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What is reactive power and under which circumstances may power factor correction reduce electricity consumption in a plant or reduce electricity cost only or reduce both electricity cost and electricity consumption.

Introduction:

The main advantage of power factor correction is the reduction in electricity cost. However, the additional benefits are reduction in I^2R losses in the electrical system and improvement in system efficiency, release of additional capacity, reduction in size of electrical equipment for delivery of same amount of power and improvement in voltage regulation.

What is reactive power?

Any industrial plant or we may say in a more broader term that any system whether it is a large, medium or small plant, commercial establishment, Township (large or small) has reactive load. Some of the examples of reactive loads are;

- Motors
- Transformers
- Fluorescent Lamps
- Rectifiers
- Furnace
- Various types of electronic equipment
- Computers

These reactive load draws reactive power from the utility. The current drawn by the electrical equipment has two component. One is active or some times call useful component which is responsible for doing useful work like producing power at a motor shaft. The other component is reactive component which is also called wattless component. The wattless component is responsible for producing necessary flux across the air gap of a induction motor or in the core of a transformer. It is required for building up flux for magnetic field of an inductive circuit. Without magnetising current electrical energy can not flow across the air gap of a motor or in the core of a transformer. The total current as read in the ammeter is the vector sum of these two components. In an inductive load the reactive component lags at 90^0 from the active component.

This lagging component is responsible for power factor. The power factor is affected by the reactive component. If the magnetising current (reactive component) is more in comparison to the active component, the power factor will be poor as in a lightly loaded induction motor.

Now the question arises that how the power poor power factor affects the utility and why the utility companies fixes a power factor limit and impose penalty on the consumers if the power factor fells below that limit?

It can be explained in a very simple manner that if reactive current will be more for a load of poor power factor and as mentioned earlier that the reactive current is also a part of the total current supplied by the utility, it loads the equipment of the utility like transmission lines, transformers, switch-gear etc. In another way we can say that for supplying the same useful power to a load of poor power factor more capacity of the equipment is utilized in comparison with a load of good power factor.

What is Power Factor? :

Power factor is the ratio of active power to the apparent power. For example on a electrical panel ammeter, voltmeter and wattmeter are provided. The ammeter is showing 200 ampere, voltmeter is showing 415 Volts and wattmeter is showing 120 KW. Then apparent power will be (1.732x200x415)/1000 = 143.76 KVA and the power factor will be 120/143.76 = 0.83. Trigonometrically, the Power factor is KW/KVA= Cos ϕ.Generally, any power factor below 0.9 is called poor power factor.

Remedy of poor power factor:

The remedy is to install a capacitor bank or sometimes synchronous motors to improve the power factor. The function of the capacitor banks is to supply the reactive power required locally and relieve the utility from supplying the reactive power to the load. Before, installation of capacitor banks we should look into the following points.

- How much power factor compensation is required i.e. how much power factor is needed to improve.
- Capacitor bank of what capacity is required
- Where these capacitor banks are to be located
- **What is the economics of power factor improvement and how it affects the electricity bill.**

What should be the power factor?:

Many electrical engineers give different replies. Some say it should be 0.9,others say 0.95 and the most common reply is that it should be as near as possible to unity. I think that before fixing a power factor we should look into the following points.

- What is the limit of target power factor imposed by the utility company?
- What is the existing power factor and capacity of system and how much the system is loaded?
- What is the cost of adding additional capacitor banks to improve the power factor beyond the limit as imposed by the utility company. How much additional capacity is released and also its cost.
- Pay back period of installation of capacitor bank.

If the system has enough spare capacity and additional capacity is not required, the power factor should be kept as per he limit imposed by the utility company, which is normally 0.95,since 0.95 is the most economical power factor. Addition of more capacitor banks may not be economical if additional capacity of the system is not required.

