Module-5 :- Economics

Classification of costs
Cost analysis
Interest and Depreciation } - refer your notes

Methods of determination of depreciation :-

Depreciation is the most important item in the fixed costs and it represents the reduction in the value of the equipment and other property of the plant every year due to continuous wear and tear and also due to obsolescence.

The method used for determination of annual depreciation charges are -

(i) straight line method
(ii) diminishing value method and
(iii) sinking fund method

I) Straight Line method :-

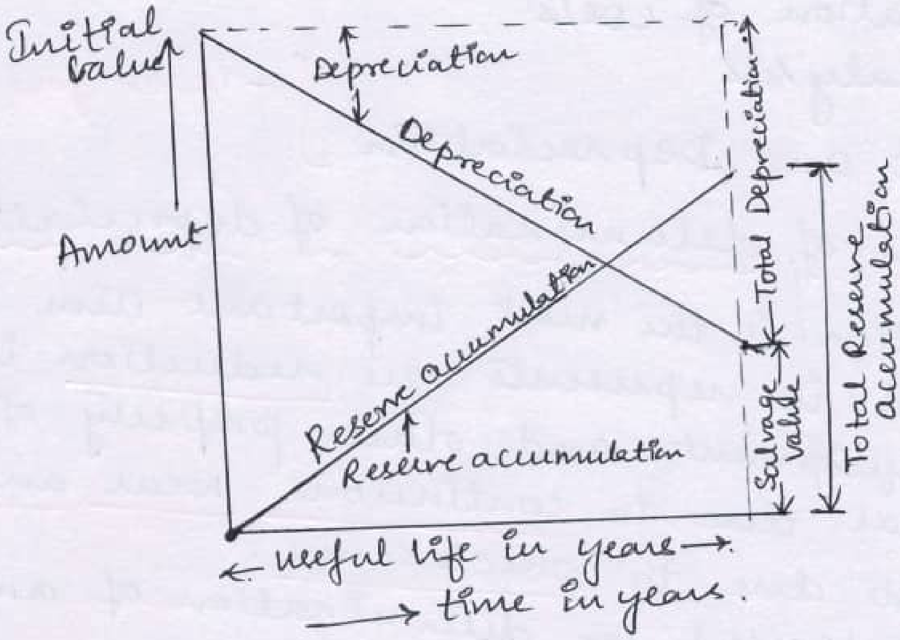
→ This method assumes that certain depreciation occurs according to the straight line law and in this method a constant depreciation charge is made every year on the basis of total depreciation (initial cost - scrap (or) salvage value) and useful life of the equipment/property.

ie Annual depreciation charge = $\dfrac{\text{Initial cost} - \text{salvage value}}{\text{Number of years of useful life}}$

$$= \frac{P-S}{n}$$

→ This method is very popular because of its simplicity but it does not take into account the amount of interest earned by the amount set aside yearly.

→ The assumption of constant depreciation every year is also not correct.



II) Diminishing value (or) Declining Balance Method :-

→ In this method provision is made for setting each year a fixed rate, first applied to the original cost and then to the diminishing value; such rate depending upon the useful life of the plant.

→ In this method depreciation charges are heavy in early years when maintenance charges are low & depreciation charges are low in late years when maintenance charges are heavy.

→ Drawback :- Heavy burden towards depreciation charges is imposed in the early years when the plant is to develop and build up its income.

→ In this method, the amount of interest earned by the reserve accumulation is ignored.

Derivation :-

Let capital cost of the plant $= P$

Salvage value after useful life of equipment of n years $= S$

annual ~~dep~~ unit depreciation $= x$

The value of plant after one years $= P(1-x)$

The value of plant after two years $= P(1-x)(1-x)$

$$= P(1-x)^2$$

The value of plant after n years,

$$S = P(1-x)^n$$

or $$(1-x) = \left(\frac{S}{P}\right)^{1/n}$$

or $$x = 1 - \left(\frac{S}{P}\right)^{1/n}$$

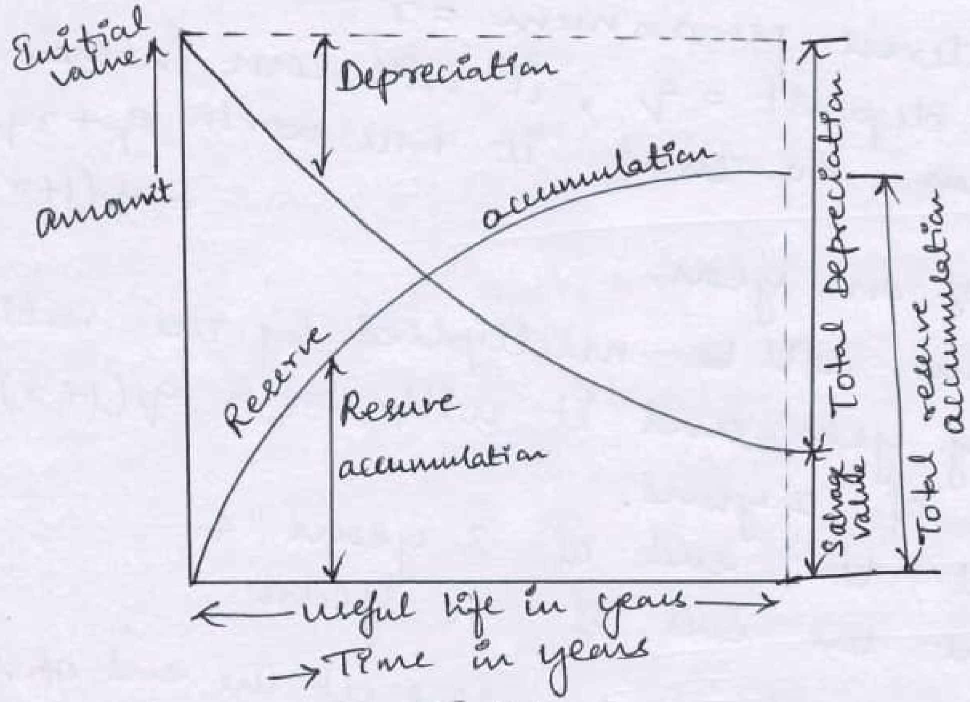
Deposit to be made at the end of first year of completion of the plant

