POWER FACTOR CORRECTION

“A COMPONENT OF NHP’s GREEN STAR SOLUTION…”
Power Factor - What does it mean?

Where open electricity markets have been introduced, the supply of electrical energy becomes competitive between the supply utilities. Although private distribution companies are obligated to run a profitable and successful business, they are also committed to maintain the quality of supply at a high level. Competition in an open electricity market creates new opportunities for even better quality of supply of electricity.

One very important aspect of improving quality of supply is the control of power factor. Low power factor means poor electrical efficiency. The lower the power factor, the higher the apparent power drawn from the distribution network. This means that the supply company must install larger generation capacity, larger size transmission lines and cables, transformers and other distribution system devices, which otherwise would not be necessary. This results in a much higher capital expenditures and operating costs for the Electricity Supply Company, which in many cases is passed on to the consumer in the form of higher tariff rates.

This is the main reason behind why the Electricity Supply Companies in modern economies demand reduction of the reactive load in their networks via improvement of the power factor. In most cases, special reactive current tariffs penalize consumers for poor power factors.

Electrical load types

Loads on an electrical distribution system can be categorized as resistive, inductive and capacitive. Under normal operating conditions certain electrical loads (e.g. transformers, induction motors, welding equipment, arc furnaces and fluorescent lighting) draw not only active power (kW) from the supply, but also inductive reactive power (kVAr).

All inductive loads require active power: kW to actually perform the work, and reactive power (kVAr) to maintain the electromagnetic field. This reactive power is necessary for the equipment to operate but it imposes an undesirable burden on the supply.

No Power Factor Correction

\[ \cos \theta = 0.75 \]

1000 kW Inductive load

Power utility supplying true and reactive power to consumption

With Power Factor Correction

\[ \cos \theta = 0.95 \]

1000 kW Inductive load

Power utility supplying true and reduced reactive power only after capacitor bank installed. Reactive energy now supplied by capacitors

Capacitor bank compensating 553 kVAr
The power factor of a load is defined as the ratio of active power to apparent power, i.e. kW divided by kVA and in mathematical terms is referred to as cos Ø. The closer cos Ø is to unity, the less reactive power is drawn from the supply. Power Factor (cos Ø) = Active Power (kW) / Apparent Power (kVA).

Harmonics
The presence of harmonics in the waveform of the network voltage can be attributed to various causes such as rectifiers, variable speed drives, thyristors, saturated transformer, arc furnaces, etc.

The main problems caused by harmonics are:
- Interferences in telecommunications systems and equipment.
- Distortion of the Electricity Supply Voltage
- Erratic operation of control and protection relays
- Failures in transformers and motors due to overheating caused by core losses.

If the harmonic power is significant, i.e. THVD greater than 7 %, THID greater than 40 %, this may result in overvoltages and overloads, which may lead to the failure of the capacitors, circuit breakers, contactors etc.

Resonance
Amplification of both voltage and current at the same time will occur if the resonant frequency is close or equal to one of the harmonic frequencies present in the distribution system.

The power feeder (overhead line or underground cable) have an inductive impedance. By putting a capacitor in parallel with the load (for Power factor correction) it is possible for the combined system to have a resonance condition.

Cable Losses
As the power factor of a three phase system decreases, the current rises. The heat dissipation in the system rises proportionately by a factor equivalent to the square of the current rise.

Please refer to the Cost Savings of a Power Factor Correction Unit to see how the above example works in with a practical situation.
Power Factor Correction and Variable Speed Drives

As a general rule, standard power factor correction systems should not be used when there are Variable Speed Drives (VSD’s) connected to the same point of connection unless some precautions are taken.

Two situations arise when using power factor correction systems:

1. Installation of the power factor correction between the VSD and the motor, and
2. Installation of the power factor correction on the line side of the VSD

In the first case, power factor correction should not in any case be connected between the output of the VSD and the motor. 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.

In the second case, power factor correction can be installed on the line side of the VSD but only under certain conditions. In all cases, VSD’s produce a certain level of harmonic distortion back into the main supply. This harmonic distortion is in the form of both THID (total harmonic current distortion) and THVD (total harmonic voltage distortion) and the levels of this THD is dependant upon the size of the drive, the supply transformer impedances, short circuit levels, primary and secondary voltage levels plus cable lengths and cable size.

Because of the inherent harmonic distortion produced by the VSD’s, the capacitors within power factor correction equipment will cause any THD to be amplified which results in higher voltage impulses applied to the input circuits of the inverter and the energy behind the impulses is much greater due to the energy storage of the capacitors. This will in turn prematurely damage the input rectifier of the VSD causing costly repairs.

In addition, the increased current and voltage transients on the line side are passed back through the PFC capacitors causing increased operating voltage and current, which produces higher operating temperatures and may cause premature failure of the capacitors.

By reducing the effects of THVD and THID through the use of input reactors, harmonic filters, active harmonic filtering on the line side of the VSD or using a 12-pulse rectifier (or even better an Active Front End solution), this reduces the effect of the transient impulses which can damage both the VSD and the PFC capacitors. Ensure that the capacitors used in the PFC system have a harmonic tolerance level greater than the harmonic distortion produced by the VSD installation.

Power Factor Correction and Soft Starters

Individual or ‘Static’ power factor correction capacitors can be used with soft starters provided they are installed on the input side of the soft starter and switched via a dedicated contactor only after the motor has reached full speed. The contactor should be AC6 rated for the motor full load current.

Automatic or ‘Bulk’ power factor correction systems make use of a power factor controller to monitor changing power factor and automatically switch capacitors as needed. When used with a soft starter the automatic switching of capacitors should be inhibited until the motor is running at full speed.

