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Improvement of Reactive Power in an Automated Plant: A Technical Survey

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Abstract: **New recommendations and future standards have increased the interest in power factor correction. The paper clearly states the effect of uncorrected electrical loads in a plant and gives the solution to overcome the effect of such harmonics using Power Factor Correction Capacitors.**

Keywords: **Improvement, Reactive Power, Automated Plant, effect, power factor correction.**

I. INTRODUCTION

POWER supplies connected to ac mains introduce harmonic currents in the utility. It is very well known that these harmonic currents causes several problems such as voltage distortion, heating, noise and reduce the capability of the line to provide energy.

In electrical plants the loads draw from the network electric power (active) as power supply source (e.g. personal computers, printers, diagnostic equipment, etc.) or convert it into another form of energy (e.g. electrical lamps or stoves) or into mechanical output (e.g. electrical motors).

To get this, it is often necessary that the load exchanges with the network (with net null consumption) the reactive energy, mainly of inductive type. This energy, even if not immediately converted into other forms, contributes to increase the total power flowing through in the electrical network, from the generators, all along the conductors, to the users.

To smooth such negative effect, the power factor correction of the electrical plants is carried out. The power factor correction obtained by using capacitor banks to generate locally the reactive energy necessary for the transfer of electrical useful power, allows a better and more rational technical-economical management of the plants.

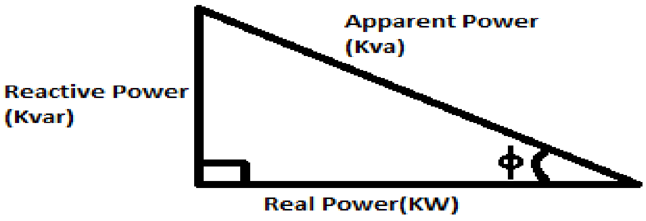
This technical paper has the purpose of analyzing these problems without going into technical details, but, starting from the definition of power factor correction, from an analysis of the technical-economical advantages and describing the forms and modalities to achieve power factor correction, it wishes to guide to the convenient choice of the devices for the switching of the capacitor banks and the filtering of the harmonics.

II. ELEMENTS OF POWER FACTOR

What Is Power Factor?

Power factor is a measure of the relationship between the input voltage and current waveforms to an electrical load that is powered from an AC source. P.F= Real power (Kw)/Apparent power (Kva)

Power Factor Triangle:



$\cos\Phi$=Real power(kw)/Apparent power(Kva)

$P=V*I*\cos\Phi$ (Watts)

P→Reactive power, V→voltage, I→current

$\cos\Phi=P/V*I$ (Power factor is an inverse proportion with Current)

- So, we have to reduce the reactive current that is mainly due to the magnetic field that arises because of inductive components, now this reactive current tends to decrease the power factor.
- Hence power factor correction banks are installed on LV side of transmission. Mainly capacitors are banked Parallel to the mains.

III. POWER FACTOR CALCULATIONS

AC power flow has three components: real power (also known as active power) (P), measured in watts (W); apparent power (S), measured in volt-amperes (VA); and reactive power (Q), measured in reactive volt-amperes (var).

The power factor is defined as:

P/S

In the case of a perfectly sinusoidal waveform, P, Q and S can be expressed as vectors that form a vector triangle such that:

$$S^2=P^2+Q^2$$

If φ is the phase angle between the current and voltage, then the power factor is equal to the cosine of the angle, **COSφ** , and

$$|P|=|S|\mathrm{COS}\varphi$$

Since the units are consistent, the power factor is by definition a dimensionless number between −1 and 1.

When power factor is equal to 0, the energy flow is entirely reactive, and stored energy in the load returns to the source on each cycle.

When the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle. Capacitive loads are leading (current leads voltage), and inductive loads are lagging (current lags voltage).

If a purely resistive load is connected to a power supply, current and voltage will change polarity in step, the power factor will be unity (1), and the electrical energy flows in a single direction across the network in each cycle.

Inductive loads such as transformers and motors (any type of wound coil) consume reactive power with current waveform lagging the voltage.

Capacitive loads such as capacitor banks or buried cable generate reactive power with current phase leading the voltage. Both types of loads will absorb energy during part of the AC cycle, which is stored in the device's magnetic or electric field, only to return this energy back to the source during the rest of the cycle.

