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ABSTRACT

The topic under discussion is very relevant as far as the importance of its role in energy conservation and national economy is concerned. In general , this is a topic which was considered relevant only as a means to cut the demand charges and to get rid of from the penalty charges of Electricity supply companies. But in fact , it can do lot more than this depending on the method of power factor correction being adopted for a plant . As far as a factory or plant is concerned there are lot of energy getting wasted in the distribution network within the plant and could be reduced to a great extend by judicious placement of p.f correctors close to the load points instead of keeping at the power source.

Mostly one can find p.f correctors installed at the power receiving point of a plant only to improve the p,f at the supply point and take advantage of only cost reduction towards KVA demand. But fact is that , by putting the p.f correctors near to the load centers within a plant can eliminate the cable network from carrying the reactive current required by the loads . This will result into reduction in the network losses within the plant giving advantage of reduction in energy charges also.

Hence effective and judicious way of p,f correction will lead to reduction in both cost as well as energy consumption. The issue is discussed in detail in this paper.

INTRODUCTION

Power factor improvement is an age old topic and is a topic very close to the heart of all power Engineers. As far as a power Engineers are concerned , first and foremost concern should be to use the available energy for any application with maximum efficiency and with minimum wastage or no wastage. So the topic of energy conservation has to be a part and parcel of power Engineers to strengthen the economy of a nation with minimum or no damage to the environment.

Use of energy should maintain harmony among the **3Es of Economy growth , Environment and Energy security**. To achieve this , all power engineers have to play an instrumental role in the area of energy conservation. It is a fact that one can survive without money in hand for hours or days together but not without energy even for a while. So from this , one can understand the importance of energy in our day to day life and its role in the economic development of a country. It is heartening to note that Govt. has enacted Energy conservation act-2001 as an administrative tool to ensure energy efficiency in all facets of our energy use in the process of economic development.

Here the topic under discussion is very relevant to the concept of energy conservation and will be discussed in detail in this paper. Paper will discuss about the concept of p.f correction and its role in reducing the power consumption as well as energy cost in a systematic way in the form of questions and answers for better understanding of the concept and topic.

2.1 . What is meant by real , reactive and apparent power?

Answer:

- Real power in an electrical system could be sensed physically in the form of heat or motion and is measured in Kilowatt (KW) .
- Reactive power is the power to maintain electro-magnetic fields in an electrical system .Reactive power shuttles between the power source and the load but does not consume anywhere in the circuit .Its role is only reactive (not active) and hence to compensate its reactive role we have to supply some power called reactive power to keep the electrical circuit doing its job. This power is represented by the term Kilo Volt Ampere Reactive (KVAR). There are two types of reactive powers1) Capacitive and 2) Inductive. These two properties in a circuit are 180 out of phase and the property of one could be used to neutralize the effect of other.

- Apparent power is the total power consumed by an electrical load and is nothing but the vector sum of real and reactive power and is measured as Kilovoltampere(KVA). The mathematical relation of these three parameters

could be represented by the formula $KVA = \sqrt{(KW^2 + KVAR^2)}$

2.2 What is meant by power factor , p.f lagging and p.f leading?

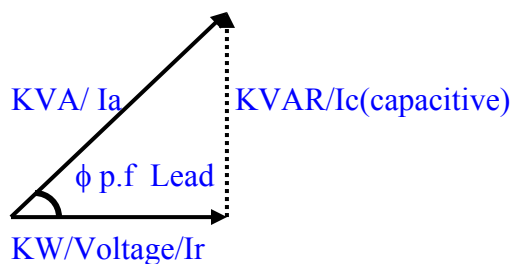
If an electrical circuit is supplied with A C Power the current and voltage will vary with a phase difference . These two parameters will reach its peak values at different instances depending on the reactive power property of the circuit. The phase difference between the two parameters reaches its peak value is called the phase angle and the cosine of this phase angle is called **power factor**.