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

Deposit to be made at the end of second year of completion of the plant

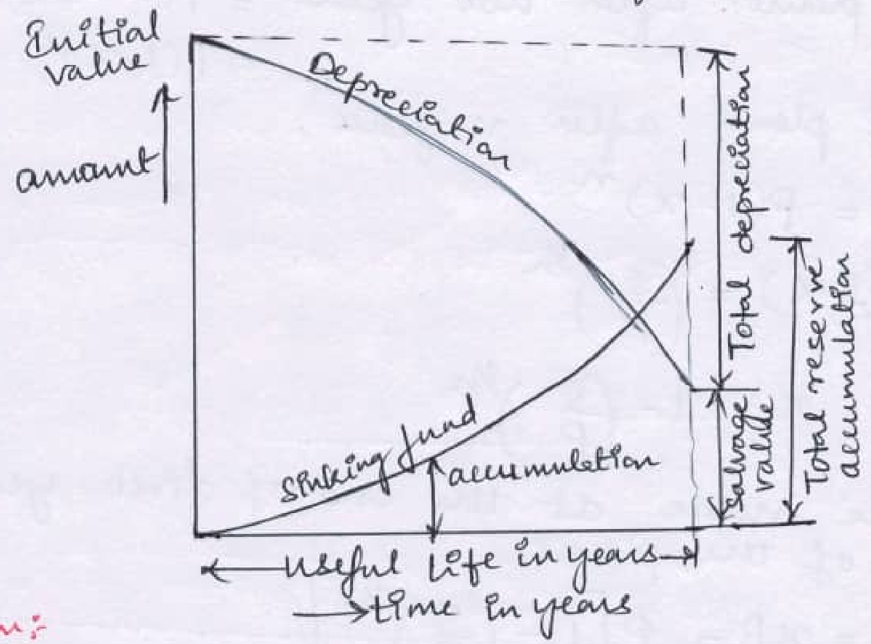
$$= x(1-x)P = xP(1-x) = P\left[1-\left(\frac{S}{P}\right)^{1/n}\right] \times \left(\frac{S}{P}\right)^{1/n}$$

and so on.



III) Sinking Fund method :-

→ In this method provision is made for setting aside each year such a sum as invested at certain interest rate compounded annually, will give the amount equal to replacement cost of the installation at the end of its useful life.



Derivation:-

Let initial value of equipment = P

useful life of equipment in years = n

Salvage value or scrap value after useful life of equipment of n years = S

rate of interest per annum = r

If annual deposit = q, it will earn interest rq in one year, so that it will worth $q + rq = q(1+r)$ at the end of one year.

Thus its value will be multiplied by the ratio $(1+r)$ every year and it will worth $q(1+r)^2$ at the end of 2 years.

$q(1+r)^3$ at the end of 3 years &

$q(1+r)^n$ at the end of n years.

Thus an amount of q deposited at the end of first year, in n-1 years will be $= q(1+r)^{n-1}$

An amount of q deposited at the end of second year, in n-2 years will be $= q(1+r)^{n-2}$

IIIrly the amount of q deposited at the end of third year, in $n-3$ years will be $= q(1+r)^{n-3}$

& the amount of q deposited at the end of $(n-1)^{th}$ year, in one year will be $= q(1+r)$

Thus after n years total sinking fund will be

$$= q\left[(1+r)^{n-1} + (1+r)^{n-2} + (1+r)^{n-3} + \dots + (1+r)\right]$$

from geometric progression,

$$\text{Total Sum} = \frac{\frac{1}{1+r}q - q(1+r)^{n-1}}{\frac{1}{1+r} - 1} = \frac{q\left[1-(1+r)(1+r)^{n-1}\right]}{1-(1+r)}$$

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

This must be equal to the cost of replacement Q which is equal to $(P-S)$.

So, $Q = \frac{q\left[(1+r)^n - 1\right]}{r}$ or annual deposit, $q = \frac{Qr}{(1+r)^n - 1}$

Problems on depreciation - refer your notes.

Economics of power generation :-

For deciding the type and rating of generating plant it is necessary that engineer should be familiar with the following important terms.

1) Load curves :-

→ The load on the power station varies time to time. The daily variation in load is given by load curve.

→ Load curve is graphical representation of variation of load w.r.t time in chronological order.

→ The following useful information can be obtained from load curve –

↳ The variation of the load during different hours of the day.

↳ The area under the curve represents the total number of units generated in a day.

↳ The peak of the curve represents the maximum demand on the station on the particular day.

↳ The area under the load curve divided by the number of hours represents the average load on the power station.

↳ The ratio of the area under the load curve to the total area of the rectangle in which it is contained gives the load factor.

2. Load Duration curve :-

→ A rearrangement of daily load curve with loads setup in descending order of magnitude.

→ The area under the load duration curve and corresponding load curve are equal & measures kilowatt hour of energy for that period.

→ This load duration curve gives a clear analysis of generating power economically.

→ Proper selection of base load power plant and peak load power plant become easier.

→ It is very useful tool for financial studies of the power station.

(iii) Integrated load duration curve :-

→ This curve gives the total number of units generated for the given demand. The ordinate represents the demand in KW or MW and the abscissa represents the units (kWh) generated at or below given demand.

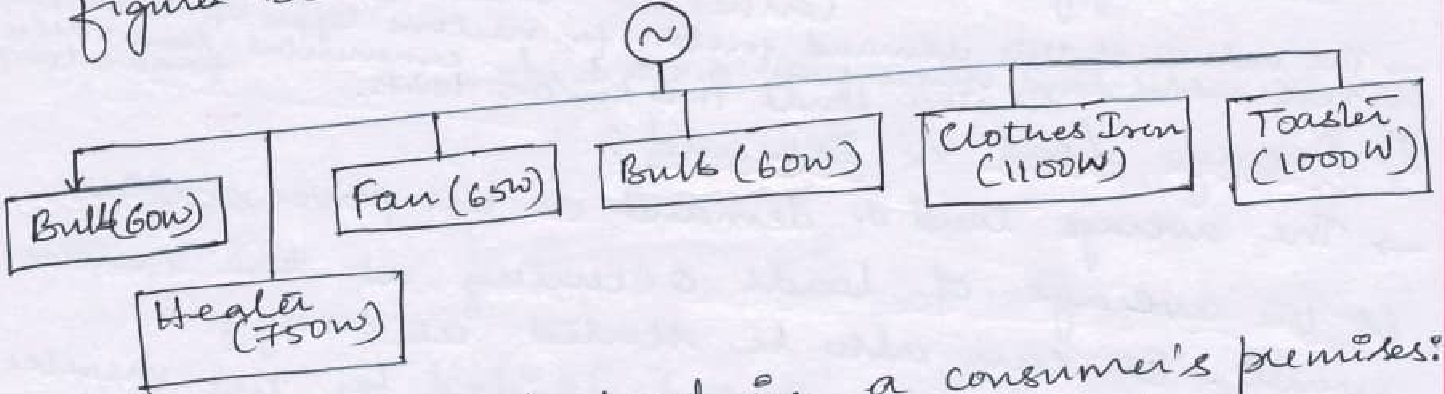
4) Mass curve :-

→ This curve is plotted with units (kWh) as ordinate and time as abscissa. Thus a mass curve gives the total energy consumed by the load upto a particular time in a day.