Electrical loads consuming alternating current power consume both real power and reactive power. The vector sum of real and reactive power is the apparent power. The presence of reactive power causes the real power to be less than the apparent power, and so, the electric load has a power factor of less than 1.

A negative power factor (0 to -1) can result from returning power to the source, such as in the case of a building fitted with solar panels when their power is not being fully utilised within the building and the surplus is fed back into the supply.

IV. ADVANTAGES OF POWER FACTOR CORRECTIONS

- Better utilization of electrical machines
- Better utilization of electrical lines
- Reduction of losses
- Reduction of voltage drops

TABULATION RESULT

POWER OF THE TRANSFORMER IN kVA	**POWER OF THE TRANSFORMER IN kW**					
	COSφ					
	0.5	0.6	0.7	0.8	0.9	
100	50	60	70	80	90	100
160	80	96	112	128	144	160
200	100	120	140	160	180	200
250	**125**	**150**	**175**	**200**	**225**	**250**

NOTE: When the power factor is unity the real power utilization of the transformer tends to be highest.

CALCULATION

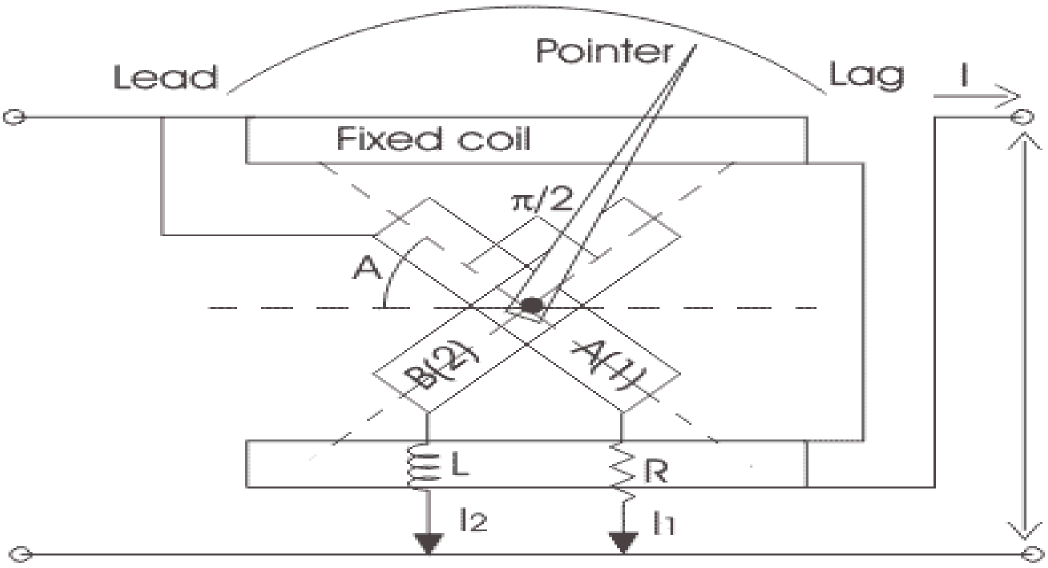
cosΦ*kva=Kw → Kva=Kw/cosΦ

For, 0.7pf → Kva=175/0.7 →250Kva

For,0.9pf→ Kva=175/0.9→200Kva

- From the above calculation it is clear that 50kva is saved by correcting the power factor near unity
- Every plant has to setup the capacitor banks in-order to reduce the reactive current.

V. ELECTRODYNAMO TYPE POWER FACTOR METER



Now the pressure coil is spitted into two parts one is purely inductive another is purely resistive as shown in the diagram by resistor and inductor. At present the reference plane is making an angle A with coil 1. And the angle between both the coils 1 and 2 is 90°. Thus the coil 2 is making an angle (90°+A) with the reference plane. Scale of the meter is properly calibrated shown the value values of cosine of angle A. Let us mark the electrical resistance connected to coil 1 be R and inductor connected to coil 2 be L. Now during measurement of power factor the values of R and L are adjusted such that R=wL so that both coils carry equal magnitude of current. Therefore the current passing through the coil 2 is lags by 90° with reference to current in coil 1 as coil 2 path is highly inductively in nature

VI. GENERATION MEANS OF REACTIVE POWER

The main means for the generation of reactive power are:

- synchronous alternators
- synchronous compensators (SC)
- static var compensators (SVC)
- Banks of static capacitors.

