

# **Chapter 2**

## ***Load Characteristics and Economic Aspects***

## Terms used commonly:

- 1. Connected load:** Sum of the continuous rating of the entire load consuming apparatus connected to the system.
- 2. Maximum demand:** It means the maximum power that the circuit is likely to draw at any time.
- 3. Demand factor:** It is the ratio of maximum demand to connected load. Demand factor has to be less than one.
- 4. Diversity factor:** It is the ratio of sum of individual maximum demand to the maximum demand of the whole power system. It is always greater than one.
- 5. Coincidence factor:** Coincidence factor is the ratio of the maximum demand by the sum of the individual maximum demands. It is always less than one.

**6. Load diversity :** It is defined mathematically as,

Load diversity = Sum of individual loads – Peak of the combined load

**7. Contribution factor:** It is the contribution of a particular load, in per unit of the individual demand, to the group maximum demand.

**8. Loss factor:** It is the ratio of average power loss to power loss at peak load.

**9. Load factor:** It is the ratio of average demand to maximum demand.

Load factor = Energy produced in a given time / (maximum demand \* hours of operation in the given period)

**10. Plant capacity factor:** It is the ratio of average annual load to the plant rated capacity.

Also, Plant capacity factor = Energy produced in one year / (Plant rated capacity \* 8760)

11. **Plant use factor:** It is defined as,

Plant use factor = Actual energy produced / (Plant capacity \* plant operation time in hours)

12. **Utilization factor:** It is the ratio of maximum load to rated capacity.

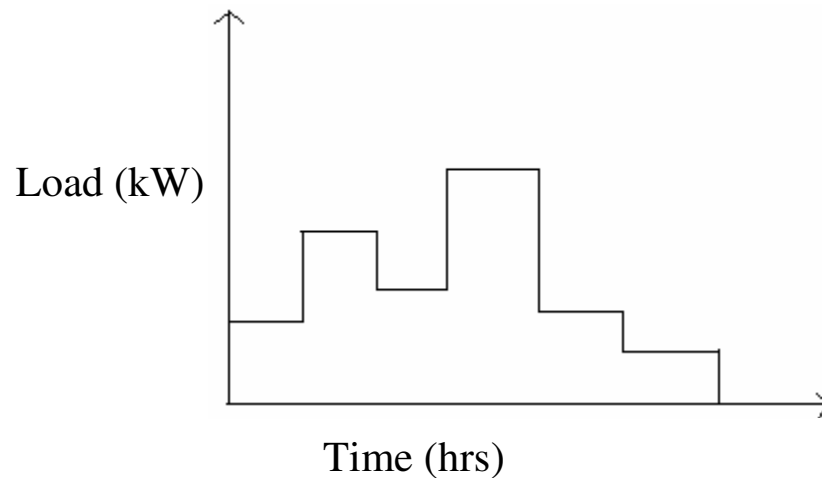
# Reserves:

- **Spinning reserve:** It is the generating capacity which is connected to a bus (common connection) and is ready to take the load.
- **Cold reserve:** It is that reserve generating capacity which is available for service but not in operation.
- **Hot reserve:** It is that reserve generating capacity which is in operation but not in service.
- **Firm power:** It is the power intended to be always available (even under emergency condition)
- **Reserve margin:** It is the difference between the rated capacity and the actual loading on the generator.

# Load Curve:

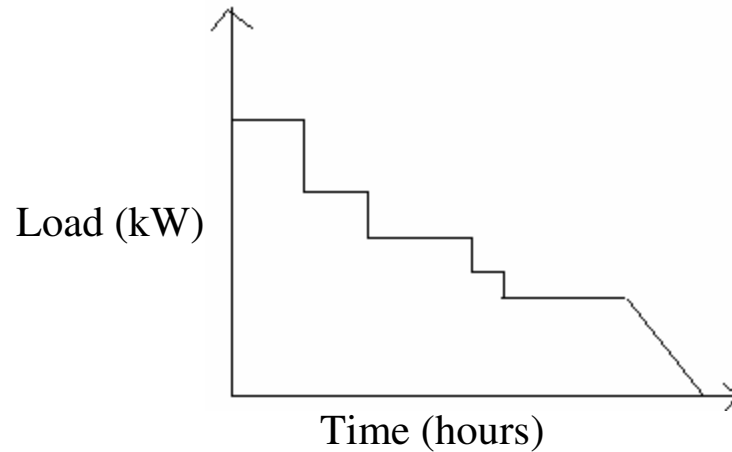
It is useful as it gives –

1. Maximum demand (peak of the curve)
2. Energy produced (area under the curve)
3. Load factor (The ratio of the area under the curve to the total area under the rectangle in which it is contained gives the Load factor for the period).
4. Average loading (The area under the curve divided by the number of hours gives the average demand).