Hence the power factor is nothing but the part of the total current which does useful work in a circuit . So if the power factor of a circuit is 0.8 it does mean that , only 80% of the total current is doing useful work .

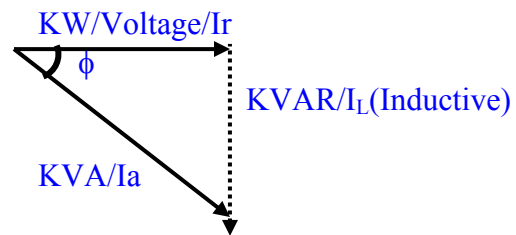
If a circuit dominates in its capacitive property then the current will be leading the voltage or in other words the current peak will be reaching first than its voltage peak with a phase difference of 90 degree or less. So we call the circuit as a circuit with **leading power factor**.

If a circuit dominates in its inductive property then the current will be lagging the voltage or in other words the current peak will be reaching second than its voltage peak with a phase difference of 90 degree or less. So we call the circuit as a circuit with **lagging power factor**.

The vector representation of the three parameters are as follows



Fig(1) Vector diagram with leading p.f. Current I leads Voltage by angle ϕ . P.f = Cos ϕ (Lead)



Fig(2) Vector diagram with lagging p.f. Current lags voltage by angle ϕ . P.f = cos ϕ (Lag)

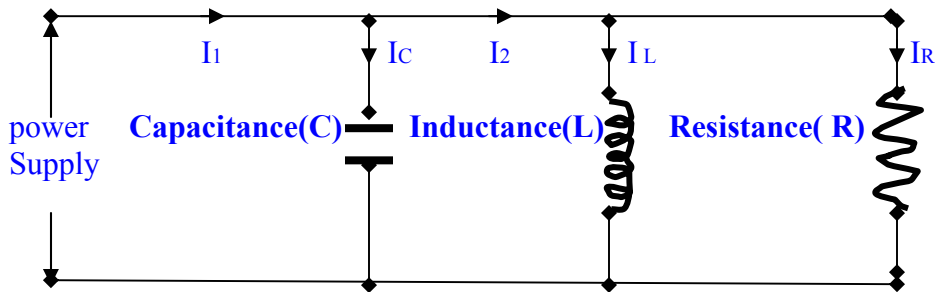
KVA is the vector sum of KW and KVAR. In Fig(1) KVAR is capacitive and in Fig(2) KVAR is inductive and are 180 degree out of phase .

Here the current in phase with KVAR are the reactive currents and are 180 degree out of phase. The current I_r or active current is in phase with active power KW and the supply voltage. The apparent power KVA is in line with the resultant current I_a (Vector sum of I_r and I_c/I_L)

2.3 What is meant by power factor correction?

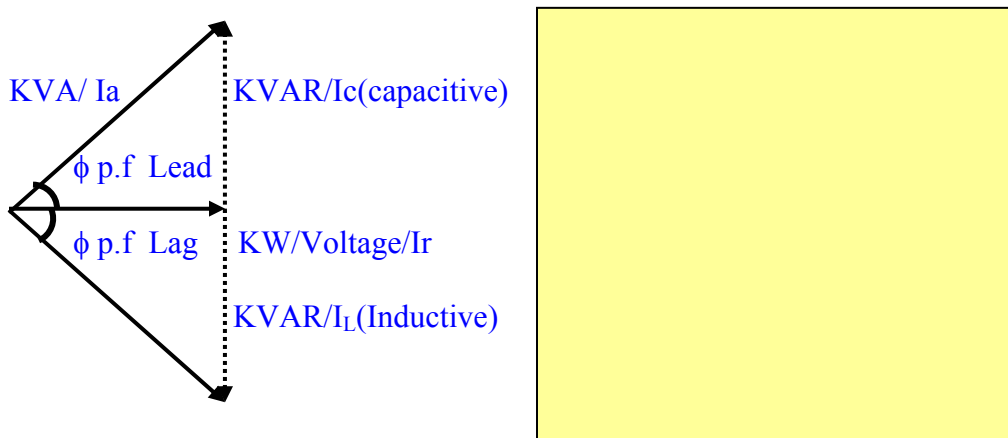
Answer: From the above discussion it is clear that the capacitive and inductive currents are 180 out of phase and hence their effect will be nullified if these two effects are equal and the circuit will behave like a pure resistance circuit with unity power factor. Hence it is clear that the effect of capacitance and inductance could be used to enhance the power factor of a circuit for effective utilization of the available power. The formula for p.f is real /apparent power = KW/KVA

