Reduce electricity costs and free up capacity

By E Solot, Alpha Power Solutions

Power factor correction – how it can benefit industrial and commercial businesses in terms of savings in electrical energy costs as well as the freeing up of electricity supply capacity.

Until fairly recently, the return on investment for power factor correction equipment, in commercial and industrial applications, was unacceptably long for most companies.

Avoidance of wasteful electricity demand and consumption was not given the attention it deserves and energy efficiency has only very recently become a strategic objective. The significant electricity tariff increases introduced in recent years, have made investments in power factor correction very attractive for most commercial and industrial consumers.

What is power factor?

Power factor (also referred to as cosine phi) is the ratio between the active load power (kW) and the apparent load power (kVA) drawn by an electrical installation. It is a measure of how effectively the current drawn by the load is being converted into useful work output.

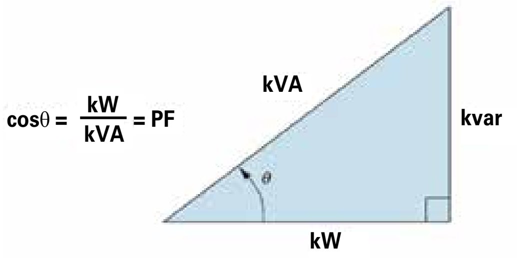

Figure 1: Power triangle

All current will cause losses in supply and distribution systems. A load with a power factor of 1,0 results in the most efficient loading of the supply and a load with a power factor of 0,5 will result in much higher losses in the supply system. A poor power factor can be the result of a significant phase difference between the voltage and current at the load terminals.

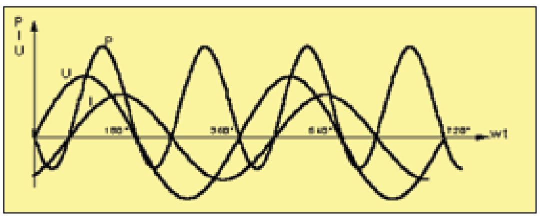

Figure 2: Phase angle.

Poor load current phase angle is generally the result of an inductive load such as an induction motor, power transformer, lighting ballasts, welder or induction furnace.

A poor power factor due to an inductive load can be improved with the addition of power factor correction. A poor power factor can also be caused by a high harmonic content or distorted/discontinuous current waveform. A distorted current waveform can be the result of a rectifier, variable speed drive, switched mode power supply, discharge lighting or other electronic load. The power factor of a load with a distorted current waveform requires a change in equipment design or expensive harmonic filters to gain an appreciable improvement.

Power factor correction of inductive loads

An inductive load, such as a motor, draws current from the supply, which is made up of resistive components and inductive components.

The resistive components are:

- Loss current (small)
- Load current

The inductive components are:

- Leakage reactance current (small)
- Magnetising current

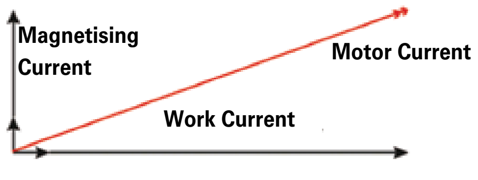

Figure 3: Current vectors.

The current due to the leakage reactance is dependent on the total current drawn by the motor, but the magnetising current is independent of the load on the motor. The magnetising current will typically be between 20% and 60% of the rated full load current of the motor.

The magnetising current is the current that establishes the flux in the iron and is very necessary if the motor is going to operate. The magnetising current does not actually contribute to the actual work output of the motor.

It is the catalyst that allows the motor to work properly. The magnetising current and the leakage reactance can be considered passenger components of current that will not affect the power drawn

by the motor, but will contribute to the power dissipated in the supply and distribution system. In the interest of reducing the losses in the distribution system, power factor correction is added to neutralise a portion of the magnetising current of the motor. Typically, the corrected power factor will be above 0,95. Some municipalities penalise consumers with a poor power factor by charging them for excessive kvarh consumed (> 30% of kWh consumed during the same period) and by doing so encourage them to reduce wasted energy by applying power factor correction.

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and can be applied at the motor (static power factor correction), or applied at the distribution panel (bulk power factor correction). The resulting capacitive current is a leading current and is used to cancel the lagging inductive current flowing from the supply to the inductive load.

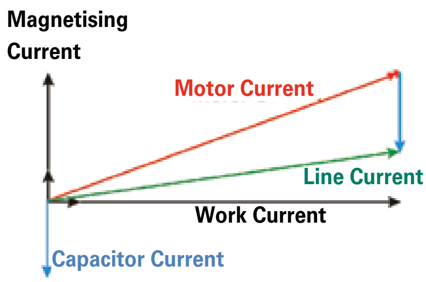

Figure 4: Power factor correction current vectors.