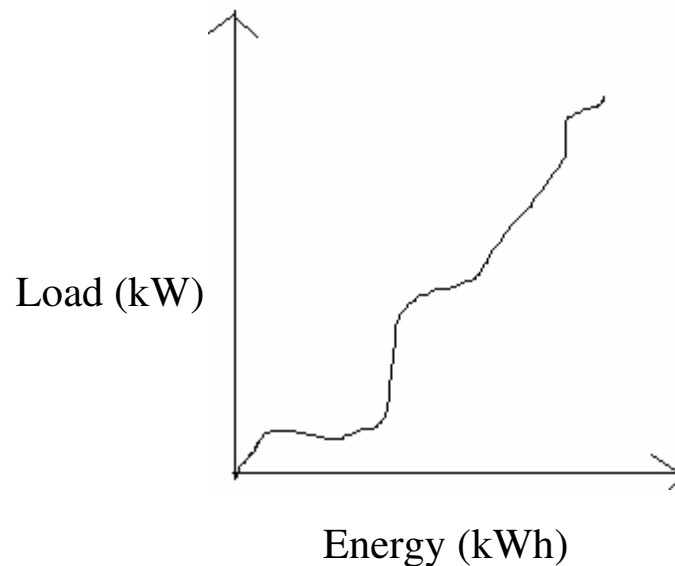
## Load Duration Curve:

All the loads are rearranged in descending order.



## Energy Load Curve:

It plots the cumulative integration of area under load curve starting at zero load to a particular load and it is also called integrated duration curve.



1. A residential consumer has a connected load of 6 lamps each of 100W and 4 fans of 60W at his premises. His demand is as follows:

From midnight to 5 am – 120W

From 5 am to 6 pm – no load

From 6 pm to 7 pm – 380W

From 7 pm to 9 pm – 680W

From 9 pm to midnight – 420W

a. Plot the load curve.

b. Find the energy consumption in 24 hours:

$$\text{Area under curve} = (5 \times 120) + (380 \times 1) + (680 \times 2) + (420 \times 3) = 3600 \text{Wh}$$

c. Calculate the demand factor, the average load, the maximum load and load factor.

Maximum load = 680W (from load curve)

$$\begin{aligned} \text{Demand factor} &= \text{Maximum Demand} / \text{Connected Load} = 680 / (6 \times 100 + 4 \times 60) \\ &= 0.809 \end{aligned}$$

$$\text{Average load} = \text{Energy consumed} / \text{no. of hours} = 3600 / 24 = 150 \text{W}$$

$$\text{Load factor} = \text{Average load} / \text{Maximum load} = 150 / 680 = 0.22$$



2. A generating station has a maximum demand of 80MW, a load factor of 65%, a plant capacity factor of 40% and a plant use factor of 85%. Find:

a. Daily energy produced.

b. Reserve capacity of plant.

c. The maximum energy that could be produced daily if the plant was running all the time.

d. The maximum energy that could be produced daily if the plant was running as per operating schedule.

a. Average demand = Load factor \* Maximum demand =  $0.65 * 80\text{MW}$   
= 52MW

Daily energy produced =  $52 * 24 = 1248\text{MWh}$

b. Installed capacity = Average demand / Plant capacity factor  
=  $52\text{MW} / 0.4 = 130\text{MW}$

Reserve capacity = Installed capacity – Maximum demand  
=  $130\text{MW} - 80\text{MW} = 50\text{MW}$

c. Maximum energy that could be produced daily if it was running all the time = Installed capacity \* 24 =  $130 * 24 = 3120\text{MWh}$

d. Maximum energy that could be produced daily if the plant was running as per operating schedule = Daily energy produced / plant use factor  
=  $1248 / 0.85 = 1468.23\text{MWh}$