Location of Capacitor Bank:

Now as far as location of capacitor bank is concerned, the best location should be as near as possible to the load. Sometimes, capacitor banks are installed to act as group correction i.e. it is connected with the main bus bar and the main bus has many feeders, since it not always economical to install the capacitor for individual feeders. For example, if the motors of different rating are installed, many capacitors of different ratings will be needed resulting in increase in cost. Group correction is also economical in cases when different feeders have different load at different time. Because in such cases automatic power factor sensing relay continuously keep on sensing the power factor of the load and keep on switching on and off the capacitor banks to adjust the power factor as per the pre set value.

The another important point, which should be taken care of, is that the improvement takes place only from point of application towards the source of power and not in the opposite direction. Therefore, it is always advantageous to place the capacitor bank near the load that reduces the losses in the circuit between the load and the feeder.

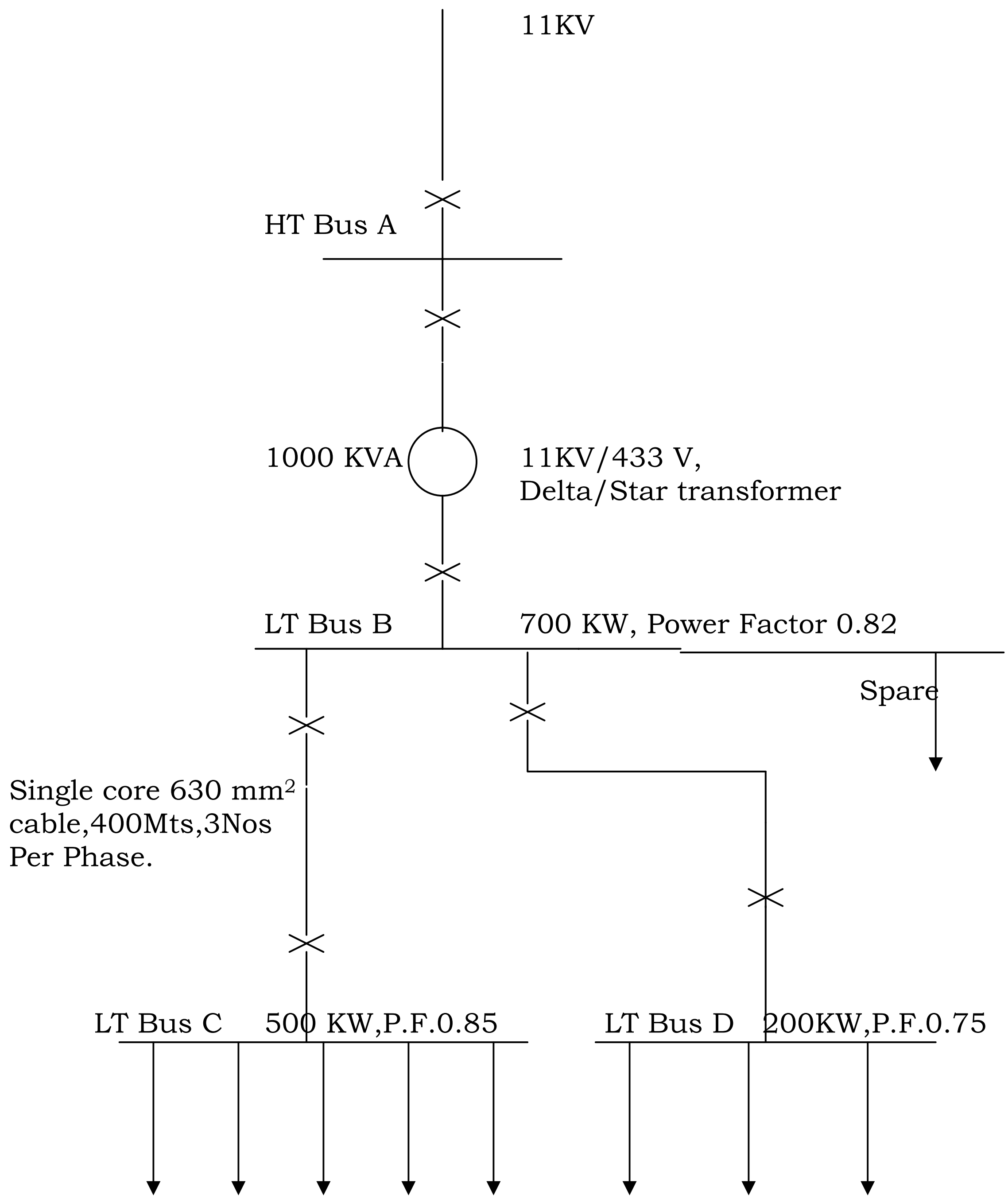
<u>What is the economics of power factor improvement?:</u>