Bulk power factor correction

When bulk power factor correction is applied, the power factor of the total current supplied to the distribution board is monitored by a controller which then automatically switches capacitor banks in a fashion to maintain a power factor better than a preset limit (typically between 0,95 and 0,98).

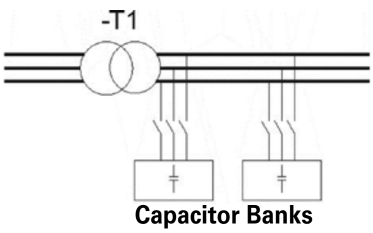

Figure 5: Bulk power factor correction.

Ideally, the power factor should be as close to unity as possible. There is no problem with general correction operating at unity (even though this is usually not the most cost effective target power factor), but correction should not be applied to an unloaded or lightly loaded transformer. If correction is applied to an unloaded transformer, you create a high Q resonant circuit between the leakage reactance of the transformer and the capacitors and destructive high voltages can result.

Static power factor correction

As a large proportion of the inductive or lagging current on the supply is due to the magnetising current of induction motors, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters.

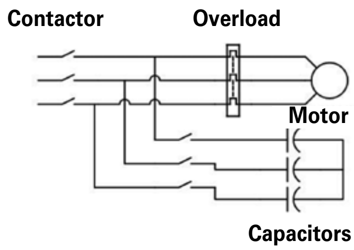

Figure 6: Static power factor correction.

With static correction, it is important that the capacitive current is less than the inductive magnetising current of the induction motor. In many installations employing static power factor correction, the correction capacitors are connected directly in parallel with the motor windings. When the motor is off line, the capacitors are also off line.

When the motor is connected to the supply, the capacitors are also connected providing correction at all times that the motor is connected to the supply. This removes the requirement for any expensive power factor monitoring and control equipment.

Power factor correction and harmonics

Harmonics are caused by many non linear loads, the most common in the industrial market today, are the variable speed controllers and switch-mode power supplies.

Harmonics cause a higher current to flow in the capacitors of a power factor correction installation because the impedance of the capacitors goes down as the frequency goes up. This increase in current flow through the capacitor will result in additional heating of the capacitor and reduce its life. Harmonic voltages can be reduced by the use of a harmonic compensator, which is essentially a large inverter that cancels out the harmonics and is an expensive option. Passive harmonic filters comprising resistors, inductors and capacitors can also be used to reduce harmonic voltages but this is also an expensive exercise.

In order to reduce the damage caused to the capacitors by the harmonic currents, it is becoming common today to install detuning reactors in series with the power factor correction capacitors. These reactors are designed to make the correction circuit inductive to the higher frequency harmonics. Typically, a reactor would be designed to create a resonant circuit with the capacitors above the third harmonic. Adding the inductance in series with the capacitors will reduce their effective impedance at the supply frequency. Reducing the resonant or tuned frequency will reduce the effective impedance further. The object is to make the circuit look as inductive as possible at the 5th harmonic and higher, but as capacitive as possible at the fundamental frequency.

Examples of power factor correction

Assume an active load of 100 kW and an associated apparent power of 142 kVA, resulting in a power factor of 0,70.

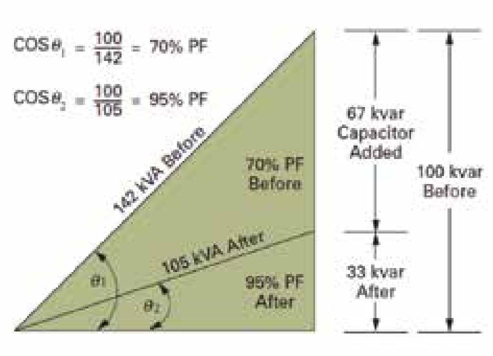

Figure 7: Apparent power before and after adding capacitors.

By reducing the reactive power to 33 kvar (by means of a 67 kvar power factor correction panel), the power factor improves to 0,95 and the apparent power decreases to 105 kVA. The reduction of apparent power (37 kVA) not only results in financial benefits to the consumer (reduction in maximum demand and associated costs) but also a reduction in heat losses of the system

Benefits of power factor correction

Reduced electricity costs

Eskom provides working (kW) and reactive power (kvar) in the form of apparent power (kVA). While reactive power (kvar) does not register on kW demand or kW hour meters, Eskom's transmission and distribution system must be large enough to provide the total power. Eskom and the municipalities have various ways of passing along the expense of larger generators, transformers, cables, switches, etc to the consumer. A reduction in apparent power results in a reduction in electricity costs.

Reduced losses

Losses caused by poor power factor are due to reactive current flowing in the system. These are watt-related charges and can be eliminated through power factor correction. Power loss (watts) in a distribution system is calculated by squaring the current and multiplying it by the circuit resistance (I^2R).