5) Connected Load :-

→ The sum of ratings in kW of the equipments installed in the consumer's premises.

→ The connected loads in the premises of an individual consumer are as shown in the figure below -



The total connected load in a consumer's premises:

$= 60W + 750W + 65W + 60W + 1100W + 1000W$

$= 3035W$.

6) Maximum Demand :-

→ It is the maximum load which a consumer uses at any time.

It can be less than or equal to connected load.

→ If all the devices fitted in the consumer's house run to the fullest extent simultaneously then the maximum demand will be equal to the connected load.

→ But generally the actual maximum demand is less than the connected load because all the devices never run at full load at the same time.

→ Maximum demand of a power station is the maximum load on the power station in a given period.

7) Demand Factor :-

→ It is defined as the ratio of maximum demand to connected load. Demand factors are always less than unity.

$$\text{Demand factor} = \frac{\text{Maximum demand (kW)}}{\text{Connected load (kW)}}$$

→ The values of this demand factor for various types of loads are: for residential load varies from 0.5 to 1, for commercial load varies from 0.5 to 0.7 for other loads it is from 0.5 to 0.75.

8) Average Load or Demand :-

→ The average load or demand on the power station is the average of loads occuring at the various events. It can also be stated as energy delivered in a given period divided by the number of hours in that period.

→ Depending upon the duration of time period such as a day, a month or a year, we get daily, monthly or annual average load.

$$\text{Daily average load} = \frac{\text{kWh supplied in a day}}{24}$$

$$\text{Monthly average load} = \frac{\text{kWh supplied in a month}}{24 \times 30}$$

$$\text{Annual average load} = \frac{\text{kWh supplied in a year}}{24 \times 365}$$

9) Load Factor :-

→ The ratio of average load to the maximum demand during a certain period of time such as day or a month or a year is called the load factor.

$$\text{Load factor} = \frac{\text{Average demand}}{\text{Maximum demand}}$$

(or)

$$\text{Load factor} = \frac{\text{Units generated in a given period}}{\text{Maximum demand} \times (\text{number of hours of operation in the given period})}$$

10) Diversity Factor :-

→ It is the ratio of the sum of maximum demands of the individual category to the maximum demand of the power station.

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand of power station}}$$

It is always greater than unity.

11) Coincidence Factor :- The reciprocal of the diversity factor is called the coincidence factor.

$$\text{ie Coincidence Factor} = \frac{\text{Maximum demand of power station}}{\text{Sum of individual maximum demands}}$$

It is always less than unity.

12) Capacity factor or Plant factor :-

→ Capacity factor is defined as the ratio of the average load to the rated capacity of the power plant.

$$\text{Capacity factor} = \frac{\text{Average demand}}{\text{Rated capacity of power plant}}$$

→ The plant capacity factor is an indication of the reserve capacity of the plant. A power station is so designed that it has some reserve capacity for meeting the increased load demand in future. ∴ Reserve capacity = plant capacity − max. demand

→ If the max. demand on the plant is equal to the plant capacity, then load factor and plant capacity factor will have the same value. In such a case plant will have no reserve capacity.

13) Utilisation Factor :- It is a measure of the utility of the power plant capacity and is the ratio of maximum demand to the plant capacity.

$$\text{Plant utilization factor} = \frac{\text{max. demand}}{\text{plant capacity}}$$

14) Plant operating factor (or) Plant use factor :-

→ It is defined as the ratio of actual energy generated during a given period to the product of capacity of the plant and the number of hours the plant has been actually in operation during the period.

$$\text{i.e. Plant use factor} = \frac{\text{Total kWh generated}}{\text{Rated capacity of the plant} \times \text{no. of operating hours}}$$

Explaination of load factor :-

→ This load factor and demand factor are always less than unity and plays very important role on the cost of generation per unit. The higher the load factor less will be the cost of generation per unit for same maximum demand.

→ Power plant which are used to take the base load run on a high load factor and the plants which are used to take the peak load run on low load factor.

Explaination of Diversity factor :-

→ High diversity factor is always desirable for the economic operation of the plant because the load factor increases with an increase in diversity factor.

→ Since the maximum demand of station is dependent upon the diversity of the load, the greater the diversity lesser will be the maximum demand & lesser will be the capital cost of generators.

Additional definitions:-

① Installed Capacity :- The total of station capacities available to supply the system load is called installed capacity.

② Firm power :- It is the power intended to be always available.

③ Prime power :- It is the power that is always available for conversion into electrical power.

④ Dump Power :- It is power in excess of the load requirements and it is made available by surplus water. It refers to hydro-power plants.

⑤ Cold Reserve :- It is that reserve generating capacity which is available for service but not normally ready for immediate loading.

⑥ Hot reserve :- It usually refers to boiler excess capacity, which is kept hot and with steam pressure, ready for use.

⑦ Operating Reserve :- It refers to capacity in service in excess of peak load.

⑧ Spinning Reserve :- It is the generating capacity connected to the bus and ready to take load.

Problems on economics of power generation - refer your notes.

Significance of Load factor and Diversity factor:-

→ Load factor and diversity factor play an important part in the cost of the supply of electrical energy. Higher the values of load factor and diversity factor, lower will be the overall cost per unit generated.

→ Higher load factor means greater average load, resulting in greater number of units generated for a given maximum demand.

→ Thus the standing charges, which are proportional to maximum demand and independent of number of units generated, can be distributed over a larger number of units supplied and therefore overall cost per unit of electrical energy generated will be reduced.

→ The capital cost of the power station depends upon the capacity of the power station.

→ Lower the maximum demand of the power station, the lower is the capacity required and therefore lower is the capital cost of the plant.

→ With a given number of consumers the higher the diversity factor of their loads, the smaller will be the capacity of the plant required and consequently the fixed charges due to capital investment will be much reduced.

→ The suppliers should always try to improve the load factor as well as diversity factor by inducing the consumers to use the electrical energy during off peak hours and they may be charged at lower rates for such schemes.

