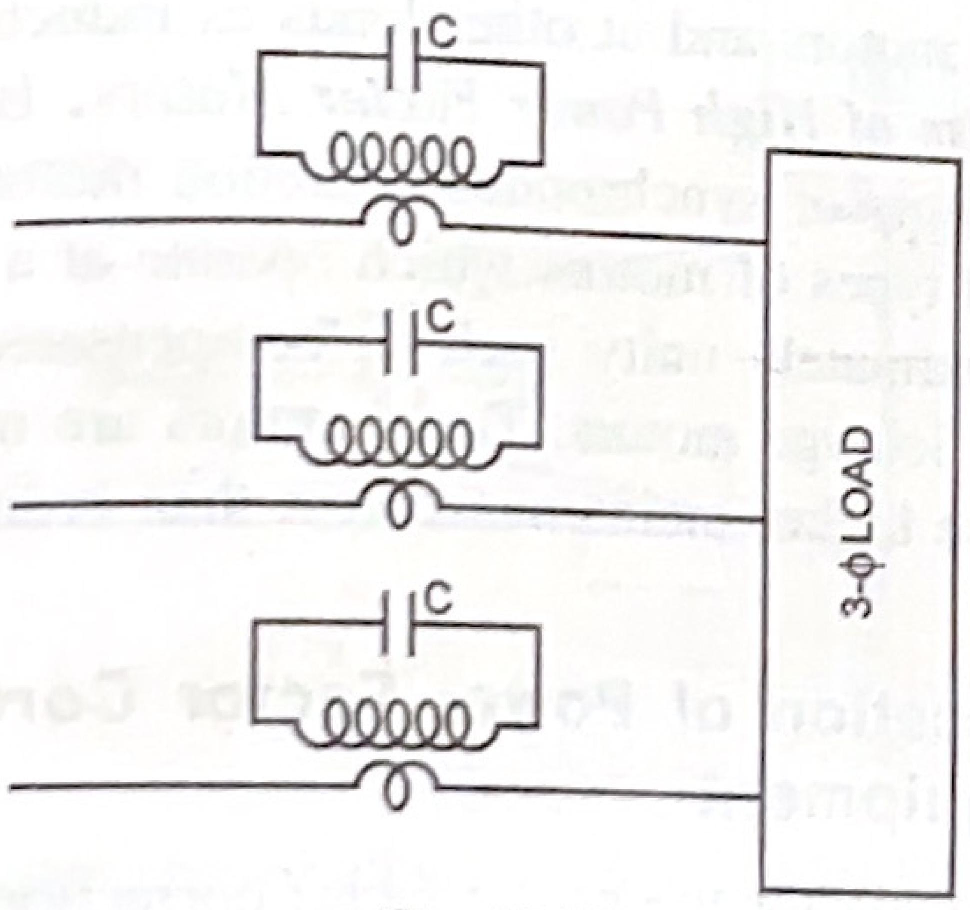

Fig. 17.11

Shunt capacitors are used in ratings from 15 kVAR to 10,000 kVAR. Small capacitors, up to a few hundred rating are used on individual distribution circuits of customers. Capacitors banks of 500 – 3,000 kVAR ratings are employed in small distribution substations and those with larger rating at big substations.

Three phase capacitor banks can be connected in star earthed, star unearthed or in delta arrangements. Ungrounded star connection is preferred because of easier protection. In this method, the fault current in case of a fault in any unit in one of the phases is restricted by the capacitors in the sound phases. This results in the use of smaller fuses and less protection materials. The capacitor must be provided with a suitable discharge device to dissipate the stored energy, and to reduce the residual voltage to a safer value within a short period (50 V or less within one minute in case of medium voltage capacitors and within five minutes in case of high voltage capacitors as per ISS 2834–1963). The discharge resistance is usually incorporated within the 'unit' itself in the case of medium voltage capacitors and in case of high voltage capacitors, potential transformers of the circuit breakers are generally utilised as a discharge device.

The reactive output of the capacitors in kVAR is given by

$$\frac{\text{Voltage} \times \text{line current}}{1{,}000} \text{ kVAR or } 2\pi f C V^2 \times 10^{-9} \text{ kVAR in case of single phase circuit} \quad \text{...(17.4)}$$

where V is the line voltage, f the supply frequency and C is the capacitance in microfarads.

$$\text{and } \frac{\sqrt{3}\ \text{voltage} \times \text{line current}}{1{,}000} \text{ kVAR or } 2\pi f C V_L^2 \times 10^{-9} \text{ kVAR in case of 3-phase star-connected circuits.} \quad \text{...(17.5)}$$

$$\text{and } = 6\pi f C V_L^2 \times 10^{-9} \text{ kVAR in case of 3-phase delta-connected circuits} \quad \text{...(17.6)}$$

where V_L is the line voltage, f is the supply frequency in Hz and C is the capacitance in μF between the line terminals.

Thus we see that the corrective capacity of the capacitors is a function of the line voltage and supply frequency, varying in accordance with the square of the voltage and directly with the supply frequency. The units as manufactured are designed for a variation of voltage of ±10% of normal voltage. It is, therefore, impossible to overload these units so long as normal voltage and frequency are maintained.

The characteristics of capacitors, in general, are similar to those of synchronous condensers except that the corrective kVAR of the synchronous condenser is adjustable and may be controlled automatically whereas that of the capacitor is fixed unless there is a possibility of change in the number of units connected.

17.8.2. By Use of Synchronous or High Power Factor Machines

Synchronous machines are excited by dc, and the power factor may be controlled by controlling the field excitation. The various synchronous machines available for power factor correction comprise synchronous motors, synchronous condensers, synchronous converters, synchronous phase modifiers, phase advancers, and synchronous-induction motors.