For any consumer,(except small domestic consumer),the electricity tariff consists of two parts .One is Demand Charges and another Unit Charges. Demand charges are KVA charges and it depends on power factor. If power factor is low the KVA will be more and vise versa and electricity bill for poor power factor will be more. The unit(KWH) charges will not be affected. By installing capacitor bank, the intake of reactive power from the utility grid will get reduced since, it is now supplied by the capacitor banks provided locally.
At present utility companies are not charging for reactive power(KWARH) But it is heard that in near future they are planning to charge for reactive power instead of KVA charges.

<u>Case Study:</u>

We take a case, which will clarify all the points mentioned above. As shown in the single line diagram supply is taken at 11KV and stepped down to 433 volt through 11KV/433V, 1000 KVA, Delta-Star connected step down transformer. After stepping down it is supplied to BUS B of power control center. Bus-B consists of three feeders.

1. Feeder 1 is connected to a motor control center having a load of 500KW at 0.85 power factor. The power supply to motor control center is fed through a 630 sq.mm, single core, PVC insulated, aluminum conductor cables. Three numbers of such cables are provided in each phase and two numbers in neutral. The approximate distance between MCC feeder of Bus-B and the incomer of Bus-C(Bus of Motor control center) is 400 meters.



2. Feeder 2 is connected to a miscellaneous load consisting of lighting load ,lifts load, window air conditioner, computers etc. The total load is 200 KW at 0.75 power factor. It is fed through two number, three and a half core,240 sqmm, aluminum conductor ,PVC insulated cables. The distance is approximately 40meters.
3. The third feeder is spare.

The utility has imposed a condition that the power factor should not be less than 0.95.The demand charges are Rs.250.00 per KVA. Unit charges are Rs.4.60 per unit.

We would do analysis for working out the KVAR requirement and cost of the capacitor banks for improving the power factor and also for the best location of the bank.

Analysis:

Case 1:

Capacitor banks are provided at bus-B(Group compensation).

The total load on bus –B is 700 KW and combined power factor will be 0.82. For improving power factor from 0.82 to 0.95 the KVAR required can be calculated from the following formulae.

$$KW(\tan\phi_1-\tan\phi_2),$$

Where $\cos\phi_1$ is existing power factor and $\cos\phi_2$ is the improved power factor. Alternatively standard tables are also available to determine the KW multiplying factor for determining the required KVAR for required power factor correction.

The multiplying factor for improving power factor from 0.82 to 0.95 is 0.369.
Therefore the KVAR required is **0.369x700 = 258.3**
Assuming the cost of supply and installation of capacitor bank per KVAR Rs.980.00,then the total cost of installation of capacitor banks will be **Rs.(258.3x980) = Rs2,53,134.00**

Pay –back Period:

KVA at 0.82 power factor will be 700/0.82 = 853.66
KVA charges
853.66x250 = Rs.2,13,415.00
KVA at 0.95 power factor will be 700/0.95 = 736.84
KVA charges
736.84x250 = Rs.1,84,210.00

Difference in demand charges Rs.(2,13,415 – 1,84,210) = Rs.29,205.00
i.e. saving per month = **Rs.29,205.00**

Pay – Back period will be 2,53,134/29,205 = **8.66 months** say approximately eight and a half month.