The above discussion could be made clear with the following circuit.



Fig(3) with capacitive , inductive and resistive load

If the inductive and capacitive reactance of the above circuit are equal then the vector diagram would be as follows



Fig(4) Vector diagram showing the effect of inductive and capacitive reactance in a circuit.

In practice we make use of the property of capacitance and inductance to enhance the power factor of a circuit near to unity to utilize the maximum capacity of an

installation for doing useful work and we call this technique as **power factor correction**.

Here $I_1 = I_c + I_L + I_R$ (Vector sum)

Case 1 : If $I_c = I_L$, The capacitive and inductive reactive currents will get cancelled and the circuit will act like a purely resistive circuit with **unity power factor** .

Case 2 : If $I_c < I_L$, The inductive reactive current will dominate over capacitive reactive current and the net current drawn from the supply will be inductive. So the circuit will behave like an inductive circuit with **lagging power factor**.

Case 3 : If $I_c > I_L$, The capacitive reactive current will dominate over inductive reactive current and the net current drawn from the supply will be capacitive. So the circuit will behave like a capacitive circuit with **leading power factor**.

From the above discussion it is clear that by adjusting the value of capacitance and inductance we can achieve the power factor we need to make an electrical system more efficient and economical and this technique is nothing but power factor correction.

3.1 Is power factor correction leads only to reduction in cost of energy to a firm or reduction in both power consumption and cost ?

Answer: It reduces both cost and energy consumption . How?

This is discussed below in detail.

3.2. What is the nature of industrial load and How p.f correction could be made more beneficial or effective to reduce energy bill of a firm?

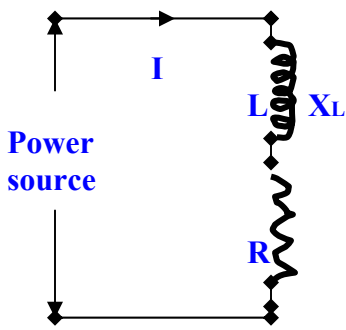
Nature of Industrial loads and p.f correction:-

As far as an industrial plant is concerned there are various types of loads which determines the load power factor either capacitive/inductive or leading /lagging depending on the type of load. Combination of various types of electrical loads in a plant will be as follows

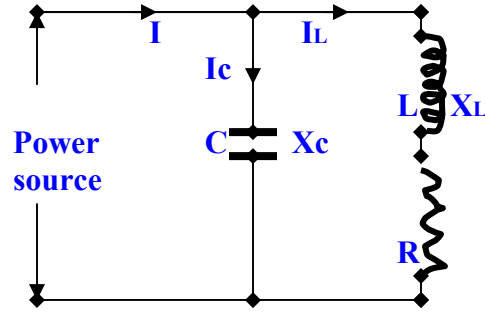
- Lighting load with HPMV,HPSV,CFL.TUBE LIGHTS etc (Inductive)
- Induction motors for various applications like Pumps, Blowers , Air compressors, Air conditioning plants etc (Inductive)

- Welding transformer (Inductive)
- Distribution/Power/lighting Transformers (Inductive)
- Furnaces , UPS, Rectifiers, AC/DC motor drives etc (Inductive)
- Geysers , Oven , Incandescent lamps etc (Resistive)