3. Maximum demand of a generating station is 100MW. The load factor is 65%. The plant capacity factor and the plant factor are 50% and 80% respectively. Determine:

- a. The daily energy produced.
- b. The installed capacity of the plant.
- c. The reserve capacity of the plant.
- d. The maximum energy that could be produced daily if the plant is running all the time.
- e. The maximum energy that could be produced daily at full load (according to operating schedule).
- f. Utilisation factor.

a. Average demand = Load factor \* Maximum demand =  $0.65 * 100\text{MW}$   
= 65MW

The daily energy produced = Average demand \* 24 =  $65\text{MW} * 24$   
= 1560MWh

b. The installed capacity = Average demand / Plant capacity factor  
=  $65\text{MW} / 0.5 = 130\text{MW}$

c. Reserve capacity = Installed capacity – Maximum demand  
= 130MW – 100MW = 30MW

d. Maximum energy that could be produced daily if it was running all the time =  
Installed capacity \* 24 = 130MW \* 24 = 3120MWh

e. Maximum energy that could be produced daily if the plant was running as per  
operating schedule = Daily energy produced/ plant use factor  
= 1560/ 0.85= 1950MWh

f. Utilisation factor = Maximum load/ Rated capacity  
= 100/130 = 0.769

4. The load (in kW) on a substation is as follows:

<b>Time</b>	<b>Street lighting</b>	<b>Domestic</b>	<b>Commercial</b>	<b>Total</b>
12 am	400	600	400	1400
1 am	400	500	400	1300
2 am	400	450	400	1250
3 am	400	450	400	1250
4 am	400	500	400	1300
5 am	400	700	500	1600
6 am	400	1000	400	1800
7 am	0	800	700	1500
8 am	0	700	900	1600
9 am	0	600	1200	1800
10 am	0	500	1300	1800
11 am	0	500	1200	1700
12 pm	0	500	1100	1600
1 pm	0	600	900	1500
2 pm	0	600	1100	1700
3 pm	0	600	1000	1600
4 pm	0	600	900	1500
5 pm	0	700	600	1300
6 pm	400	800	500	1700
7 pm	400	1050	500	1950
8 pm	400	1200	500	2100
9 pm	400	1100	500	2000
10 pm	400	900	400	1700
11 pm	400	700	400	1500

- a. Find the maximum demand, average demand and the load factor pf the feeder
- b. The class contribution factor for street lighting and the remaining load
- c. The diversity factor of the feeder.
- d. The coincidence factor of the load group.
- e. If the feeder has the average loss of 14kW and annual loss factor of 0.14. Find the following:
  1. The peak power loss of the feeder at peak load.
  2. Total annual loss of feeder.
  3. Demand factor of the feeder if the connected load is 2500kW.

**Solution**

a. Maximum demand = 2100kW

Average demand = Sum of total demands/ 24 = 1602.08kW

Load factor = Average demand/ Maximum demand  
 = 1602.08/ 2100 = 0.763 =76.3%

b. Class contribution factor = load of class at peak load/ maximum load of that class

$$C_{SL} = 400/400 = 1$$

$$C_{Dom} = 1200/1200 = 1$$

$$C_{Com} = 500/1300 = 0.385$$

c. Diversity factor = Sum of maximum demands for each class/ Maximum demand  
 $= (400 + 1200 + 1300)/2100 = 1.381$

d. Coincidence factor = 1/Diversity factor = 0.724

- e. 1. Power loss at peak load = average power loss/ loss factor  
 $= 14\text{kW}/0.14 = 100\text{kW}$
2. Total annual loss = Average loss \* 365 = 5110kW
3. Demand factor = Maximum demand/ Connected load  
 $= 2100/2500 = 0.84$

5. A residential consumer has a connected load of 10 lamps of 100W each. his demand is as follows:

From midnight to 5am – 100W

From 5am to 6pm – no load

From 6pm to 7pm – 800W

From 7pm to 9pm – 900W

From 9pm to midnight – 400W

- a. Plot the load curve.
- b. Find the energy consumed during 24 hours.
- c. Calculate the demand factor, average load, maximum load and load factor.