Synchronous Alternators

Synchronous alternators are the main machines used for the generation of electrical energy. They are intended to supply electrical power to the final loads through transmission and distribution systems. Besides, without going into technical details, by acting on the excitation of alternators, it is possible to vary the value of the generated voltage and consequently to regulate the injections of reactive power into the network, so that the voltage profiles of the system can be improved and the losses due to joule effect along the lines can be reduced.

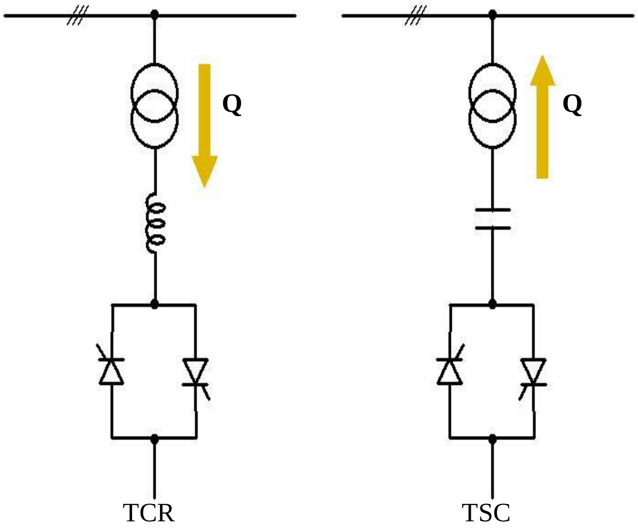
Static Var Compensators

The considerable development of power electronics is encouraging the replacement of synchronous compensators with static systems for the control of the reactive power such as for example TSC *(thyristor switched capacitors)* and TCR *(thyristor controlled reactors)*. These are an electronic version of the reactive power compensation systems based on electromechanical components in which, however, the switching of the various capacitors is not carried out through the opening and closing of suitable contactors, but through the control carried out by couples of anti parallel tyristors

TSC allow a step-by-step control of the reactive power delivered by groups of capacitors, whereas with TCR a continuous control of the reactive power drawn by the inductors is possible.

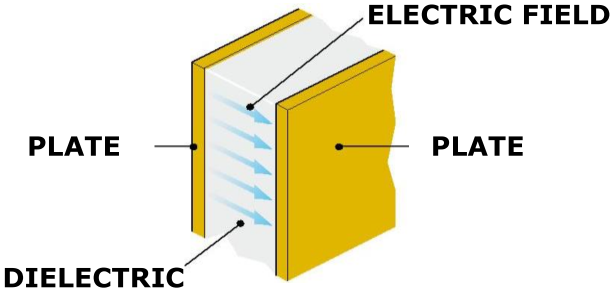
By coupling a TSC with a TCR it is possible to obtain a continuous modulated regulation of the delivered/drawn reactive power.

From the point of view of applications, these devices are used above all in high and very high voltage networks



BANKS OF STATIC CAPACITORS

A capacitor is a passive dipole consisting of two conducting surfaces called plates, isolated from one another by a dielectric material



The system thus obtained is impregnated to prevent the penetration of humidity or of gas pockets which could cause electrical discharges.

The last generation capacitors are dry-type and undergo a specific treatment which improve their electrical characteristics. Using dry-type capacitors there is no risk of pollution because of the incidental leak of the impregnating substance

VII. TYPES OF POWER FACTOR IMPROVEMENT

Capacitor power factor improvement:

This is a simple method of providing power factor improvement. It is often applied to areas where machines using electric motors are used. These motors are inductive. Applying a capacitor neutralizes the power factor error.

Often these systems monitor the power factor and switch in further reactance (capacitive) to provide the required power factor improvement

- ***Load type:*** Capacitors are used to provide linear load power factor improvement. The capacitors are only able to provide a change in phase and are not able to cater for the issues surrounding non-linear loads.
- ***Capacitive & inductive reactance cancel:*** For the system to work correctly the capacitive reactance must cancel out the inductive reactance. This may require banks of capacitors to be switched to enable the power factor improvement to be in place as the load varies and the power factor changes.
- ***Beware instability:*** The situation of capacitive and inductive reactance cancelling out equates to resonance of a tuned circuit. Care smut be taken when deigning these systems to ensure instability does not arise.
- ***Applicability:*** This form of power factor improvement is normally applied to large workshops using electrically driven machines and other similar situations.