Increased system capacity

Power factor correction capacitors increase system current-carrying capacity. Raising the power factor on a kW load reduces kVA. Therefore, by adding capacitors, additional kW load can be added to a system without altering the kVA.

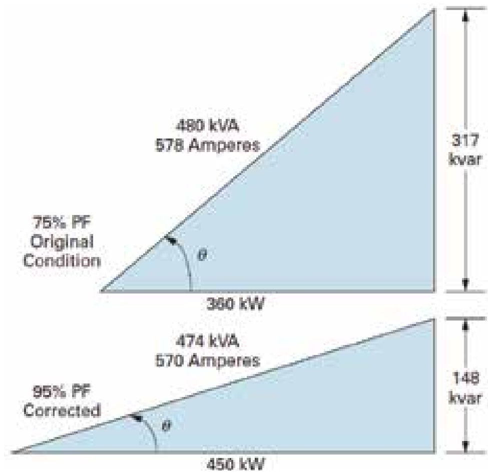

Figure 8: Power factor correction increases transformer output.

Improved voltage conditions

Low voltage, resulting from excessive current draw, causes motors to be sluggish and overheated. As power factor decreases, total line current increases, causing further voltage drop. By adding capacitors to an installation and improving the system voltage, motor efficiency, life and performance is improved.

Industries benefiting most from power factor correction

Low power factor results when inactive motors are operated at less than full load. This often occurs in cycle processes - such as those using circular saws, ball mills, conveyors, compressors, grinders, punch presses, etc - where motors are sized for the heaviest load.

Examples of situations where low power factor (from 30% to 50%) occur include a surface grinder performing a light cut, an unloaded air compressor and a circular saw spinning without cutting.

The following industries typically exhibit low power factors:

Industry	Uncorrected power factor
Saw Mills	45 – 60%
Plastic (especially extruders)	55 – 70%
Machine tools, stamping	60 – 70%
Plating, textiles, chemicals, breweries	65 – 75%
Hospitals, granaries, foundries	70 – 80%

Table 1: Typical industries with low power factor.

Factors influencing investment payback periods for power factor correction equipment

Each electrical installation is unique and the required investment in power factor correction equipment as well as the associated payback period is influenced by the following factors:

- **Uncorrected power factor:** The worse the uncorrected PF, the shorter the payback period of the investment in PFC equipment
- **Requested target power factor:** If the end-user insists on achieving a PF of 1 under peak load conditions (rather than 0,96 – 0,98), this will have a significant impact on the total investment required as well as the associated payback period
- **Current and voltage harmonics present in the installation:** If the harmonic levels are excessive, blocking reactors will have to be fitted in the PFC panel, which increases the investment costs, without there being a direct saving in maximum demand
- **Load changes:** Pulse loads (for example large spot welding machines required for the manufacturing steel meshing) require thyristor controlled PFC equipment, which has a negative impact on the total investment required
- **Unbalanced loads:** Large single phase loads in a 3-phase installation - such as large single phase welding machines - require single phase thyristor controlled PFC, which has cost implications
- **Installation constraints:** Installation costs can represent a significant portion of the total investment in PFC equipment, especially for smaller installations of less than 150 kvar. Factors influencing the total installation costs are:
  - o Labour (manhours and travel time)
  - o Cabling (size and length)
  - o Electrical consumables required for the installation of the PFC equipment
  - o Protection equipment such as (fused) isolators and circuit breakers
  - o Required IP rating of the PFC panel to prevent dust and water ingress
  - o Elevated ambient temperatures necessitating the fitment of air conditioning systems to the PFC equipment
- **Actual maximum demand rate being charged:** Ranges from R15/kVA to R138/kVA! This has obviously a significant impact on the payback period

Examples of savings and investment payback periods for PFC equipment

Example 1:

Load profile (under peak load conditions) of an installation with a very poor power factor and a customer being charged fairly costly maximum demand rates:

Current (A)	645,0
Voltage (V)	393,4
Power Factor	0,50
Active Power (kW)	219,5
Apparent Power (kVA)	439,0
Reactive Power (kvar)	380,2
Target Power Factor	0,97
Required pf correction (kvar)	325,2

Table 2: Load profile of customer 1.

This customer required making an investment of R88 000 in power factor correction equipment (on a turnkey basis) in order to elevate the power factor of the installation to 0,97 under peak load conditions.

The investment resulted in an associated reduction in maximum demand of 213 kVA, which represents a monthly saving in electrical costs of R24 990 at the current maximum demand rate being charged, being R117 49/kVA.

Active power (kW)	219,5
Uncorrected power factor	0,50
Uncorrected apparent power (kVA)	439,0
Corrected power factor	0,97
Corrected apparent power (kVA)	226,3
Savings (kVA)/month	212,7
Cost per kVA (maximum demand)	R 117 49
Saving (R/month)	R 24 990

Table 3: Monthly savings customer 1.