Ans:

$$\begin{aligned} \text{b. Energy consumed} &= \text{area under the curve} = 100 \times 5 + 1 \times 800 + 2 \times 900 + 3 \times 400 \\ &= 4300 \text{Wh} \end{aligned}$$

$$\text{c. Demand factor} = \text{Maximum load} / \text{Connected load} = 900 / (10 \times 100) = 0.9$$

$$\text{Average load} = \text{Energy consumed} / \text{no.of hours} = 4300 / 24 = 179.167 \text{W}$$

$$\text{Maximum load} = 900 \text{W}$$

$$\begin{aligned} \text{Load factor} &= \text{Average demand} / \text{Maximum demand} = 179.167 / 900 \\ &= 0.199 \end{aligned}$$

**Power factor:** For a 3 phase balanced system, if P is the power,  $V_L$  and  $I_L$  are the line voltage and current respectively and  $\cos\phi$  is the power factor then the above mentioned quantities can be related as follows:

$$P = \sqrt{3}V_L I_L \cos\phi$$
$$\cos\phi = P/\sqrt{3}V_L I_L$$

If P and  $V_L$  are assumed to be constant (for transmitting the same power at the same voltage),

$$I_L \propto 1/\cos\phi.$$

Hence it is very clear from the last equation that if power factor is decreased then the current increases, because of which the following drawbacks are there:

1. The ratings of the generators and transformers will increase.
2. Since  $I_L$  increases the thickness of the conductor in the transmission lines will increase. Due to this copper will be used more and cost of transmission lines will go up.
3. Since the losses in the transmission line directly proportional to the square of the current, the loss increases.
4. The voltage regulation is poor because of more drop.



## **Various causes of low power factor:**

1. Most of the induction motors operate at lagging power factor. The power factor of these motors falls with decrease in load.
2. The arc and induction furnaces operate on very low lagging power factor.
3. Transformers draw magnetising current which causes the total current to lag behind.

## **Measures to avoid low power factor:**

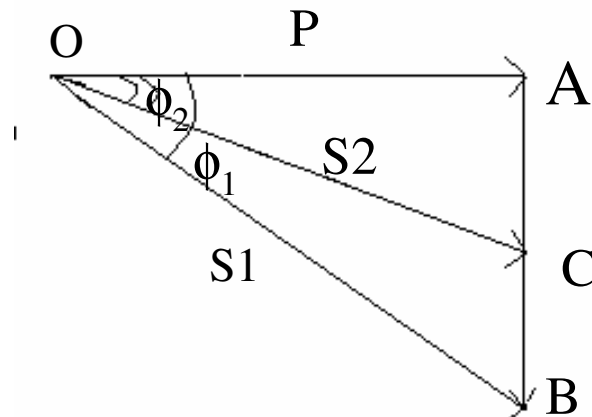
1. By using synchronous motors instead of induction motors.
2. By using high speed induction motors instead of low speed induction motors.
3. By using operating the induction motor at rated output.
4. By switching the induction motor from delta winding to star winding.
5. By using dc motors instead of ac motors wherever possible.

Usually static capacitors, synchronous condensers, phase advancers or modifiers are usually added to improve power factor of the entire power system.

Methods to improve power factor:

1. Constant kW method:

OAB is the power triangle of the initial plant without phase modifier. P is the real power in kW.  $\phi_1$  is the power factor angle.  $S_1$  is the kVA power and C is the apparent power and AB is the reactive power in kVAr. After addition of phase modifier, the new power triangle is OAC. It is clear that the kW power is not changing but the kVA power is getting reduced from  $S_1$  to  $S_2$ . The power factor is improved ( $\cos\phi_2$ ).



If 'a' is the rate of charge of kVA in Rs/kVA and 'b' is the expenditure associated with the capacitor banks in Rs/kVAr then the net saving is

$$c = a(S_1 - S_2) - b(BC)$$

$$\Delta S = S_1 - S_2 = (P/\cos\phi_1) - (P/\cos\phi_2)$$

$$BC = AB - AC = P\tan\phi_1 - P\tan\phi_2$$

$$\text{Total saving : } c = a((P/\cos\phi_1) - (P/\cos\phi_2)) - b(P\tan\phi_1 - P\tan\phi_2)$$

For maximum saving, differentiate 'c' with respect to  $\phi_2$ .

$$dc/d\phi_2 = 0$$

⇒ Therefore when,  $\sin\phi_2 = b/a$

saving is maximum.