→ Typical values of demand factors and diversity factors for different types of consumers are given below :-

Type of Consumers	Demand Factors	Diversity Factors
1) Domestic lighting upto 1kW	0.5 – 0.7	3 – 5
2) Domestic power	0.5	1.5 – 2
3) Commercial loads mostly of lighting	0.5 – 0.7	1.5 – 2
4) Industrial power	0.5 – 0.8	1.5 – 2

Load Sharing between base load and peak load Plants :-

Base Load :- Base load plants run throughout the year and high load factors.

↳ The economic characteristics of base load plants should be ~~such~~ such that they supply power at high capital costs but low cost of operation.

↳ Hydro and nuclear power plants are classified as base load plants.

Peak load :- Peak load plants run for a few hours in the year and work at low load factors.

↳ The economic characteristics of peak-load plants should be such that they supply power at low capital costs but high cost of operation.

Derivation :-

Let the operating costs of base load and peak load plants be Rs. (a_1kW + b_1kWh) and Rs. (a_2kW + b_2kWh) where $a_1 > a_2$ & $b_2 > b_1$.

Let P = maximum demand on the power plant and x = total number of units generated.

If P_1 = maximum demand on base load plant.
x_1 = number of units generated by the base load plant.

Peak load on peak-load plant $P_2 = P - P_1$

Units generated by peak-load plant, $x_2 = x - x_1$

Total annual cost of operation of the system,

$$C = a_1P_1 + a_2(P - P_1) + b_1x_1 + b_2(x - x_1)$$
$$= P_1(a_1 - a_2) + a_2P + x_1(b_1 - b_2) + b_2x$$

or $\dfrac{dC}{dP_1} = (a_1 - a_2) + \dfrac{dx_1}{dP_1}(b_1 - b_2)$

For minimum cost, $\dfrac{dC}{dP_1} = 0$

$\therefore (a_1 - a_2) + \dfrac{dx_1}{dP_1}(b_1 - b_2) = 0$

or $\dfrac{dx_1}{dP_1} = \dfrac{a_1 - a_2}{b_2 - b_1}$ hours

i.e. for economic load sharing, peak-load power plant will operate for $\dfrac{a_1 - a_2}{b_2 - b_1}$ hours per year.

Choice of size and number of generating units:-

→ The number of units and the size of each unit is decided from the load curve.

→ The following factors should be considered while deciding the number of units and preparing the operating schedule -

(i) The total capacity of the generating units must be capable of meeting the peak demand of the power station.

↳ 2 Since the machines operate with maximum efficiency at the three-fourth of the rated capacity, hence the number and size of units must be so selected that they operate at maximum efficiency and better overall efficiency and load factor of the power station.

↳ 3 Reliability of service is a very important factor. Cheaper power without reliability of supply is of no use. There should be a spare set of capacity of that largest unit in the power station so that maintenance and repair or overhaul of the working units may be carried out without any disturbance in power supply.

↳ 4 The growth of the demand in near future should be kept in view.

↳ 5 The capacity of the power station should be 15 or 20% more than expected maximum demand.

→ The selection of a single generating unit having a capacity equal to the maximum demand on the system or slightly more has following drawbacks.

↳ During light load period the generating unit ~~would be much less than the~~ may be running at 50% of the rated output or even practically on no load. Hence the unit would not be running at all times under conditions best suited for its operation to give maximum efficiency. So generating cost per unit would be high.

↳ There will be complete failure of supply due to breakdown or maintenance and repairs to be carried out on the generating unit for weeks together.

→ The drawbacks and difficulties involved in this alternative of selecting large number of smaller units are given below–

↳ The floor area required and initial cost per kW would be increased.

↳ There would be substantial increase in maintenance cost and in personnels for handling and operating the equipment.

Tariff :-

→ The rate at which electrical energy is supplied to a consumer is known as tariff.

Objective of Tariff :-

The main objective of the tariff is to distribute equitably the cost of supplying energy among the various classification of use.

∴ 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.

Principal Factors affecting Framing of Tariff :-

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

(i) Proper return :-

The tariff should be such that it ensures the proper return from each consumer. In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.

(ii) Fairness :-

The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy. Similarly, a consumer whose load conditions do not deviate much from the ideal should be charged at a lower rate than the one whose load conditions change appreciably from the ideal.

(iii) Simplicity :-

The tariff should be simple so that an ordinary consumer can easily understand it. A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

(iv) Reasonable profit :-

The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. ∴ the investment is relatively safe due to non-competition in the market. This calls for the profit to be restricted to 8% or so perannum.

(v) Attractive :-
The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy. Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

(vi) Off peak hours :-
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. The consumers are penalised for poor power factor.

Types of Tariffs :-

1) Flat Demand Tariff :-

→ In this type of tariff, the total demand and the energy consumption were fixed.

→ when the use of electricity such as lamps, 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.

→ If x is number of lamps or load connected in kw and a is the rate per lamp or per kw of connected load then,

Energy charges = Rs $a.x$.

→ The metering equipment, meter reading, billing and accounting costs are eliminated resulting in overall decrease of total cost.

Disadvantage :-

→ It does not differentiate between the consumers who use same appliance or equipment but for different duration of time.

Advantage :-

→ It encourages the consumers to keep their appliances connected to the supply mains even when not required.

2) Simple Tariff :-

→ In this type of tariff the cost of energy is charged on the basis of units consumed. The rate can be derived as

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

→ The price charged per unit is constant ie it does not vary with increase or decrease in number of units consumed.

Disadvantages :-

→ There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed charges.

→ The cost per unit delivered is high

→ It does not encourage the use of electricity.

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.
(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) <u>Flat Rate Tariff</u>:

→ When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.
→ The consumers are grouped into different classes and each class of consumer is charged at a different uniform rate.
→ The different classes of consumers are made taking into account their diversity factor and load factors.

<u>Advantage</u>:-
→ It is more fair to different types of consumers and is quite simple in calculations.

<u>Disadvantage</u>:-
(i) Separate meters are required for lighting load, power load etc.
(ii) Difficult 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 decrease as the consumption increase.

4) Step Rate tariff :-

→ The step rate tariff is a group of flat rate tariffs of decreasing unit charges for higher range of consumption, for example.

Re. 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 not exceed 200 kwh

Rs. 3.0 per unit if the consumption exceed 200 kwh.

→ This type of tariff take 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.

Drawback:-

→ 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.

This drawback is removed by block rate tariff.