So from the above it is clear that mostly an industrial unit will be having loads of inductive nature with lagging power factor in the range of 0.5 to 0.8. So to make the electrical system efficient we can put a capacitor across the supply of suitable rating to raise the p.f near to unity in the range of > 0.95 or to achieve the most economical power factor (Discussed later) of a plant. This is made clear with an example below



Fig(5)



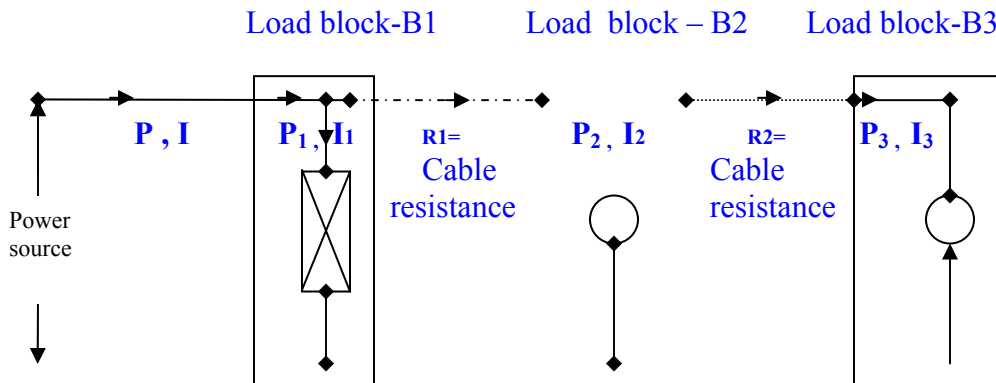
Fig(6)

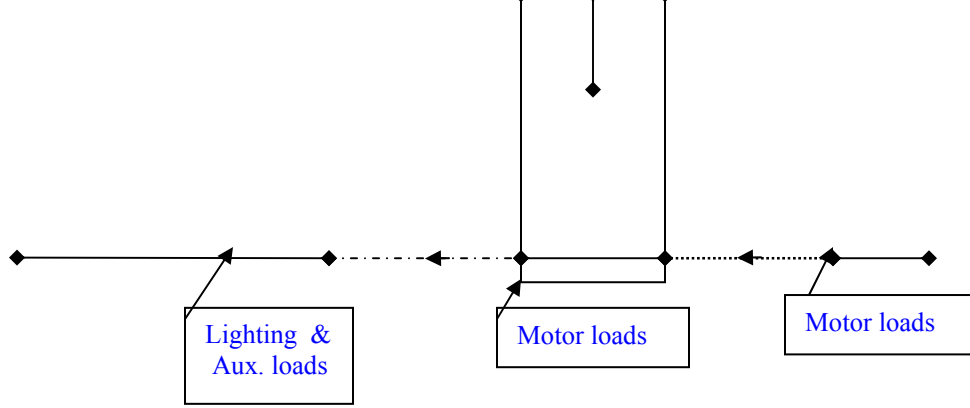
Assume that Fig(5) represents the equivalent circuit of the total loads in a plant which is Inductive in nature or load with lagging power factor. Here the load resistance is R , Inductance is L and Inductive reactance is represented as X_L . Now to improve the power factor of the plant we can use one static capacitor C or reactive power generator to deliver the reactive power requirement of the plant so that power drawn from grid could be eliminated/reduced. This is depicted in Fig(6)

From the above discussion it is clear how power factor correction is playing a decisive role in an industrial plant.

Now our subject of discussion is How p.f correction could be made more beneficial or effective?