## 2. Constant kVA method:

Initially the power triangle of the plant is OAB where OA is the real power and AB is the reactive power. The kVA power is  $S=OB$  and  $\phi_1$  is the power factor angle. Now assuming that there is a kW increase .this can be met by increasing the kVA supply(addition of a new unit). Or by adding capacitor banks of reactive value CF kVAr. The final vector diagram for the overall plant becomes ODF(after adding capacitor banks/ phase advancing plant) and  $\phi_2$  is the new power factor angle. It is clear from the vector diagram that S is maintained constant, therefore we save on the kVA(=BC new gen. plant/unit) and the expenditure is on the kVAr(=CF/ phase adv. plant).

$$BC = BE/\cos\phi_1$$

$$BE = AD = OD - OA = S\cos\phi_2 - S\cos\phi_1$$

$$BC = S(\cos\phi_2 - \cos\phi_1)/\cos\phi_1$$

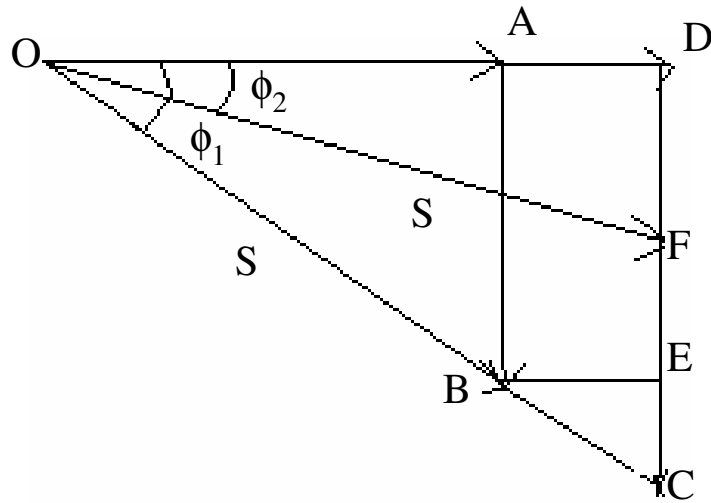
$$CF = DC - DF$$

$$\tan\phi_1 = DC/OD$$

$$DC = OD\tan\phi_1 = (OA + AD)\tan\phi_1 = [P + S(\cos\phi_2 - \cos\phi_1)]\tan\phi_1$$

$$DF = S\sin\phi_2$$

$$CF = [P + S(\cos\phi_2 - \cos\phi_1)]\tan\phi_1 - S\sin\phi_2$$



If 'a' is the rate of charge in Rs/kVA and 'b' is the charge in Rs/kVAr (if it is annual charge, then the interest and depreciation rate per annum has to be considered), then the net saving is

$$\text{Saving} = a(BC) - b(CF) = a(S(\cos\phi_2 - \cos\phi_1)/\cos\phi_1) - b([P + S(\cos\phi_2 - \cos\phi_1)]\tan\phi_1 - S\sin\phi_2)$$

## **Interconnections**

### ***Advantages of interconnection:***

- The total reserve capacity can be reduced.
- The requirement of high installed capacity is also reduced.
- The most effective units can be used at high load factor and the inefficient stations can be used only at peak hours.
- The reliability of the system is increased.

### ***Drawbacks:***

- Fault in one system gets transferred to other parts on the system.
- High switch gear rating equipment needs to be employed at various parts of the system.
- Proper management is required.

## **Tariffs:**

For proper management of any electricity utility it is important to have a source of income to meet its expenses. It is also required for future expansion.

There are two types of charges:

**1.Fixed:** Fixed charges include the interest and depreciation, cost of plants, buildings, transmission and distribution network, part of salary of staff, cost of meter, the billing collection and service etc.