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 rate.

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.

Advantage :-

→ 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.

Drawback :-

→ It lacks a measure of the consumer's demand.

This type of tariff is used for majority of resident-ial and small commercial consumers.

6) Hopkinson Demand Rate (or) Two-part Tariff :-

→ In this type of tariff, the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed.

→ The total charge to be made ~~from~~ to the consumer is split into two components namely fixed charge and running charge.

→ The fixed charges depend upon the maximum demand of the consumer, while the running charges depend upon the number of units consumed by the consumer.

Total charges = Rs. ($b \times kW + c \times kWh$)

where b = charge per kW of maximum demand

c = charge per kWh of energy consumed.

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages :-

(i) It is easily understood by the consumers

(ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantage :-

→ The consumer has to pay his fixed charge irrespective of the consumption.

ex:- 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 :-

→ It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.

→ This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rateable value.

→ This tariff is almost applicable to all bulk supplies and large industrial consumers.

8) Power factor Tariff :-

→ The tariff in which power factor of the consumer's load is taken into consideration is known as power factor tariff.

→ In an A.C system, power factor plays an important role. A low power factor increases the rating of station equipment and line losses. ∴, a consumer having low power factor must be penalised. The following are the important types of power factor tariff :-

(i) KVA Maximum demand Tariff :-

→ It is a modified form of two-part tariff. In this case, the fixed charges are made on the basis of maximum demand in KVA and not in KW. As KVA is inversely proportional to power factor, ∴ a consumer having low power factor has to contribute more towards the fixed charges.

→ This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved power factor.

(ii) Sliding scale tariff :- This is also known as average power factor tariff.

→ In this case, an average power factor, say 0.8 lagging, is taken as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer.

(ii) kW and kVAR tariff :- In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately. A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

9) Three - Part Tariff (or) Doherty Rate :-

→ In this tariff ~~total~~ charge is split into three elements namely fixed charges, semi-fixed charge and variable charge.

→ Total charge = Rs $(a + b\,kW + c\,kWh)$

where a = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution & labour of cost of collecting revenues.

b = charge per kW of maximum demand.

c = charge 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 & early evening and a very low load during the night.

→ During the night, a large proportion of the generating and distribution equipment will be lying idle.

Advantage :-

→ 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 ∴ prove very profitable.

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

Problems on tariff - refer your notes

Types of Consumers & their tariffs :-

1) Domestic consumers :-

→ Residential load consists of lights, fans and appliances such as radios, TV's, heaters, electric irons, refrigerators, electric water heaters, washing machines, coolers, air-conditioners, domestic pump sets etc.

→ Domestic consumers are given single phase supply upto a load of 5kw and a 3-phase supply for loads exceeding 5kw.

→ The tariffs applicable to domestic consumers are simple tariff, flat rate tariff or block rate tariff.

2) Commercial Consumers :-

→ Non-residential premises, such as shops, business-houses, cinemas, hotels, public offices, clubs etc.

fall under this category.

→ The tariff applicable to commercial consumers are simple tariff, flat rate tariff (or) block rate tariff but charges per unit are higher in comparison to those in case of domestic consumers.

3) Agricultural consumers :-

→ Consumers drawing power upto 20 kW for irrigation pumping units are categorized as agricultural consumers. Such consumers are given a three phase supply.

→ 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.

4) Industrial consumers :-

↳ 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 20kW.

→ A block tariff is offered to such consumers.

↳ Loads exceeding 20 but not-exceeding 100kW are categorized as ~~Large~~ medium industrial consumers.

They are given ~~three~~ phase supply at 415V and are usually charged on two-part tariff.

↳ Industrial consumers with loads exceeding 100kW are categorized as large industrial consumers. They are supplied power at 11 or 33kV, consumers are charged kVA maximum demand tariff.

5) Bulk Consumers :-

→ Power consumers such as railways, public work departments, educational institutions, military establishments, hospitals having loads exceeding 10kW fall under the category of bulk consumers.

→ They are supplied by 3 phase supply at 415V or 11kV depending on their requirement.

→ They are charged at flat rate.

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.

→ They are given supply at 415V 3-phase or 240V single phase.

→ 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.

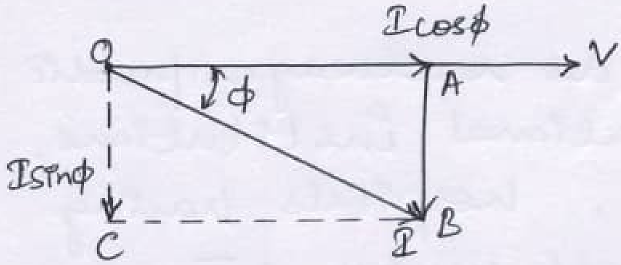
7) Water Supply :-

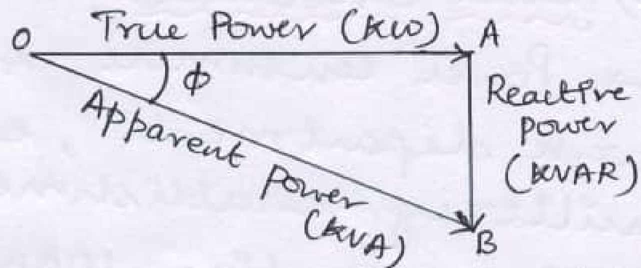
→ The load for water supply is for pumping water to the overhead tanks.

→ It is possible to fit this load during system off peak home, usually during night hours.

Power Factor :-

→ The cosine of the angle between voltage and current in an A.C circuit is known as power factor.





→ 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 the applied voltage and the power factor of the circuit is said to be leading.

→ 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 cosϕ is called active component and one perpendicular to the voltage phasor, I sinϕ is called 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 cosϕ ie VI cosϕ will represent the true power of the circuit (KW), whereas the product of voltage V and the quadrature component of current I sinϕ ie VI sinϕ will replesent the reactive power in VAR or KVAR & the product of voltage V and current I ie VI will represent the apparent power in KVA.

Thus, from power triangle, OAB,

OA = KW component of power

AB = KVAR component of power

$$\cos\phi = \frac{OA}{OB} = \frac{KW}{KVA}$$

Reactive power in KVAR = Apparent power × $\sin\phi$

$$= KVA \sin\phi = (KVA \cos\phi) \times \frac{\sin\phi}{\cos\phi}$$

$$= KW \tan\phi$$

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

Necessity :-

→ 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.