1. ***By Use of Synchronous Motors.*** These motors have characteristics that make them adaptable for a wide range of applications. The speed is constant, the efficiency is high and uniform from light loads up to considerable overloads, and the starting characteristics compare favourably with those of induction motors. Another desirable characteristic of the synchronous motor is its tendency to maintain a constant load voltage even if there are variations in the supply voltage. When the line voltage increases, the leading reactive kVA falls and when the line voltage falls, the leading reactive kVA increases. The usual practice is to keep the field excitation constant at a value corresponding to normal full-load rating as regards output and power factor. Synchronous motors are designed for 1.0 – 0.8 leading power factors at full load. The unity power factor motor costs less and has a higher efficiency, but if fully loaded, it cannot furnish leading reactive kVA to compensate for lagging reactive kVA in the system.

2. ***By Use of Synchronous Condensers.*** An overexcited synchronous motor running on no load is called the *synchronous condenser* or *synchronous phase advancer* and behaves like a capacitor, the capacitive reactance of which depends upon the motor excitation. Power factor can be improved by using synchronous condensers like shunt capacitors connected across the supply.

In phasor diagram (Fig. 17.12), phasor I_L represents the current drawn by the industrial load, lagging behind the applied voltage V by a large angle ϕ_L and phasor I_M represents the current drawn by the synchronous condenser leading the applied voltage V by the angle ϕ_M. The resultant current I is the phasor sum of I_L and I_M and now angle of lag ϕ is much smaller than ϕ_L. Thus overall power factor is improved from cos ϕ_L to cos ϕ by the use of the synchronous condenser. In this way the power factor can be made unity even.

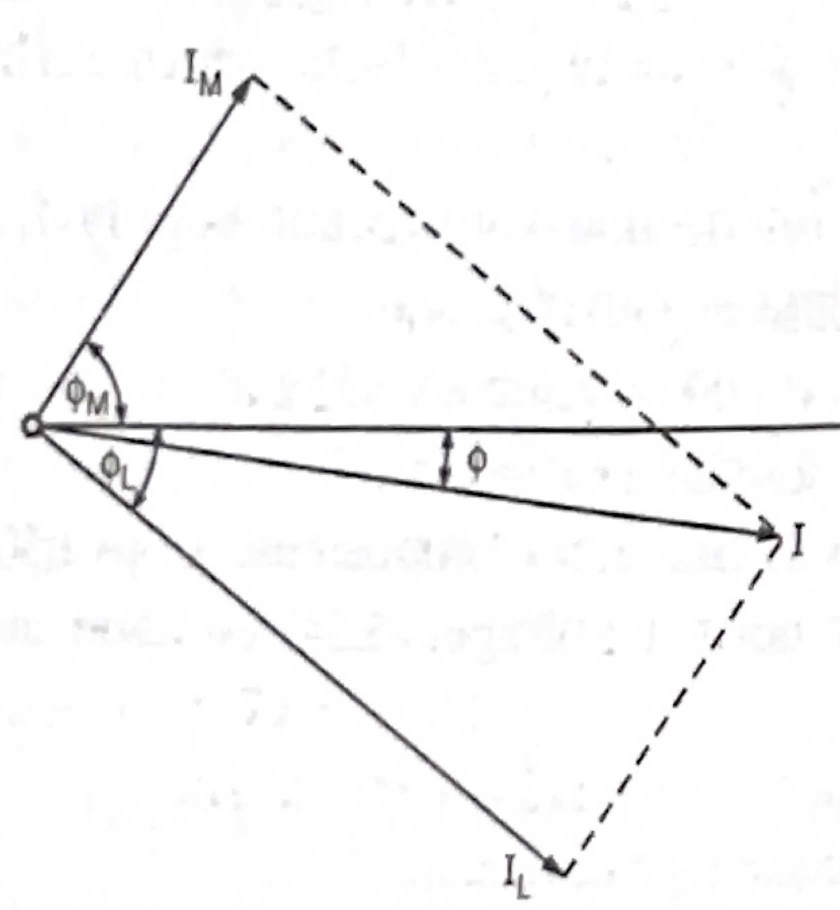

Fig. 17.12

Synchronous condensers are usually built in large units and are employed where a large quantity of corrective kVAR (say 5,000 kVAR or more) is required.

The advantages of synchronous condensers over static capacitors as a power factor correction devices are *(i)* a finer control can be obtained by variation of field excitation; *(ii)* inherent characteristic of synchronous condensers of stabilizing variations in the line voltage and thereby automatically aid in regulation, *(iii)* possibility of overloading a synchronous condenser for short periods, and *(iv)* improvement in the system stability and reduction of the effect of sudden changes in load owing to inertia of synchronous condenser. By use of synchronous condensers at intermediate stations, the voltage of the line can be kept constant at various points along its length, thereby, increasing the current carrying capacity of the line and improvement of power factor.

The disadvantages of synchronous condensers over static capacitors as power factor correcting devices are : *(i)* except in size above about 5,000 kVAR, the cost is higher than that of static capacitors of the same rating ; *(ii)* comparatively higher maintenance and operating costs ; *(iii)* comparatively lower efficiency (say 97%) due to losses in rotating parts and heat losses, *(iv)* noise is produced in operation *(v)* an auxiliary equipment is required for starting synchronous condensers ; *(vi)* possibility of synchronous condensers falling out of synchronism causing in interruption of supply; and *(vii)* increase of short-circuit currents when the fault occurs near the synchronous condenser.

Synchronous condensers are largely employed by utilities at large substations for improving the power factor and voltage regulation. Machines up to 100 MVAR rating or even higher have been used. The excitation current is regulated automatically to give a desired voltage level.

3. ***By Use of Phase Advancers.*** The power factor of an induction motor falls mainly due to its exciting current drawn from the ac supply mains, because exciting current lags behind the voltage by $\pi/2$. It may be improved by equipping the set with an ac exciter or phase advancer which supplies this exciting current to the rotor circuit at slip frequency. Such an exciter may be mounted on the same shaft as the main motor or may be suitably driven from it. Use of phase advancer is not generally economical in connection with motors below 150 kW output but above this size, phase advancers are frequently employed. Shunt and series type of phase advancers are available according to whether the exciting winding of the advancer is connected in parallel or series with the rotor winding of the induction motor.