**2.Running charges:** It is also called variable cost or charge. It includes the operation, fuel costs and maintenance.

### **General form of tariffs:**

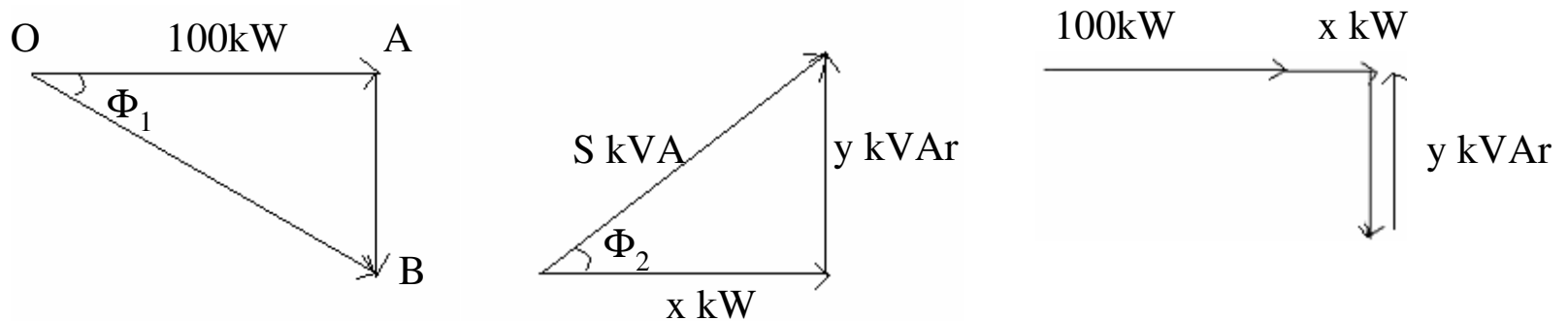
$$a k W h + b k W + c$$

## Types of tariffs:

1. **Flat rate tariff:** The electricity charge is directly the multiplication of energy consumption and the factor a.
2. **Two part tariff:** Apart from the energy consumed, there is charge for the maximum demand also.
3. **Block rate tariff:** Different blocks of energy consumption are charged at different rates. For example, for the first 50 units the charge will be Rs. 1.85 per unit and for the next 50 units the charge is Rs.2.90 per unit.
4. **Maximum demand tariff:** Power factor tariffs are calculated based on the maximum demand only (a and c only).
5. **Power factor tariff:** Power factor tariffs are devised to differentiate between the good power factor users and poor power factor users.
  - a. **kVA maximum demand tariff:** Instead of charging the maximum real power demand, maximum kVA demand is charged in addition to the charge corresponding to energy.
  - b. **kWh and kVAh tariff:** Both kWh and kVAh (the reactive power consumption are charged separately.
  - c. **Sliding or average power factor:** There is some extra charge if the power factor is below the set value (0.8). If consumers improve the power factor an incentive will be given to those consumers.



1. The loads on the mains of a supply system is 1000kW at a power factor of 0.8 lagging. What must be the kVA rating of the phase advancing plant which takes leading current at a power factor of 0.15 in order to increase power factor of the whole system to 1.



$$\cos\Phi_1=0.8$$

$$\Phi_1 = 36.89^\circ$$

$$AB = \tan(36.89) \cdot 1000 = 750 \text{ kVAr}$$

A phase advancing plant with  $y = 750 \text{ kVAr}$  has to be added to give a pf of 1