Synchronous motor power factor improvement:

The use of synchronous motors is another method of providing power factor improvement. The motors are run without a load and are able to provide the capacitive load required to ensure the power factor is improved.

This form of power factor improvement operates because the reactive power drawn by the synchronous motor is a governed by its field winding excitation. This can be altered to provide a variable capacitive load.

This type of load factor correction has now generally been superseded by other solid state methods.

- ***Load type:*** This type of power factor correction is only applicable to linear loads such as motors and other inductive components. It does not accommodate non-linear loads such as electronic power supplies.
- ***Large motor required:*** For this system to work, the motor must be running all the time. It is run in a non-loaded fashion to give the capacitive reactance required.
- ***Motor expense:*** Synchronous motors are not cheap and the capital cost needs to be remembered when considering this option.
- ***Limited motor life:*** As the synchronous motor needs to be run continuously it requires maintenance and also has a limited useful life. Both items add costs to this solution.

Filter power factor improvement:

Filtering the input signal to remove harmonics is a method used to provide power factor improvement. Removing harmonics generated at the input can aid the input signal to return to a better power factor. As harmonics will be at multiples of the line input frequency, a filter can be devised with a cut-off just above the line frequency to give sufficient attenuation of the harmonics to return the waveform to an acceptable form.

- ***Load type:*** This form of power factor correction is used with non-linear loads which might be electronic power supplies. The scheme only removes the harmonics of the signal to return it to a sine wave format.
- ***Performance:*** This form of power factor improvement is easier to achieve than other forms of non-linear load power factor correction, but it is not as effective as active power factor improvement.
- ***Size:*** As frequencies are low, and line input voltages often high, component sizes are large.
- ***Cost:*** The inductors and capacitors needed for a low frequency filter are large and hence costly
- ***Worldwide operation:*** A filter to provide power factor improvement for worldwide operation is difficult to configure because line frequency varies between 50 and 60 Hz and also voltages may change.

Active boost power factor improvement:

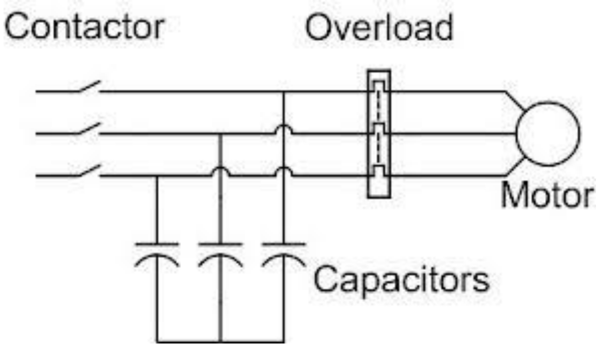
This form of power factor correction or improvement uses active circuitry in the form of a switch mode power supply boost circuit. By controlling the times when charge can be applied to a reservoir capacitor, the input current can be maintained in synchronization with the voltage.

- ***Load type:*** This form of power factor correction is used with non-linear loads.
- ***Application:*** This scheme can be accommodated relatively easily within the power supplies of small computers. As circuitry is already present for a switch mode power supply, the power factor improvement circuitry can be incorporated relatively easily and without an unacceptable cost increase.
- ***Performance:*** This form of power factor improvement is accepted as being the most effective for non-linear loads.

Each type of power factor improvement or correction has its own advantages and disadvantages. These factors must be taken into account when choosing the optimum form of load factor improvement.