There are two main advantages of phase advancers *(i)* lagging kVAR drawn by the motor are considerably reduced due to supply of exciting ampere-turns at slip frequency and *(ii)* the phase advancers can be conveniently employed where the use of synchronous motor is inadmissible.

4. ***By Use of Synchronous-Induction Motors.*** These are special types of motors which operate at certain loads as synchronous motors and at other loads as induction motors.

5. ***By Use of High Power Factor Motors.*** Besides synchronous motors or synchronous-induction motors there are other several types of motors which operate at a power factor of approximately unity such as compensated induction motors, and Schrage motors. These motors are more expensive and have higher maintenance cost than ordinary induction motors.

17.8.3. Location of Power Factor Correction Equipment

The best location for the power factor correction equipment to be installed is where the apparatus or equipment responsible for low power factor is operating. Synchronous condensers are used at load centres where considerable corrective kVAR is required whereas static capacitors are justifiably used in smaller units and may be placed closer to the point where the load of inductive nature is installed and thereby relieving the distributors and feeders from carrying excessive currents owing to low power factor.

In case of transmission system, if synchronous condensers are to be employed for power factor improvement then these should be installed at the receiving end so that not only the generators but also the transmission lines are relieved of carrying excessive current due to poor power factor. However, if synchronous condensers are installed near the generators then only generators will be relieved from the excessive current component and the transmission lines will have to carry it.

17.9. ADVANTAGES OF POWER FACTOR IMPROVEMENT

Modern alternators are designed to have high reactance in order that alternators may not get damaged at the time of short circuit and normally reactance is 20 times of resistance. Any change in current and power factor causes the change in terminal voltage, so voltage can be kept fairly constant by power factor control.

If the power factor of the supply or power station is raised to unity, the current for the same amount of power to be supplied is reduced to minimum. This results in reduction of transmission line copper losses, and reduction of voltage drop in transmission line and in alternator windings, as copper losses are directly proportional to the square of supply current and voltage drop is directly proportional to the current.

The terminal voltage of an alternator is given by the phasor difference of induced emf and voltage drop in synchronous impedance. Neglecting the resistance as compared to synchronous reactance, the synchronous impedance can be considered purely inductive, so synchronous impedance voltage drop leads the load current by $\pi/2$.

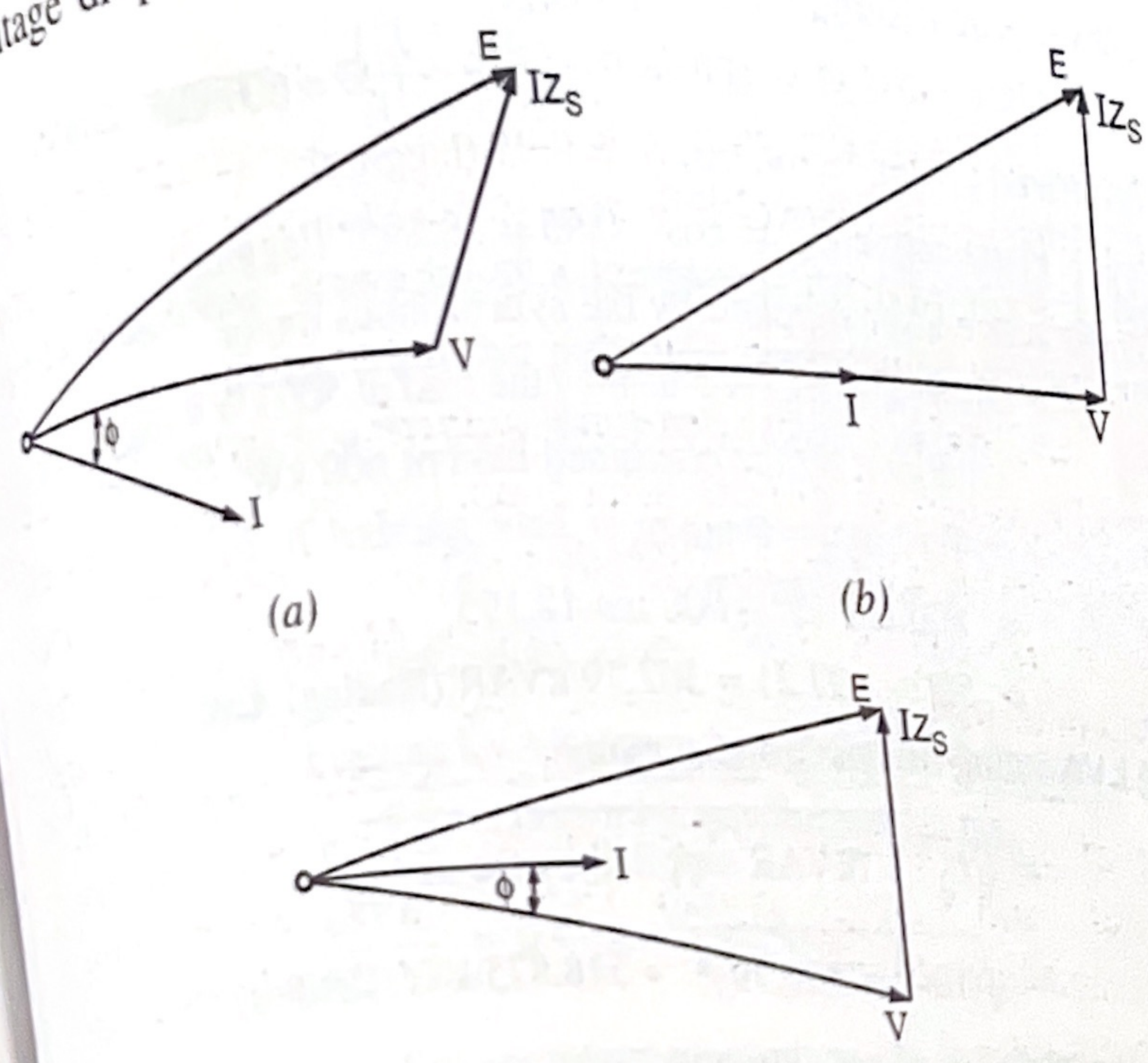

Fig. 17.13

From the phasor diagrams shown in Figs. 17.13 (*a*), 17.13 (*b*) and 17.13 (*c*) for lagging, unity and leading power factor respectively it is obvious that as the power factor is raised from lagging to unity, the difference of terminal voltage and induced emf is reduced and this difference can be reduced to zero by making the power factor, leading and less than unity. Hence to have zero regulation the power factor should be made leading one, so that no other regulating equipment is required.