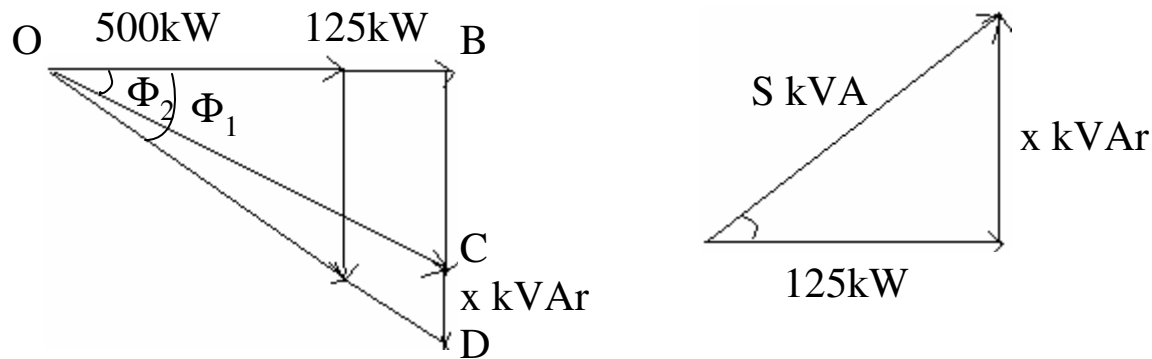
$$\cos\Phi_2 = 0.15$$

$$\Phi_2 = 81.37^\circ$$

$$S = y / \sin 81.37 = 750 / 0.9887 = 758.58 \text{ kVA}$$

Therefore kVA rating of phase advancing plant = 758.58kVA

2. A three phase synchronous motor is connected in parallel with a load of 500kW at 0.8 power factor lagging and it's field excitation is adjusted until it raises the total power factor to 0.9 lagging. If the mechanical load on the motor including losses takes 125kW, calculate the kVA input to the motor.



$$\cos\Phi_1 = 0.8$$

$$\Phi_1 = 36.89^\circ$$

$$BD = \tan(36.89) * 500 = 375 \text{ kVAr}$$

$$\cos\Phi_2 = 0.9$$

$$\Phi_2 = 25.84^\circ$$

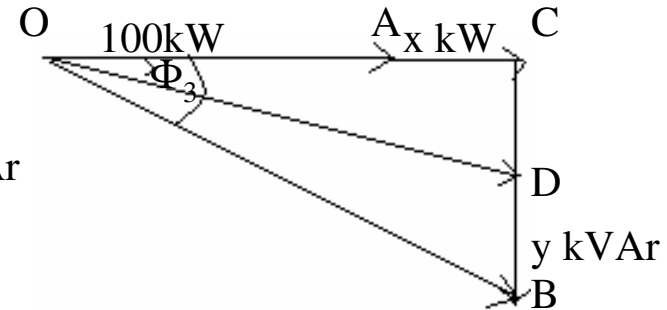
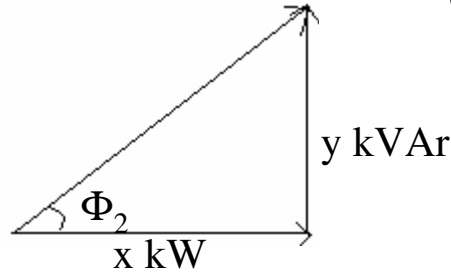
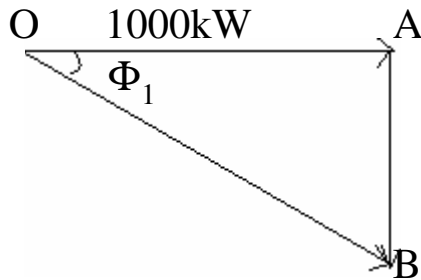
$$BC = \tan(25.84) * (500 + 125) = 302.67 \text{ kVAr}$$

$$x = CD = BD - BC = 375 - 302.67 = 72.32 \text{ kVAr}$$

$$S = \sqrt{(72.32^2 + 125^2)} = 144.41 \text{ kVA}$$

Therefore kVA rating of synchronous motor = 144.41 kVA

3. Load on a supply system is 1000kW at a power factor of 0.707 lagging. What must be the kVA rating of the phase advancing plant which takes leading current at a power factor of 0.1 in order to raise the power factor of the whole system to 0.95 lagging.



$$\cos\Phi_1 = 0.707$$

$$\Phi_1 = 45^\circ$$

$$AB = \tan(45) * 1000 = 1000 \text{ kVAr}$$

$$\cos\Phi_2 = 0.1$$

$$\Phi_2 = 84.26^\circ$$

$$y = \tan(84.26) * x = 9.949x$$

$$\cos\Phi_3 = 0.95$$

$$\Phi_3 = 18.19^\circ$$

$$\tan(18.19) = (1000 - y) / (1000 + x) = (1000 - 9.949x) / (1000 + x)$$

$$\therefore x = 65.38$$

$$y = 9.949 * x = 650.59$$

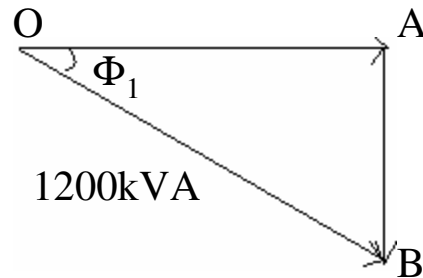
$$\therefore S = \sqrt{(65.3^2 + 650^2)} = 653.86 \text{ kVA}$$