When a soft starter is installed in close proximity to a power factor correction capacitors (less than 50m) and used without a main contactor, the switching of capacitors whilst the soft starter is not passing motor current can also lead to premature starter failure.

The use of a main contactor is therefore recommended when:

- Multiple soft starters are installed along with static power factor correction capacitors.
- A soft starter is installed along with a bulk power factor correction system.

Connecting power factor correction capacitors to the output of a soft starter will cause equipment failure due to severe over voltage. This over voltage is created by resonance between the inductance of the motor and the power factor capacitance.
Solutions

Power factor correction capacitors
A poor power factor can be improved by adding power factor correction capacitors to the plant’s distribution system. Correction capacitors provide needed reactive power (kVAr) to the load. Therefore, the Electricity Supply Company is freed from having to supply it.

Power factor correction capacitors reduce the total current supplied by the Electricity Supply Company to the load and as a result the distribution system capacity is increased.

Capacitor ratings
Power factor correction capacitors are rated in electrical units called “VAr”. One VAr is equivalent to one volt-ampere of reactive power. VAr is the unit of measurement for indicating just how much reactive power the capacitor will supply.

Filter reactors
In most cases it is necessary to reduce the effects of the harmonic currents. One way of reducing harmonic currents is to install an inductance (filter reactor) in series with the capacitor.

The filter reactors protect the electrical installations and equipment but it does not eliminate the harmonics.

The reactor value should be calculated and designed in order to reduce the resonant frequency of the circuit to a value lower than that of the lowest harmonic in the system.

A capacitor equipped with a filter reactor is protected from harmonics regardless of the layout of the network to which it is connected. Except in some cases when switching in steps the inductance and capacitance values could add up to equal one of the harmonic frequencies in the system causing resonance.

Power loss reduction
Distribution system losses are also reduced through power factor correction by reducing the total load current in the system.

Voltage improvement
Power factor capacitors decrease distribution system voltage drops and fluctuations during the start of large inductive loads.

Where should the power factor correction equipment be installed
After determining the required size capacitor in kVAr, the next step is to decide on the location for installation of the capacitor bank.

It is difficult to set definite guidelines for location of capacitor installation. However, the following general rule should be kept in mind: As close as possible to the load to be compensated.
Reactive compensation systems

Centralised compensation
Centralised compensation by means of an automatic capacitor bank with automatic regulation offers the most simple and economical solution.

The reactive power is subdivided in a number of capacitor steps that can be connected independently. A reactive power controller continuously measures the needs of the installation and connects or disconnects the capacitors until the target power factor is achieved.

The advantage of this system is that the total capacitor power is smaller than the sum needed for individual compensation. Therefore this system is a good economical solution.

Group compensation
Several inductive loads can be grouped together and equipped with a common capacitor bank. This system usually applies for users that have their own installations with distribution transformers and high voltage power lines/cables.

The reactive power that is consumed by the transformers is compensated by the permanently connected capacitors to the secondary side of the transformers.

Individual compensation
This type of compensation is applied to motors, transformers, and in general to loads with a high time of operation.

Capacitors are directly connected in parallel to the terminals of the loads.

This system minimizes the reactive current circulating through the installation, enabling the use of smaller switchgear and power lines or cables, which means a lower capital expenditure for new installations.

In the case of existing installations, utilising capacitors for power factor correction will increase the maximum apparent power that can be supplied to the installation. However great care must be taken in selecting the size of capacitor because of the risk of self excitation of the electric motor.

Power factor correction control relay
When selecting a power factor correction relay the following main functions should be considered:

• Measurement of the required reactive power and control the capacitor switching according to the power factor desired or pre-set value.

• Indication of power factor, preset parameters and specified installation data.

• Disconnect the capacitors when a system voltage drop occurs, this will prevent significant overvoltages in the installation and the subsequent damage to switchgear insulation.

• Allow manual control.

• Provision for a visual display of signal lamps for monitoring the number of capacitors steps switched into the system.

• Possible implementation into a building management system.
**Maintenance of capacitor banks**

Maintenance of a capacitor bank doesn’t require much time or energy. However it is important that regular inspections be carried out. This will help prevent early failure and pick up any fault. An inspection routine would include the following:

- Check and clean filters
- Ensure tightness of all electrical connections
- Ensure all fuses are not damaged
- Ensure all discharge resistors are operational
- Ensure all contactors are operational
- Remove all dust and deposit buildup
- Tong test capacitor current

**Cost savings of a power factor correction unit.**

Power factor correction is an investment that helps to improve company’s profit performance.

NSW, WA, and Victoria have existing penalty structures in place for customers that operate on a poor power factor.

The following is an example to illustrate the savings by installing power factor correction equipment.

Let us assume that the penalty is 37.57 cents per day per kVAr, for the kVAr necessary to improve the power factor to 0.95 lagging.

1000 kW load at a PF of 0.75 = 882 kVAr
1000 kW load at pf of 0.95 = 329 kVAr

The extra kVAr drawn from the supply is:

882 kVAr – 329 kVAr = 553 kVAr

553 x 37.57 = $207.76 penalty per day

Assume the Power factor correction unit will cost installed about $60 per kVAr

Therefore 600 kVAr x $60 = $36,000

Payback period = $36,000 divided by $207.76 = 173 days or about five to six months.

In about 5 to 6 months the cost for power factor correction is recovered and any further penalties are avoided for the life of the electrical installation.

Any further savings then become profits that add to the company’s bottom line.

**Note:** This example is for illustration purposes only. Actual savings will vary from installation to installation.
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