Disadvantages of low power factor :-

→ If load P is to be supplied at terminal voltage V and at power factor $\cos\phi$ 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, $\cos\phi$ ie 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, ∴ 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) 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.

Causes of Low power factor:-

(i) All a.c motors and transformers operate at lagging power factor. The power factor falls with the decrease in load.

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

(iii) Due to increased supply mains voltage, which occurs during low-load periods such as lunch hours, night hours etc, the magnetizing current of inductive reactances increases 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.

(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 appliance are given below :-

Type of load	Power Factor
1. Incandescent lamps	0.98 - 1.0
2. Fluorescent lamps	0.6 - 0.8
3. Neon lamps used for advertisements	0.4 - 0.5
4. Arc lamps used in cinemas	0.3 - 0.7
5. Fans	0.5 - 0.8
6. Induction motors	0.5 - 0.85
7. Fractional kW motors	0.4 - 0.75
8. Induction heaters	0.85
9. Resistance furnaces	0.6 - 0.9
10. Arc furnaces	0.85
11. Induction furnaces	0.6
12. Arc welders	0.3 - 0.4
13. Resistance welders	0.4 - 0.75

Methods of Power factor Improvement :-

→ The low power factor is almost invariably due to inductive nature of load and 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.

→ 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 to give unity power factor.

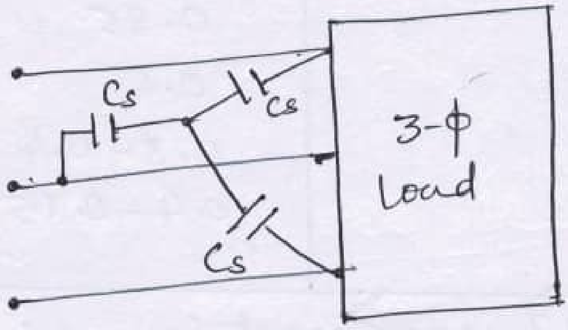
$$= I\sin\phi = I\sqrt{1-\cos^2\phi} = I\sqrt{1-(pf)^2}$$

I) By use of Static Capacitors :-

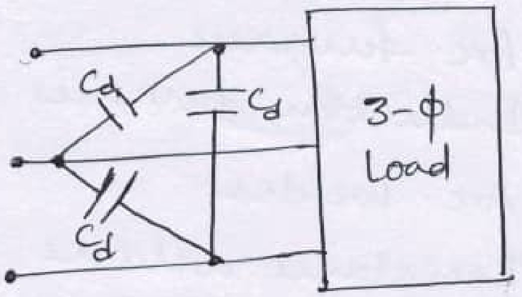
→ Power factor can be improved by connecting the capacitors in parallel with the equipment operating at lagging power factor such as induction motors, fluorescent tubes.

→ 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.

→ Static capacitors can be connected either in star or delta configuration for 3 phase system.



Star-connected Capacitor



Delta-connected Capacitors

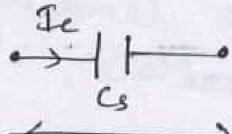
→ The value of the static capacitors for the improvement of the power factor can be determined as follows :-

For star configuration :-

Let $V_c = V_{ph}$, $I_c = I_{ph}$

∴ for star :- $V_{ph} = \frac{V_L}{\sqrt{3}}$, $I_L = I_{ph}$

KVAR of each capacitor $= \frac{3 I_c V_c}{1000}$



$V_c = I_c X_c$

$I_c = \frac{V_c}{X_c} \Rightarrow \omega C_s V_c$

$= \frac{V_c}{\left(\frac{1}{2\pi f C_s}\right)} = \frac{V_c}{\left(\frac{1}{\omega C_s}\right)}$

KVAR of each capacitor $= \dfrac{3(\omega C_s V_c) V_c}{1000} = \dfrac{3 C_s \omega V_c^2}{1000} = \dfrac{3 C_s \omega V_{ph}^2}{1000}$

$= \dfrac{3 C_s \omega (V_l/\sqrt{3})^2}{1000} = \dfrac{\cancel{3} C_s \omega V_l^2}{\cancel{3} \times 1000}$

$$C_s = \frac{1000 \times KVAR}{\omega \times V_l^2}$$

<u>for delta configuration</u>:-

Let $V_c = V_{ph}$, $I_c = I_{ph}$

for delta :- $V_{ph} = V_l$, $I_{ph} = \dfrac{I_l}{\sqrt{3}}$

$$KVAR = \frac{3 I_c V_c}{1000}$$

KVAR of each capacitor $= \dfrac{3(\omega C_d V_c) V_c}{1000} = \dfrac{3 \omega C_d V_c^2}{1000}$

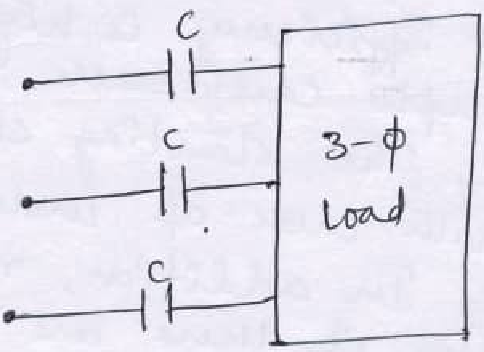
$= \dfrac{3 \omega C_d V_{ph}^2}{1000} = \dfrac{3 \omega C_d V_l^2}{1000}$

$$C_d = \frac{1000 \times KVAR}{3 \omega V_l^2} = \frac{C_s}{3}$$

$\therefore$ the delta value will be one-third of star value for given KVAR & line voltage.

→ Power factor can also be improved by connecting static capacitors in series with the line as shown in fig. 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.

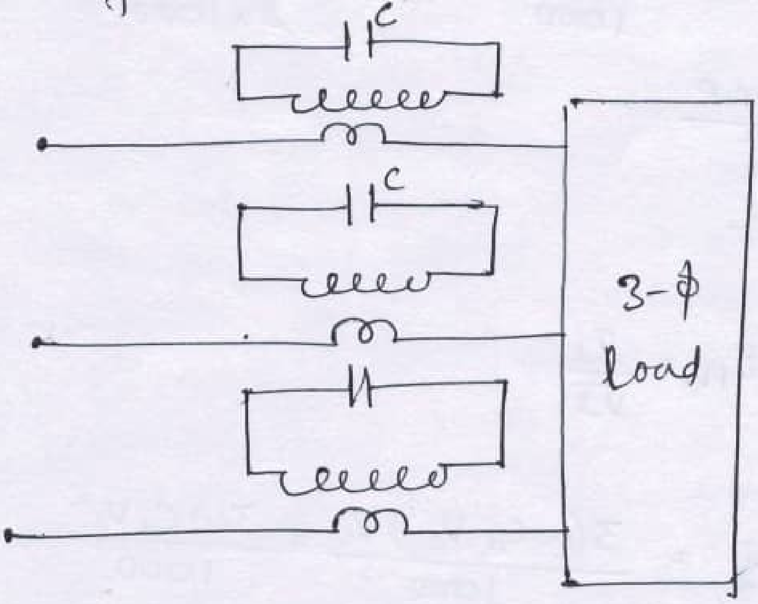
→ The capacity of the capacitors to neutralize the line reactance is given by



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

$f \rightarrow$ supply frequency, $L \rightarrow$ 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.