It is not economical to raise the power to unity or leading one due to the following reasons :

1. In case the power factor is improved to unity for full-load conditions, it would become leading for loads less than full load (unless some capacitors are switched off which is usually difficult). At power factors lower than unity (lagging or leading) the current for the same amount of power to be supplied is increased and thereby energy losses in generators, transformers, transmission lines and distribution lines will be increased.

2. As the power factor approaches unity, the capacity of power factor correction device increases more rapidly *i.e.*, the power factor of an installation can be improved from 0.7 or 0.8 to 0.8 or 0.9 by a much smaller capacitive kVAR than that required for raising the power factor from 0.9 to unity.

The advantages of good (or improved) power factor are : (*i*) reduction in load current ; (*ii*) increase in voltage level across the load ; (*iii*) reduction in energy losses in the system (generators, transformers, transmission lines and distributors) due to reduction in load current ; (*iv*) reduction in kVA loading of the generators and transformers which may relieve an overloaded system or release capacity for additional growth of load and (*v*) reduction in kVA demand charge for large consumers.

Example 17.12. Find the power factor at an installation, supplying the following loads :

(*a*) 300 kW at unity power factor (*b*) 1,000 kW at 0.9 lagging power factor and (*c*) 1,500 kW at 0.8 lagging power factor. Also find the maximum load at unity power factor which can be supplied by the substation.

[*Rajasthan Univ. Generation of Electrical Power 1997, 2003, 2004*]

Solution : Total load on the substation

$$= 300 + 1{,}000 + 1{,}500 = 2{,}800 \text{ kW}$$

Total reactive load on the substation

$$= 300 \tan (\cos^{-1} 1.0) + 1{,}000 \tan (\cos^{-1} 0.9) + 1{,}500 (\cos^{-1} 0.8)$$

$$= 300 \tan 0° + 1{,}000 \tan 25.842° + 1{,}500 \tan 36.87°$$

$$\because \text{kVAR} = \text{kW} \tan \phi \text{ and } \phi = \cos^{-1} \text{pf}$$

$$= 0 + 484.3 + 1{,}125 = 1609.3 \text{ kVAR}$$

Total kVA load on the substation

$$= \sqrt{(\text{kW})^2 + (\text{kVAR})^2} = \sqrt{(2{,}800)^2 + (1{,}609.3)^2}$$

$$= 3{,}229.53 \text{ kVA}$$

$$\text{Power factor at the substation} = \frac{\text{kW}}{\text{kVA}} = \frac{2{,}800}{3{,}229.53} = 0.867 \text{ (lagging)} \textbf{ Ans.}$$

The maximum unity power factor load which can be supplied by the substation = Total kVA × pf = 3,229.53 × 1.0 = 3,229.53 kW **Ans.**

Example 17.13. A single phase motor connected to a 240V, 50 Hz supply takes a current of 20A at a pf of 0.75 lagging. A capacitor is shunted across the motor terminals to improve the pf to 0.9. Determine the capacitance of the capacitor to be used.

[*Rajasthan Univ. Generation of Electrical Power 2003*]

Solution : Initial motor current, $I_1 = 20\text{A}$

Initial power factor, $\cos \phi_1 = 0.75$

Lagging reactive component of initial motor current

$$= I_1 \sin \phi_1 = I_1 \sqrt{1 - \cos^2 \phi} = 20\sqrt{1 - 0.75^2} = 13.229\text{A}$$

In-phase component of initial motor current

$$= I_1 \cos \phi = 20 \times 0.75 = 15\text{A}$$

Motor current after improvement of power factor

$$I_2 = \frac{\text{Active component of initial current}}{\text{Improved power factor}} = \frac{15}{0.9} = 16.667\text{A}$$

Lagging reactive component of motor current after pf improvement,

$$= I_2 \sin \phi_2 = I_2 \sqrt{1 - \cos \phi_2^{\,2}} = 16.667 \sqrt{1 - 0.9^2}$$

$$= 7.625 \text{ A}$$

Leading reactive component drawn by the capacitor

$$I_C = I_1 \sin \phi_1 - I_2 \sin \phi_2 = 13.229 - 7.265 = 5.964\text{A}$$

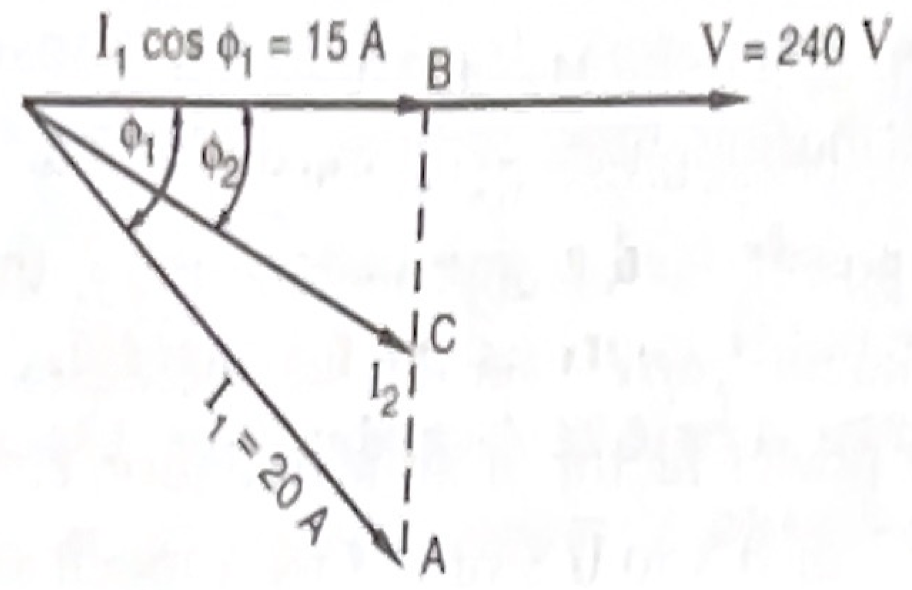

Fig. 17.14

Capacitance of the capacitor, $C = \dfrac{I_C}{2\pi f V}$ $\quad \because I_C = 2\pi f CV$