Answer is by placing the p.f capacitors near to the load points instead of at supply point. This is explained with circuits as shown in Fig(7) , Fig(8) and Fig(9) below





Fig(7) without p.f correction

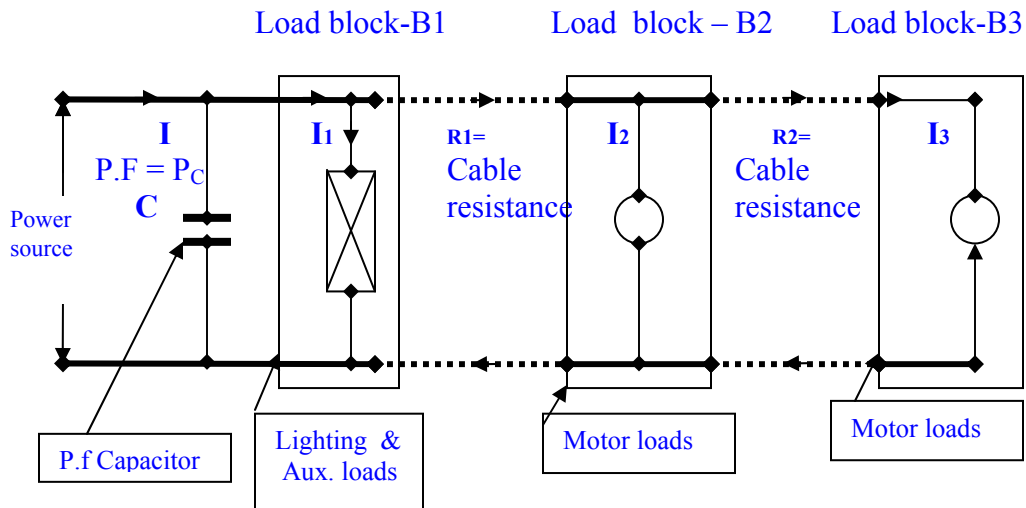
Here Fig(7) shows the equivalent circuit of a plant without p.f correction. Load blocks B_1 , B_2 and B_3 consumes current I_1 , I_2 & I_3 with power factors P_1 , P_2 and P_3 respectively. Here I is the total load current of the plant with power factor P . All three load blocks consists of inductive loads and need p.f correction with static p.f capacitors to improve p.f from P to P_c where P_c is more than P .

Now there are two alternatives for power factor correction

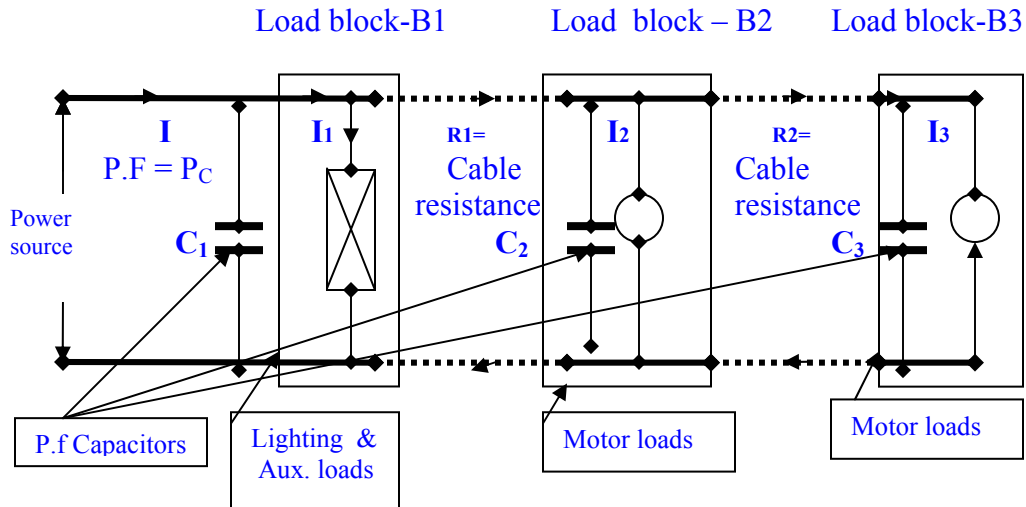
Alternative 1 : To install single p.f capacitor bank at the supply point to improve the overall p.f of power supply from P to P_c . In this case the p.f of individual load blocks will remain the same.

Alternative 2 : To install p.f capacitors bank for individual load blocks at load points so that it will improve the p.f of individual loads as well as that of the plant.