Advantages of capacitors :-
→ Less loss
→ Low initial cost
→ Easy installation
→ Long life.
→ Greater reliability and service.
→ Flexible in operation ie KVAR rating of capacitor can be adjusted according to load condition.

III) By use of synchronous or High power factor machines:-

(i) By use of synchronous motors :-
Advantage :-
→ Speed is constant
→ Efficiency is high and uniform from light loads upto considerable over-loads
→ The starting characteristics compare favourably with those of induction motors.
→ In addition, maintain a constant load voltage even if there are variations in the supply voltage.

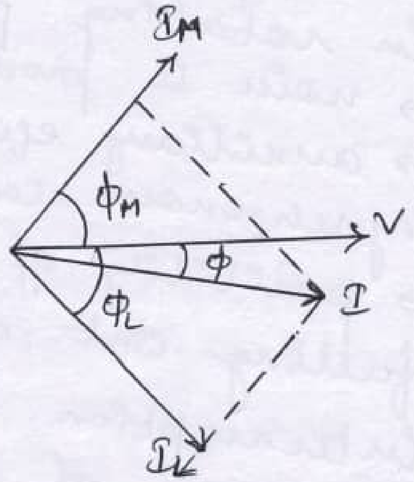
→ When the line voltage increases, the leading reactive KVA falls and when the line voltage falls, the leading reactive KVA increases.

→ It is better to keep the field excitation constant at a value corresponding to normal full-load rating as regards output & powerfactor.

→ Synchronous motors are designed for 1.0 – 0.8 leading power factor at full load.

(ii) By use of Synchronous Condensers :-

→ An overexcited synchronous motor running on no-load is called the synchronous condensers or synchronous phase advancers and behaves like a capacitor, the capacitive reactance of which depends upon the motor excitation.



→ In phasor diagram, 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 condensers leading the applied voltage V by an angle ϕ_M.

Thus overall power factor is improved from $\cos\phi_L$ to $\cos\phi$ by the use of synchronous condensers.

Advantages of synchronous condensers over static capacitors

→ A finer control can be obtained by variation of field excitation.

→ Synchronous motor has an inherent characteristic of stabilizing variations in line voltage and helps in maintaining vlg regulation.

(iii) Synchronous condensers are capable of withstanding overloads for short periods.

(iv) Improvement in system stability and reduction of effect of sudden changes in load owing to inertia of synchronous condensers.

Disadvantages :-

→ except in size above about 5000 KVAR.

→ cost is higher than that of static capacitors of same rating.

→ comparatively higher maintenance and operating costs.

→ comparatively lower efficiency due to losses in rotating parts and heat losses.

→ noise is produced in operation.

→ auxiliary equipment is required for starting synchronous condensers.

→ possibility of synchronous condensers falling out of synchronism causing in interruption of supply.

→ increase of short-circuit currents when the fault occurs near the synchronous condensers.

(iii) By use of Phase Advancers :-

→ The power factor of an induction motor falls due to its exciting current drawn from the ac supply mains, because exciting current lags behind the voltage by $\pi/2$.

→ It can be improved by equipping the set with an ac exciter or phase advancers which supplies this exciting current to the rotor circuit at slip frequency.

Advantages:-

→ lagging KVAR drawn by the motor are considerably reduced due to supply of exciting ampere-turns at slip frequency

→ the phase advancers can be conveniently employed where the use of synchronous motor is inadmissible.

(iv) 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.

(v) By use of High power factor motors:-

→ Besides synchronous motor 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.

Advantages of power factor improvement:-

→ Reduction in load current

→ Increase in voltage level across the load

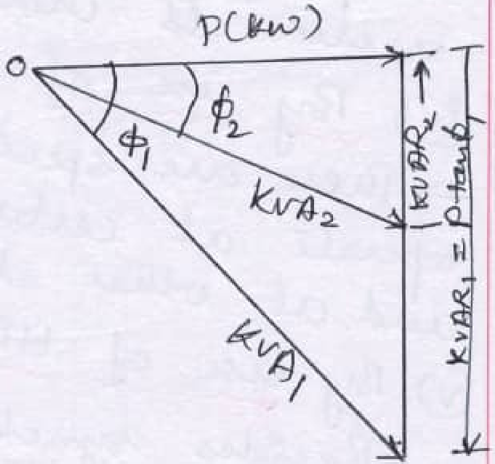
→ Reduction in energy losses in the system due to reduction in load current.

→ Reduction in KVA loading of the generators and transformers which may relieve an overloaded system or release capacity for additional growth of load

→ Reduction in KVA demand charge for large consumers.

Economics of power factor improvement :-

→ Improvement of power factor will result in reduction of maximum demand and thus affect an annual saving over the maximum demand charge but on the other hand an expenditure is to be incurred every year in the shape of interest and depreciation on account of the investment made over the power factor correcting equipment.



→ Consider a consumer taking a peak load of P kW at a power factor of $\cos\phi_1$ and charged at the rate of Rs. x per KVA of maximum demand per annum.

→ Let the expenditure per KVAR per annum of the power factor correction equipment be Rs. y.

→ Corresponding to maximum demand of P kW at power factor of $\cos\phi_1$,

Maximum demand in KVA, $KVA_1 = \dfrac{P}{\cos\phi_1} = P\sec\phi_1$

Reactive power, $KVAR_1 = P\tan\phi_1$

→ Let by installing the power factor correction equipment power factor becomes $\cos\phi_2$.