The savings achieved in the first year of installation resulted in an investment payback period of 3,5 months!

Power factor correction equipment has a life expectancy of at least 10 years with minimal maintenance. Estimated total savings over ten years, taking into consideration tariff increases of 25% in 2011 and 2012, and further annual tariff increases of 10% thereafter are approximately R6 000 000.

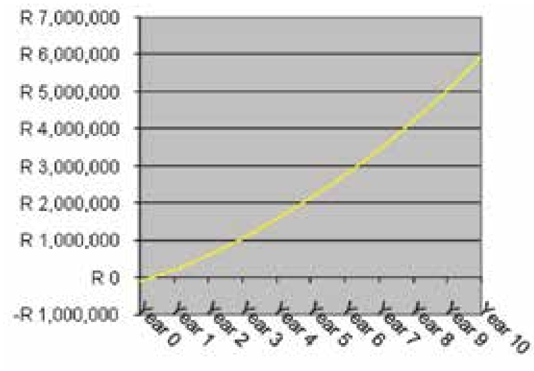

Figure 9: Total savings customer 1.

Example 2:

Load profile (under peak load conditions) of an installation with a reasonable power factor and a customer being charged fairly cheap maximum demand rates:

Current (A)	1407,5
Voltage (V)	392,0
Power Factor	0,80
Active Power (kW)	763,6
Apparent Power (kVA)	954,5
Reactive Power (kvar)	572,7
Target Power Factor	1,00
Required pf correction (kvar)	572,7

Table 4: Load profile of customer 2.

This customer required making an investment of R202 000 in power factor correction equipment (on a turnkey basis) in order to elevate the power factor of the installation to unity, under peak load conditions.

The investment resulted in an associated reduction in maximum demand of 190 kVA, but due to the very low maximum demand rated being charged to this particular customer, the associated monthly saving in electrical costs was only approximately R3 000!

Active power (kW)	763,6
Uncorrected power factor	0,80
Uncorrected apparent power (kVA)	954,5
Corrected power factor	1,00
Corrected apparent power (kVA)	763,6
Savings (kVA)/month	190,9
Cost per kVA (maximum demand)	R15,60
Saving (R/month)	R2 978

Table 5: Monthly savings customer 2.

The savings achieved will result in an investment payback period of 48,8 months!

Estimated total savings over ten years, taking into consideration tariff increases of 25% in 2011 and 2012, and further annual tariff increases of 10% thereafter are estimated at R500 000.

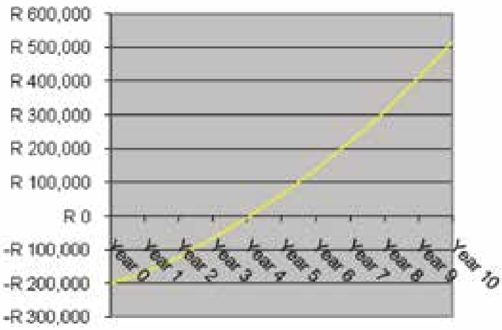

Figure 10: total savings customer 2.

Even though the return on investment was very poor, this customer decided to purchase the power factor correction equipment in order to be able to install additional machinery in the factory without overloading his 1 000 kVA supply transformer.

PFC equipment

Capacitors are the key component in any power factor correction equipment and they determine their life expectancy.

The life expectancy of the capacitors is mostly determined by the following factors:

- Quality of the polypropylene carrier film
- Heat dissipation properties of the housing (aluminium vs plastic)
- Average and maximum operating temperature
- Network pollution: Harmonics and voltage surges
- Rated voltage

Capacitors need to be well ventilated and easily replaceable.

Good quality PFC controllers keep track of the number of cycles each step has been subjected to as well as the total duration each step has been in operation. The controller uses this information to determine which step to add or remove when a load change occurs and this results in the even wear of complete power factor correction installation. It is also possible to manually add or remove a step from the controller front panel keypad. The controller will not allow the manual addition of a particular step before a preset internal timer has lapsed, ensure that the capacitors are sufficiently discharged before being re-energised. This feature increases the life expectancy of the capacitors

Conclusion

Industrial and commercial organisations can no longer ignore the benefits of power factor correction and harmonic filtration. Failure to do so will not only result in significant and unnecessary costs being incurred by these organisations but will also affect their opportunities for growth. Indeed, Eskom and municipalities have started to cap the maximum apparent power organisations can draw from the power distribution network. In order to add additional electrical equipment on their premises, organisations are now forced to improve their power factor and use more energy efficient electrical equipment.

Bibliography

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Eric Solot holds a Master of Applied Engineering (Electrotechnology) from the University College in Ghent (Belgium). At present he is the managing director of Alpha Power Solutions, which specialises in power factor correction and harmonic filtration. Enquiries: Email eric@alphapower-solutions.co.za.

About the author