Therefore kVA rating of phase advancing plant = 653.86kVA

4. The load on a certain installation may be considered constant at 1200 kVA, 0.75 lagging power factor for 8000 hours per annum. The tariff is Rs.65 per kVA maximum demand + 2 paisa per kWh.

- Determine the annual charge for electric energy before installing any apparatus.
- Power factor improving apparatus is installed to improve the power factor to 0.95 lagging from 0.75. Determine the kVAr required and the new annual charge if the power factor improving apparatus costs Rs. 65 per kVAr. The annual interest and depreciation charges are 10% of the capital cost and the losses in the apparatus are 5% of kVAr rating.

a.



$$\cos\Phi_1=0.75$$

$$\Phi_1 = 41.4^\circ$$

$$OA = 1200 \times 0.75 = 900 \text{ kW}$$

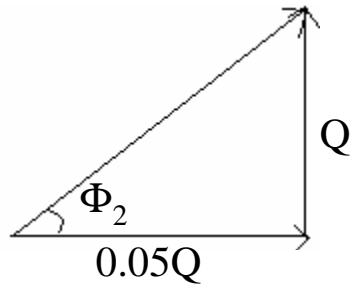
$$\text{kVA maximum demand} = 1200 \text{ kVA}$$

$$\text{kWh} = 900 \times 3000 = 2700000 \text{ kWh}$$

$$\text{Tariff} = \text{Rs.}65/\text{kVA maximum demand} + 0.02 \text{ Rs./kWh}$$

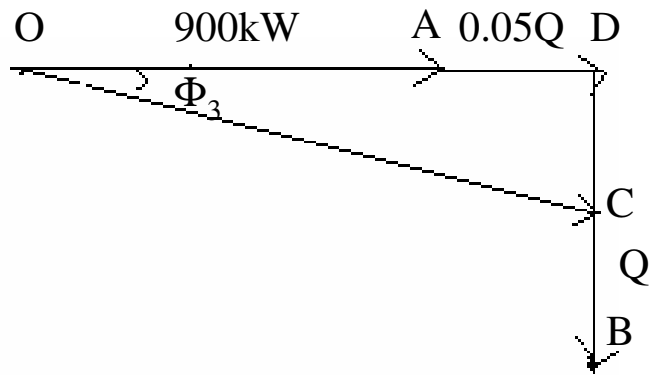
$$\text{Annual charge} = 65 \times 1200 + 0.02 \times 2700000 = \text{Rs.}132000$$

b.



Let the kVAr rating of the power factor improving apparatus be  $Q$ .

Therefore  $\text{kW} = 5\% \text{ of kVAr} = 0.05Q$



$$BD = \tan(41.4) \cdot 900 = 793.73 \text{ kVAr}$$

$$\cos \Phi_3 = 0.95$$

$$\Phi_3 = 18.19^\circ$$

$$\tan(18.19) = (793.73 - Q) / (0.05Q + 900)$$

$$\Rightarrow Q = 489.95 \text{ kVAr}$$

$$S_{\text{new}} = (793.13 - Q) / \sin(18.19) = 973.126 \text{ kVA}$$

$$OD = 900 + 0.05Q = 924.5 \text{ kW}$$

Annual charge :

1. Charge based on kVA demand :  $60 \cdot 973.126 = \text{Rs.} 63245$
2. Charges due to energy consumption is  $= 0.02 \cdot 924.5 \cdot 3000 = \text{Rs.} 55470$
3. Charges due to depreciation rate of the capacitor banks = cost of the apparatus  $\cdot \text{kVAr} \cdot \text{interest} = 60 \cdot 490 \cdot 0.1 = \text{Rs.} 2940$

Total annual charge = Rs 121655