New maximum demand in KVA, $KVA_2 = \dfrac{P}{\cos\phi_2} = P\sec\phi_2$

New reactive power, $KVA_2 = P\tan\phi_2$

Annual saving in maximum demand changes,

$= Rs.\,x\,(KVA_1 - KVA_2) = Rs.\,x\,(P\sec\phi_1 - P\sec\phi_2)$

$= Rs.\,Px\,(\sec\phi_1 - \sec\phi_2)$

Leading KVAR supplied by power factor correction equipment

= Difference of the reactive power drawn before and after power factor correction.

$= P(\tan\phi_1 - \tan\phi_2)$

Annual cost of pf correction equipment

$$= Rs.\ y \times P(\tan\phi_1 - \tan\phi_2)$$

Net annual saving, $S = x P(\sec\phi_1 - \sec\phi_2) - yP(\tan\phi_1 - \tan\phi_2)$

This saving will be maximum if the differentiation of it with respect to ϕ_2 is zero.

$$\text{ie } \frac{dS}{d\phi_2} = 0$$

$$\frac{dS}{d\phi_2}\left[xP(\sec\phi_1 - \sec\phi_2)\right] - yP\left[\tan\phi_1 - \tan\phi_2\right] = 0$$

$$-xP\sec\phi_2\tan\phi_2 + yP\sec^2\phi_2 = 0$$

$$\tan\phi_2 = \frac{y}{x}\sec\phi_2$$

$$\sin\phi_2 = \frac{y}{x}$$

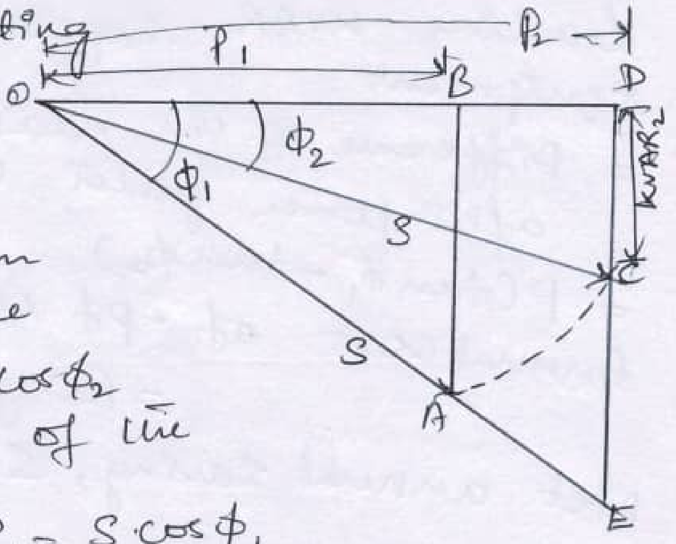
$$\boxed{\cos\phi_2 = \sqrt{1-\sin^2\phi_2} = \sqrt{1-\left(\frac{y}{x}\right)^2}}$$

The value of most economical power factor $\cos\phi_2$ can be determined which is independent of original factor $\cos\phi_1$ and is governed by the relative costs of supply and power factor correction equipment.

Economical comparison of the two methods of increasing the power supplied:-

→ The increase in power demand on the generating station can be met either by increasing the capacity of the generating plant working at the same pf or by raising the power factor of the system by installation of phase advancers.

→ Let the rating of generating station be S in kVA, supplying load at power factor $\cos\phi_2$.



→ Assume new demand can be met by improving the power factor from $\cos\phi_1$ to $\cos\phi_2$ with the same capacity of the plant.

Existing load in kW, $P_1 = S\cos\phi_1$

New load in kW, $P_2 = S\cos\phi_2$

(i) Cost by increasing the capacity of the generating station.

Increase in load $= P_2 - P_1 = S(\cos\phi_2 - \cos\phi_1)$

Increase in the capacity of the generating plant operating at pf $\cos\phi_1$

$$= \frac{\text{Increase in load kW}}{\text{Power factor of plant}} = \frac{P_2 - P_1}{\cos\phi_1}$$

$$= \frac{S(\cos\phi_2 - \cos\phi_1)}{\cos\phi_1} \text{ kVA.}$$

Increase in annual cost due to increase in capacity of the plant, $= \text{Rs.}\, x S\,\frac{(\cos\phi_2 - \cos\phi_1)}{\cos\phi_1}$

x → annual cost per kVA of generating plant.

(ii) Cost on power factor correction equipment.

Reactive power drawn by load operating at the old power factor, $\cos\phi_1 = P_2\tan\phi_1 = S\cos\phi_2\tan\phi_1$

Reactive power supplied by the plant = capacity of the plant in kVA $\sin\phi_2$

$= S\sin\phi_2$

kVAR rating of the p.f correction equipment

$= S\cos\phi_2\tan\phi_1 - S\sin\phi_2 = S(\cos\phi_2\tan\phi_1 - \sin\phi_2)$

Annual cost on pf correction equipment

$= \text{Rs.}\, y\, S(\cos\phi_2\tan\phi_1 - \sin\phi_2)$

$y \rightarrow$ annual cost per KVAR rating of power factor correction equipment.

→ Power factor correction equipment will be cheaper if annual cost on it is less than annual cost on account of increasing the generating capacity.

$$S y (\tan\phi_1 \cos\phi_2 - \sin\phi_2) < S x \frac{(\cos\phi_2 - \cos\phi_1)}{\cos\phi_1}$$

$$y (\tan\phi_1 \cos\phi_2 - \sin\phi_2) < x \frac{(\cos\phi_2 - \cos\phi_1)}{\cos\phi_1}$$

assumption,

$$y \left[\frac{\sin\phi_1}{\cos\phi_1} \cos\phi_2 - \sin\phi_2 \right] = x \frac{(\cos\phi_2 - \cos\phi_1)}{\cos\phi_1}$$

$$y \left[\frac{\sin\phi_1 \cos\phi_2 - \cos\phi_1 \sin\phi_2}{\cos\phi_1} \right] = x \frac{(\cos\phi_2 - \cos\phi_1)}{\cos\phi_1}$$

$$y \sin(\phi_1 - \phi_2) = x (\cos\phi_2 - \cos\phi_1)$$

$$\boxed{y = \frac{x (\cos\phi_2 - \cos\phi_1)}{\sin(\phi_1 - \phi_2)}}$$

Choice of equipment :

→ The choice between alternative types of electrical equipment depends upon the relative costs of the alternative equipment.

→ In selecting equipment for a particular service, the choice must fall upon that which makes the sum of the fixed charges and the operating charges minimum.

→ Saving can be affected only by incurring increased fixed costs and vice-versa, for ex:- an electric motor of a particular type and size of lower operating efficiency will usually costs less than a similar motor of higher efficiency.