$$= \frac{5.964}{2\pi \times 50 \times 240} = 791\ \mu\text{F} \ \textbf{Ans.}$$

Example 17.14. A 400 V, 50 Hz, 3-phase line delivers 200 kW at 0.8 pf lagging. It is desired to raise the line power factor to unity by installing shunt capacitors. Calculate the capacitance of each unit if they are connected in (*i*) star and (*ii*) delta.

[Rajasthan Technical Univ. Generation of Electrical Power 2008]

Solution : Load P = 200 kW

Power factor, $\cos \phi_1 = 0.8$ (lag) ; $\phi_1 = \text{Cos}^{-1} 0.8 = 36.87°$ and Tan $36.87° = 0.75$

Power factor, $\cos \phi_2 = 1.0$; $\phi_2 = \text{Cos}^{-1} 1.0 = 0°$ and Tan $0° = 0$

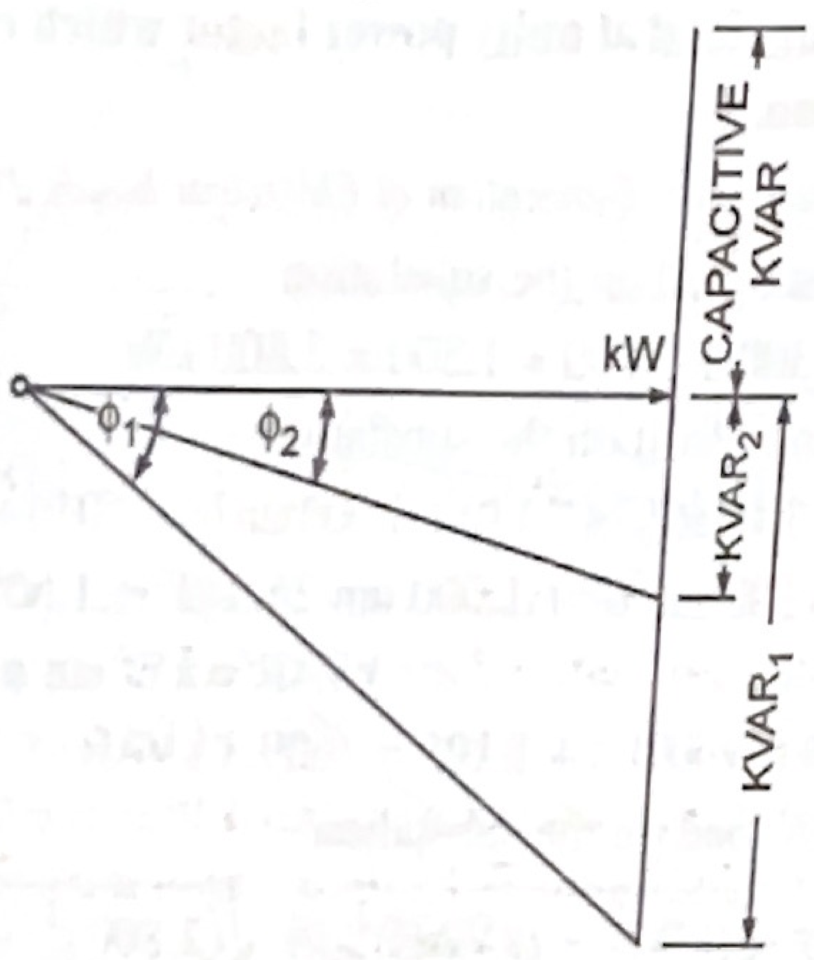

Fig. 17.15

Leading kVAR supplied by static capacitors,

Capacitive kVAR = $\text{kVAR}_1 - \text{kVAR}_2$

$$= \text{P}(\tan \phi_1 - \tan \phi_2) = 200\,(0.75 - 0) = 150$$

Since reactive kVAR output of capacitors when connected in star (Eq. 17.5) is given by $2\pi f C V_L^2 \times 10^{-9}$, where C is in μF

$$\therefore\ 2\pi f C V_L^2 \times 10^{-9} = 150$$

$$\text{or}\ \ C = \frac{150 \times 10^9}{2\pi f V_L^2} = \frac{150 \times 10^9}{2\pi \times 50 \times (400)^2} = 2{,}984\ \mu\text{F}\ \textbf{Ans.}$$

Since reactive kVAR output of capacitors when connected in delta (Eq. 17.6) is given as $6\pi f C V^2 \times 10^{-9}$ where C is in μF

$$\therefore\ C = \frac{150 \times 10^9}{6\pi f V_L^2} = \frac{150 \times 10^9}{6\pi \times 50 \times (400)^2} = 995\ \mu\text{F}\ \textbf{Ans.}$$

Example 17.15. The load on the mains of a supply system is 1,000 kW at a power factor of 0.707 lagging. What must be the kVA rating of the power factor improvement equipment which takes leading current at a power factor of 0.1 in order to raise the power factor of the entire system to 0.95?