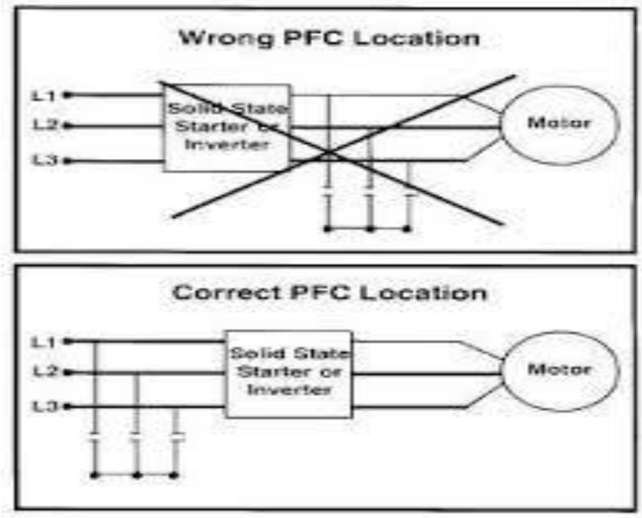
VIII. CIRCUIT IMPLEMENTATION OF POWER CAPACITOR

TYPE 1



- ➢ Here the power capacitor is placed in midway of overload relay and contactor. Now when the contactor coil gets energized the capacitor starts charging and discharging and the current required by the motor coil is supplied by the capacitor and thereby reducing the effect of reactive current form the mains.
- ➢ The capacitor can be connected in other way on the motor side means connect the capacitor after the overload relay unit. Now the motor behaves as generator if power goes off then the current is supplies via capacitor. From this it is clear that motor acts as a generator.
- ➢ Please ensure that motor has a startup capacitor otherwise addition of more capacitor becomes a problem. Leading power factor draws extra current from the mains. So be careful to add capacitor to the circuits.

TYPE 2



- In typical DOL situations, some installations will have a fixed KVAR value of capacitors sized to counteract the motors inductive reactance hence increase the power factor on the supply line.
- Be cautious when replacing DOL components with a VSD– if there are PF correction capacitors connected to the motor remove them as premature damage to the inverter and motor will occur due to the high frequency switching voltage occurring on the output of the inverter. Most capacitors are not designed to withstand the high switching currents produced by VSD's.
- Adding excess amount of capacitors turns into load and they tends to pull extra power from the mains and increase the current consumption. So it is always good if we maintain unity power factor.

IX. POWER FACTOR CALCULATION FOR SINGLE TARGET MOTOR

For 3Φ induction motor

$$Kvar_{(req)}=\frac{hp\times 0.746}{\%EFF}\left[\frac{\sqrt{1-pfa^2}}{pfa}=\frac{\sqrt{1-pft^2}}{pft}\right]$$

- Pfa→power factor actual
- Pft→power factor target
- %EFF→Efficiency of motor
- Hp→horse power rating

Assume, 3Φ,3hp motor,83.4%EFF,pfa=.65

$Kvar_{(req)}=\frac{3\times 0.746}{0.834}\left[\frac{\sqrt{1-0.65^2}}{0.65}\right]$→2.9kvar compensation required

When we increase the power factor by 0.9 then kvar rating is decreased

$Kvar_{(req)}=\frac{3\times 0.746}{0.834}\left[\frac{\sqrt{1-0.9^2}}{0.9}\right]$→1.3 kvar compensation required

X. POWER FACTOR CALCULATION FOR PLANT

All the power factor values are obtained from the standard power factor data sheet.

Assume plant consumes 410kW, 0.73pf, for 0.95pf Kvar=?

Step 1→Get the multiplier for 0.95pf from datasheet.

Step 2→Multiply the factor with Real power (kW)

So, form the data sheet it is clear that for 0.95pf→0.607

kVAR=410×0.607=250kVAR

It is clear that 250kVAR is required to correct the pf to 0.95

CALCULATION OF EB BILLS IN A PALNT

Main Aim of increasing the power factor is to reduce the EB cost in an economical way.

Assume uncorrected load of 460kVA(Demand) at 480V,3Φ,at 0.87 pf

Correction to 0.95pf ? pf→Power factor

Assume Slab/kVA=35RS

kVA×pf=kW→[460×0.87=400kW]

$\text{kVA}=\frac{\text{kW}}{\text{pf}}=\frac{400}{0.97}=412\text{kVA(Corrected)}$

For rise from 0.87 to 0.95 the multiplier is 0.316

0.316×400=126kVAR(use 140 kVAR) to correct the EB Bill

BILLING UNCORRECTED LOAD

460kVA×35=16100 Rs

Saving/Month=1680 Rs

BILLING CORRECTED LOAD

412×35=14420 Rs

Annual savings

1680×12=20160 RS

XI. RESULT

This survey clearly shows that the power in the industry can be corrected to the best level by installing proper amount of power capacitors in the LV side of the transmission with proper discharge resistance mounted on its terminals. By doing so we can able to reduce the amount of kVAr demand and thereby reducing the Electricity Bills.

NOTE: The capacitors should be added with prior calculations if we add excess amount then the Result will leads to leading power factor.

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