Additional capacity released = 853.66 – 736.84 = **116.82 KVA**

Similarly we can do the calculation for 0.99 power factor improvement.
The KVAR required will be **388.5** and charges for capacitor bank will be **Rs. 3,80,730.00**.The saving will be **Rs.36,650.00** per month and the Pay –back period will be **10.38 months.**
Additional capacity released =853.66-707 = **146.66 KVA**

Cost of per KVA capacity released when power factor if improved to 0.95 will be 2,53,134/116.84 = **Rs.2,166.50**
Cost of per KVA capacity released when power factor is improved to 0.99 will be Rs.3,80,730 /146.66 = **Rs. 2,596.00**

Case 2:
<u>Capacitor banks are provided at Bus – C and Bus –D(Individual correction)</u>
Bus C

The multiplying factor for improving power factor from 0.85 to 0.95 is 0.291.
Therefore the KVAR required is 0.291x500 = **145.5**
The total cost of installation of capacitor banks will be Rs.(145.5x980) = **Rs1,42,590.00**
Saving in demand charges per month = 61.68x250 = **Rs.15,421.00**

Bus D

The multiplying factor for improving power factor from 0.75 to 0.95 is 0.553.
Therefore the KVAR required is 0.553x200 = **110.6**
The total cost of installation of capacitor banks will be Rs.(110.6x980) = **Rs1,08,388.00**
Saving in demand charges per month = 56.17x250 = **Rs.14,036.00**
Total cost = Rs (1,42,590 + 1,08,388) = **Rs. 2,50,978.00**
Total saving in demand charges per month =29,457.00

<u>Reduction in I^2R losses :</u>

Current for 500 KW, three phase, load at 0.85 power factor = 818.5 amp.
Resistance of 630 sq. mm cable =0.047 ohm/kilo meter
Resistance of 400 mts length =.0188 ohm

Since three cables are provided in parallel, the total resistance of cable in one phase will be one third i.e. 0.00626 ohm.
The I^2R losses losses in one phase =4193.8 watt
The losses for three phases = 3x4.2 =12.6 KW
Reduction in losses if power factor is improved from 0.85 to 0.95 will be
1-(origional p.f.)^2/(improved p.f.)^2
= 0.2x12.6 =2.51 KW
Assuming that the load remain constant for 20 hrs a day then monthly energy saving will be 30x20x2.15 = 1506 units
Assuming cost per unit is Rs.4.60 then per month saving will be 1506x4.6 = **Rs.6927.60** and annual saving will be 20x365x2.15x4.6 = **Rs.72197.00**
Pay back period = 2,50,978/(29,457+6,927) = 6.89 months
Say, approximately **7 months**

Summary:

We can summarize the above analysis as following:

- The main benefit in power factor improvement is reduction in electricity bill due to reduction in demand charges.
- If the length of feeding cable in more then we will get the additional benefit of reduction in I^2R losses, and saving in unit charges if the capacitor bank is installed at the load end as seen in the above case study in case of individual correction.
- It is not always economical that the power factor should be near to unity as we have seen that the pay back period for improving power factor to 0.99 is more than the power factor of 0.95.And also per KVA cost of released capacity is more if power factor is improved to 0.99 instead of 0.95.

Conclusion:

1. Finally it is concluded that main advantages of power factor improvement is Reduction in KVA demand, which results in reduced power cost. In addition, the losses in the system get reduced and a saving in energy is realized. But as compared to saving which is obtained in KVA charges, it is very small and installation of capacitor bank just for saving due to reduction in losses is not justified. It should always be looked as additional benefit.

2. Lastly one more important point I would like to add that before installation of capacitor bank measurement of harmonic in the system

shall be made and if is more than the permissible limit harmonic filter shall be provided since presence of harmonics adversely affects the performance of capacitor bank. The stability of standby/captive power generators may be affected if power factor is improved to unity and excitation current becomes zero.