Alternative 1 & 2 are depicted in figures 8 & 9 respectively.



Fig(8) with p.f capacitor bank placed at the power source improving the p.f at the supply point but not that of the total plant.



Fig(9)

Fig(9) represents plant layout with p.f capacitors C_1 , C_2 & C_3 placed at load points improving the p.f at the supply point as well as at load ends improving the p.f of the total plant.

This will lead to reduction in current through the cable lengths between the load centers reducing the resistive losses in the cable network. Normally the cable network losses in a plant will be in the range of 2 to 4%.

To quantify the benefit of p.f correction at load points, assume that the power consumption of a plant is 500 kw without p.f correction. If we take the network losses as 2% of power intake without p.f correction, then the annual savings of electricity would be $500 \times 0.02 \times 24 \times 365 = 87600$ units and financial benefit @Rs4.80/- per unit would be Rs 420480/- which is a substantial amount, adding to the profit of a firm.

In addition to the direct benefit of cost and energy reduction additional benefits of load end power factor correction are summarized below

- It relieves the plant distribution network from carrying reactive currents enabling better utilization of the network resulting in better economy of operation.
- Savings in additional investment in case of expansion projects
- Less investment towards distribution network in case of new plants.
- Better operating voltage at motor terminals resulting in better motor efficiency.
- It reduces the KVA demand of the plant.

3.3. What is the most economical power factor for p.f correction?

Answer: For power factor correction , improving p.f to unity may not be economical as the investment required for the same may be very high in comparison to the return in the form of savings in KVA demand and KWH charges. Hence to find out the most economical power factor at which the plant should operate could be found out by the the following formula

$$\text{Most economical power factor} = \sqrt{1 - (y/x)^2}$$

Where y = The expenditure per KVAR per year of P.F improvement Capacitor

And x = The demand charges per KVA of Grid power.

CASE STUDY (With p.f correction bank at supply point)

The effect of power factor correction at supply point was tested at our ONGC Rajahmundry office complex substation of 2*750 KVA with and without p.f. capacitors and the readings were as follows.

	KW	KVA	P.F
Without capacitor	435	489	0.89
Without capacitor	426	450	0.95

Here without power factor correction the KW consumption was **435 kilowatts** and with p.f correction the KW consumption was **426 kilowatts**. Here for power factor correction , p.f bank of **100 KVAR** was put on the system to improve the p.f from 0.89 to 0.96 based on the following calculation for most economical p.f.

$$\begin{aligned} \text{The economical power factor of a plant} &= \sqrt{1 - (y/x)^2} = \sqrt{1 - (54.15/195)^2} \\ &= \mathbf{0.96 \text{ p.f lag}} \end{aligned}$$

$$\begin{aligned} \text{Hence the theoretical KVAR required} &= \text{KW} (\tan\phi_1 - \tan\phi_2) \\ &= 435 (0.512 - 0.292) \\ &= 435 * (0.22) \\ &= 95.7 \text{ KVAR} \end{aligned}$$

= 100 KVAR(Approx)

After putting the p.f correction bank of 100KVAR the actual value achieved was 426 KW and 450KVA ie the actual power factor achieved was 0.95 instead of 0.96 with a reduction in KW consumption of 435-426 = 9 kw ie a reduction of 2% in KW consumption.

CONCLUSION

From the above case study it is very clear that even with p.f bank at supply end also there is a reduction in KW consumption in the range of 2% . Hence if the p.f correction banks are kept at load points the KW reduction could be reduced further with an overall benefit of KW reduction in the range of 4 to 6 %. The reduction in KW consumption is mainly attributed to the reduction in transformer resistance losses due to reduction in input current and due to better efficiency of motor load at improved terminal voltage due to p.f correction.

Hence from the above discussion it could be concluded that p.f correction will lead not only to cost reduction towards energy by reducing KVA demand but also reduction in KWH consumption of a plant.