[Pb.Technical Univ. Generation of Electric Power May 2010]

Solution : Load, P = 1,000 kW

Phase angle of load, $\phi_1 = \cos^{-1} 0.707 = 45°$ (lagging)

Improved phase angle of load, $\phi_2 = \cos^{-1} 0.95 = 18.195°$ (lagging)

Required rating of pf improvement equipment

$$= P(\tan \phi_1 - \tan \phi_2)$$
$$= 1{,}000\,(\tan 45° - \tan 18.195°)$$
$$= 1{,}000\,(1.0 - 0.32868) = 671.32\ \text{kVAR}$$

Phase angle of pf improvement equipment,

$$\phi = \cos^{-1} 0.1 = 84.26°\ \text{(leading)}$$

Rating of pf improvement equipment

$$= \frac{\text{Reactive kVAR supplied by the equipment}}{\sin \phi}\ \text{kVA}$$

$$= \frac{671.32}{\sin 84.26°} = 674.7\ \text{kVA}\ \textbf{Ans.}$$

Example 17.16. A synchronous motor improves the power factor of a load of 500 kW from 0.707 lagging to 0.95 lagging. Simultaneously the motor carries a load of 100 kW. Find (*i*) the leading kVAR supplied by the motor (*ii*) kVA rating of the motor and (*iii*) power factor at which the motor operates.

[Rajasthan Univ. Generation of Electrical Power 1999]

Solution : Load $P_1 = 500$ kW

Initial power factor of load, $\cos \phi_1 = 0.707$ (lagging)

Phase angle $\phi_1 = \cos^{-1} 0.707 = 45$ (lagging)

Motor load, $P_2 = 100$ kW

Motor load including its own load, P

$$= P_1 + P_2 = 500 + 100 = 600\ \text{kW}$$

Improved power factor, $\cos \phi_2 = 0.95$ (lagging)

Phase angle $\phi_2 = \cos^{-1} 0.95 = 18.195°$ (lagging)

(*i*) Reactive kVA supplied by the synchronous motor

= Reactive kVA drawn by the load of 500 kW – reactive kVA drawn by the combined load of 600 kW

$$= P_1 \tan \phi_1 - P \tan \phi_2$$
$$= 500 \tan 45° - 600 \tan 18.195°$$
$$= 500 - 197.21 = 302.79\ \text{kVAR (leading)}\ \textbf{Ans.}$$

(*ii*) kVA rating of synchronous motor

$$= \sqrt{P_2^2 + (\text{kVAR supplied by the motor})^2}$$

$$= \sqrt{(100^2 + 302.79)^2} = 318.875\ \text{kVA (leading)}\ \textbf{Ans.}$$

(*iii*) Power factor of synchronous motor

$$= \frac{100}{318.875} = 0.3136\ \text{(leading)}\ \textbf{Ans.}$$

Example 17.17. A 400 V, 3-phase installation draws a current of 50A at 0.8 lagging power factor. It is desired to install a synchronous motor to improve the overall power factor to 0.95 lagging. The synchronous motor will drive a 25 hp (metric) load at an efficiency of 0.9. Find kVA and pf of synchronous motor.

[Rajasthan Univ. Generation of Electrical Power 1998]

Solution : Load of installation,

$$P_1 = \sqrt{3}\, V_L I_L \cos \phi_1 = \sqrt{3} \times 400 \times 50 \times 0.8$$
$$= 27{,}713\ \text{W or } 27.713\ \text{kW}$$

kVAR rating of installation,

$$Q_1 = P_1 \tan \phi_1 = 27.713 \tan(\cos^{-1} 0.8) = 20.785\ \text{kVAR}$$

kW input to synchronous motor, $P_2 = \dfrac{25 \times 735.5}{0.9 \times 1{,}000} = 20.43$ kW

Total load, $P = P_1 + P_2 = 27.713 + 20.43 = 48.143$ kW

Overall power factor angle, $\phi = \text{Cos}^{-1} 0.95 = 18.195°$ (lagging)

Total reactive kVA, $Q = P \tan \phi = 48.143 \tan 18.195°$

$$= 48.143 \times 0.3287 = 15.82\ \text{(lagging)}$$

Q. 2. Name the different types of tariffs.
[Pb. Technical Univ. December 2008, May 2009]

Ans. Different types of tariffs are :
(*i*) Flat demand tariff (*ii*) Simple tariff (*iii*) Flat rate tariff (*iv*) Step rate tariff (*v*) Block rate tariff (*vi*) Hopkinson demand or two part tariff (*vii*) Maximum demand tariff or Wright demand rate (*viii*) Power factor tariffs (*ix*) Three part tariff or Doherty rate tariff (*x*) Off peak tariff.

Q. 3. What is tariff? What is general form of tariff?
[Rajasthan Univ. 2005]

Ans. Tariff means the schedule of rates or charges. Tariff, in case of electric supply, means the schedule or rates framed for supply of electrical energy to different classes of consumers.

General form of tariff is

Total energy charges, e = Rs $a + b$ kW + c kWh

where a is a constant charge made each billing period.

b = Unit charge in Rs per kW of metered maximum demand in kW during billing period. In some cases it is also charged in Rs per kVA so that the consumers are penalised for poor power factor.

and c = Unit charge for energy in Rs per kWh of energy consumed.

Q. 4. Why is tariff less for power load than lighting load?
[Rajasthan Univ. 2003]

Ans. Power load spreads the fixed charges over greater number of units, thus reduces the overall cost of generation of electrical energy. Lighting load has low load factor and therefore cost of generation of electrical energy is higher. These are the reasons that tariff is less for power load than lighting load.

Q. 5. What type of tariff is employed for domestic consumers ?

Ans. Block rate tariff.

Q. 6. What is two part tariff ?

Ans. In the two part tariff, the total charge to be made to the consumer is divided into two components namely fixed charge (proportional to connected load or maximum demand) and the running or operating charges (proportional to the units consumed).

Q. 7. For which category of consumers two part tariff is used ?

Ans. Two part tariff is mostly applicable to medium industrial consumers.

Q. 8. How do demand factor, load factor and diversity factor in a power system affect the fixation of tariffs?
[Rajasthan Univ. 2004]

Ans. The tariff must cover the following items :

(*i*) Recovery of cost of capital investment in generating, transmitting and distributing equipment.

(*ii*) Recovery of cost of operation, supplies and maintenance of equipment.

(*iii*) Recovery of cost of metering equipment, billing, collection costs and miscellaneous services and

(*iv*) A satisfactory return on the total capital investment.

The unit cost depends quite substantially on the load factor. The fixed cost remains constant irrespective of the load factor. At low load factor the fixed cost is shared by a smaller number of units of energy resulting in a relatively higher energy cost. At high load factor, the same fixed cost is shared by a large number of units of energy thereby reducing the unit energy cost.

The demand factor, being the ratio of maximum demand to connected load, determines the capacity of the system and hence the cost of power equipment required to serve a given load. Thus demand factor affects the fixtation of tariff.

Diversity between the loads of different consumers and different areas leads to reduction in peak demand resulting in reduction in generation, transmission and distribution costs. So the fixation of tariff is affected.

Q. 9. Explain reasons, why power factor tariff is imposed ?
[Rajasthan Univ. 2005]

Ans. Since the efficiency of plant and equipment depends upon the power factor, therefore, in order to increase the utility of plant and equipment to the maximum, the plant must be operated at the most economical power factor. That is why, sometimes consumers are penalised for poor power factor by imposing the power factor tariff.

Q. 10. Which type of tariff encourages the consumers to keep the load factor and power factor high ?

Ans. KVA maximum demand tariff encourages the consumers to keep the load factor and power factor high.

Q. 11. Can a power factor be included in a tariff ?

Ans. Yes, power factor is included in power factor tariffs such as kVA maximum demand tariff, kWh and kVARh tariff and sliding scale or average power factor tariff.

Q. 12. What type of tariff is usually applied to bulk consumers.

Ans. Three part tariff.

Q. 13. What are the advantages of using industrial/agricultural loads during night hours ?

Ans. During night hours a large proportion of the generating and distribution equipment remains idle due to extremely low demand. In case industrial and agricultural consumers are encouraged to use electricity during night and other off-peak hours by giving a special discount, the energy can be supplied without incurring any additional capital cost.

Q. 14. What are the different types of loads ?

Ans. The main types of loads on a power system are domestic, commercial, agricultural, industrial, municipal, traction etc.

Q. 15. Draw an approximate load curve for domestic load during 24 hours. **[Pb. Technical Univ. May 2008]**

Ans. Refer to Fig. 17.1

Q. 16. Define power factor. **[Pb. Technical Univ. May 2009]**

Ans. The cosine of the angle between voltage and current in an ac circuit is known as power factor.

Q. 17. Define active, reactive and apparent power.
[Pb. Technical Univ. December 2008]

Ans. The product of voltage V, current I and power factor cos ϕ *i.e.* VI cos ϕ is known as active power.

The product of voltage V, current I and sine of phase angle ϕ *i.e.,* VI sin ϕ is known as reactive power.

The product of voltage V and current I *i.e.,* VI is known as apparent power.

These three powers are related as follows :

$$\text{Apparent power} = \sqrt{(\text{Active power})^2 + (\text{reactive power})^2}$$

Q. 18. Why is the power factor not more than unity?
[Pb. Technical Univ. December 2010]

Ans. Power factor being the cosine of the phase angle between voltage V and current I can never exceed unity.

Q. 19. What are the effects of low power factor.
[Pb. Technical Univ. December 2007]

Ans. Refer to Art 17.6.

Q. 20. What is the effect of power factor on the cost of generation?
[Pb. Technical Univ. December 2010]

Ans. Lower power factor means higher kVA for the given load, therefore, large sized generators, transformers, switchgear, bus-bars, more energy loss and poor voltage regulation thereby increasing the cost of generation.

Q. 21. What is the need of improving power factor?
[Pb. Technical Univ. December 2009]

Ans. Low power factor causes the ratings of generators a transformers, cross-sectional area of the bus-bars and contact surface of the switchgear, the size of the fee and distributors, energy losses, voltage drops in genera transformers, transmission lines and distributors to incr So power factor needs to be improved to reduc generation, transmission and distribution costs.

Q. 22. What are the advantages of power factor improvem
[Pb. Technical Univ. Decembe

Ans. The advantages of good (or improved) power fact (*i*) reduction in load current ; (*ii*) increase in volta across the load ; (*iii*) reduction in energy losse system (generators, transformers, transmission distributors) due to reduction in load current ; (*iv*) in kVA loading of the generators and transform may relieve an overloaded system or release c additional growth of load and (*v*) reduction in k charge for large consumers.

Q. 23. What is the importance of power factor?
[Pb. Technical Un

Ans. Low power factor leads to high capital cost f transformers, switchgears, transmission line and cables. So the power factor is very im

Q. 24. Where are shunt capacitors located?
[Pb. Technical Univ.

Ans. Refer to Art. 17.8.3.

Q. 25. Should the power factor to be raised to
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Why it is not economical to raise the pow
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Ans. As the power factor approaches unity, power factor improving equipment inc i.e. the power factor of an installatic from 0.8 (lagging) to 0.9 (lagging) by a kVAR than which will be required to from 0.9 to unity. So it is not econom factor to unity.

Q. 26. What factors determine the economic correction ?

Ans. Economical limit of power factor by the relative costs of the su correcting equipment.

Problems

1. Calculate the annual energy co which takes a load of 20 kW f for 7 hours per day and 50 k tariff in force is Rs 300 per Assume 6 working days in a
2. The yearly consumption of an kWh with a maximum dema annual cost of electrical energ
(*a*) Rs 1,500 per kW plus
(*b*) Flat rate of Rs 1.50 pa
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[Rajasthan Univ. 2005]
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Ans. Low power factor ... of generators and transformers, cross-sectional area of the bus-bars and the contact surface of the switchgear, the size of the feeders and distributors, energy losses, voltage drops in generators, transformers, transmission lines and distributors to increase. So power factor needs to be improved to reduce the generation, transmission and distribution costs.

Q. 22. What are the advantages of power factor improvement?
[Pb. Technical Univ. December 2007]

Ans. The advantages of good (or improved) power factor are : (*i*) reduction in load current ; (*ii*) increase in voltage level across the load ; (*iii*) reduction in energy losses in the system (generators, transformers, transmission lines and distributors) due to reduction in load current ; (*iv*) reduction in kVA loading of the generators and transformers which may relieve an overloaded system or release capacity for additional growth of load and (*v*) reduction in kVA demand charge for large consumers.

Q. 23. What is the importance of power factor?
[Pb. Technical Univ. Dec. 2010]

Ans. Low power factor leads to high capital cost for generators, transformers, switchgears, transmission lines, distributors and cables. So the power factor is very important.

Q. 24. Where are shunt capacitors located?
[Pb. Technical Univ. December 2009]

Ans. Refer to Art. 17.8.3.

Q. 25. Should the power factor to be raised to 1.
[Pb. Technical Univ. May 2009]

OR

Why it is not economical to raise the power factor to unity?
[Rajasthan Univ. 2002, 2004]

Ans. As the power factor approaches unity, the capacity of the power factor improving equipment increases more rapidly i.e. the power factor of an installation can be improved from 0.8 (lagging) to 0.9 (lagging) by a much small capacity kVAR than which will be required to raise the power factor from 0.9 to unity. So it is not economical to raise the power factor to unity.

Q. 26. What factors determine the economical limit of power factor correction ?

Ans. Economical limit of power factor correction is governed by the relative costs of the supply and power factor correcting equipment.

Problems

1. Calculate the annual energy cost for industrial consumer which takes a load of 20 kW for 1 hour per day, 150 kW for 7 hours per day and 50 kW for 8 hours per day. The tariff in force is Rs 300 per kW and Rs 1.50 per kWh. Assume 6 working days in a week. **[Ans.** Rs 732,960**]**
2. The yearly consumption of an industrial consumer is 5×10^6 kWh with a maximum demand of 1,500 kW. Compare the annual cost of electrical energy under the following two tariffs.
(*a*) Rs 1,500 per kW plus 40 paise per kWh.
(*b*) Flat rate of Rs 1.50 paise per kWh.
[Ans. (*a*) Rs 4,250,000 (*b*) Rs 7,500,000**]**
3. Load factor of a consumer is 35% and monthly consumption is 504 kWh. If the rate of electricity is Rs 180 per kW of maximum demand plus Rs 2.00 per kWh, find the monthly bill and the average cost per kWh.
[U.P. Technical Univ. Power Station Practice 2004-05]
[Ans. Rs 1,037.60**]**
4. An industrial consumer having a maximum demand of 100 kW, maintains a load factor of 60%. The tariff rates are Rs 1,500 per kVA of maximum demand per annum plus paise 30 per kWh of energy consumed. If the average pf is

0.8 lagging, calculate, the total energy consumed per annum and annual bill.
[Ans. 525,600 kWh ; Rs 345,180**]**
5. Compute the cost of electrical energy and average unit cost for consuming 450 kWh under block rate tariff quoted as below.
First 50 kWh at Rs 3.80 per kWh
Next 50 kWh at Rs 3.20 per kWh
Next 50 kWh at Rs 2.80 per kWh
Next 50 kWh at Rs 2.40 per kWh
Excess over 200 kWh at Rs 2.10 per kWh.
[Ans. Rs 1,135.00 ; Rs 2.52/kWh**]**
6. Calculate the number of units to be consumed which will justify the two part tariff over flat rate tariff from the following data :
Maximum demand 5 kW, Two part tariff Rs 1,200 per annum per kW of maximum demand plus Rs 2.10 per unit consumed. Flat rate tariff is Rs 2.60 per unit.
[Ans. 12,000 units**]**
7. A light industry has a maximum demand of 100 kW. Two alternative tariffs are as follows :
(*i*) A fixed charge of Rs 900 per kW plus a running charge of Rs 1.50 per unit.
(*ii*) A charge of Rs 1.80 per unit flat.
If the factory runs for 3,000 hours with a load factor of 80% which tariff is economical ?
[Ans. Flat rate is cheaper for Rs 18,000**]**
8. The maximum demand of a consumer is 1 MW and the units consumed per annum are 500,000 kWh. Calculate the reduction in cost if the power factor is raised from 0.5 to 0.8. The tariff is Rs 900 per annum per kW demand plus Rs 1.50 per kWh plus Re 0.30 per kVAh reactive. Calculate the flat rate tariff for a unity power factor load.
[Ans. Rs 147,310.00; Rs 3.30 per kWh**]**
9. A supply is offered on the basis of fixed charges of Rs 900 per annum per kW plus 90 paise per unit or alternatively at the rate of Rs 1.80 per unit for the first 400 units per annum and Rs 1.50 per unit for all the additional units. The maximum demand is 1 kW. Find the number of units consumed per annum for which the cost under these two tariffs becomes the same. **[Ans.** 1,300 units**]**
10. A consumer, whose connected load is 400 kVA, consumes 1×10^6 kWh per annum and the maximum demand registered is 250 kVA. He is offered the following two alternative tariffs :
Tariff A : Rs 1,000 per annum per kVA of connected load + first 150 kWh per kVA of connected load at Rs 3.0/kWh, next 50,000 kWh at Rs 2.00 per kWh and the rest at Re 1.0/kWh.
Tariff B : Rs 1,200 per annum per kVA of maximum demand + first 150 kWh per kVA of maximum demand at Rs 3.0 per kWh, next 50,000 kWh at Rs 2.0/kWh and the rest at Re 1.0/kWh.
Which tariff is economical and what is the annual gain ?
[Ans. Tariff B is cheaper ; Annual gain = Rs 145,000.00**]**
11. A consumer has a yearly consumption of 200,000 units. The tariff is Rs 1,000.00 per annum per kW of maximum demand + Rs 2.0 per kWh. Find out the total annual cost and overall cost per unit (*i*) consumption were 200,000 units per annum with the load factor of 25% (*ii*) consumption were reduced by 25% with the same load factor.
[Ans. (*i*) Rs 491,324.00 and Rs 2.46/kWh
(*ii*) Rs 368,493.00 and Rs 2.46/kWh**]**
12. Calculate the minimum two part tariff to be charged from the following data :
Generating cost per unit – Re 1.0