

Dispelling myths associated with power factor correction capacitors

by Dale Pudney, HV Power Systems

Now that Eskom intends to increase the penalty for having a low power factor, the economics of installing power factor correction (PFC) equipment are improving. It is normally most cost effective to install PFC in the form of medium voltage (MV) capacitor banks.

For the most economic MV PFC, a number of incorrectly held beliefs need to be dispelled. Many of these myths come from good practice on low voltage PFC, which do not automatically transfer to MV PFC.

Myth 1: Capacitors drive the cost of MV PFC

A common mistaken belief is that capacitors, as the critical element of PFC, drive the cost of most MV PFC projects. I.e.: that a 3 Mvar PFC bank will be about three times the cost of a 1 Mvar PFC bank or that a 3 Mvar PFC bank with three steps will be a similar cost to a 3 Mvar PFC bank with a single step.

The reality is that the capacitors are about 10 – 15% of the costs of a medium sized PFC bank (e.g. a 3 Mvar 11 kV PFC bank). The balance is made up of the switchgear, control and protection system and the required ancillary equipment, which are required for each step (often the same for each step). Similarly civil work, installation and commissioning costs are often determined by the number of steps and not by the total output of the PFC. Often the "infrastructure" part of the PFC bank cannot be scaled with the size of the PFC bank output.

The switchgear requirements of PFC banks must also be carefully considered and have a major impact on the total costs. Smaller banks are often switched with contactor or circuit breaker panels (complete with protection and control systems) and the switching frequency often drives the requirements. Optimising the switchgear arrangement has a bigger impact on the costs for each step or the total costs of the installation than the capacitor costs.

Myth 2: The supply may not have a leading power factor

While most supply contracts that customers sign with their utility include a provision that the supply may not go leading, technically, leading power factors do not cause a problem. Under some conditions exporting large quantities of reactive power may cause voltage rise situations, depending on the supply network.

The reality of today's distribution networks is that the utilities require reactive power in order to support the voltage and maximise



Fig. 1: Typical outdoors PFC installation – infrastructure determined from number of banks and not size of banks.

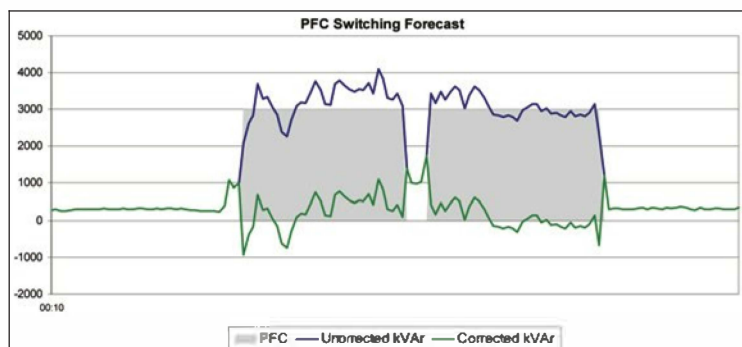


Fig. 2: PFC switching forecast determined from load profile – allowed to go leading.

the power that can be distributed through already stressed networks. If this reactive power is not provided by the customers, then the utilities need to provide the reactive power from PFC banks themselves. This is why the Eskom intend introducing low power factor penalty charges – to encourage customers to install PFC equipment for their requirements.

The problem comes from the fact that PFC costs are driven by the switching requirements and customer load profiles have varying reactive power requirements at different times. During the design study we determine the amount of reactive power that can be exported without resulting in excessive voltage rises.

The design criterion should be the quantum of reactive power that can be exported during periods of low load and not the fact that the supply is leading. Discussions with the utilities will almost always result in agreement with this proposal. It is important to note that Eskom does not give "credit" for leading power factors to offset the lagging power factors at other times. They normally use two quadrant metering, which record's leading power factors as unity power factor (or exported kvars as zero).

Myth 3: The power factor must be kept near unity for all load conditions

In low voltage PFC, there are normally

many capacitor units that are switched frequently with small and relatively inexpensive contactors. This allows low voltage PFC to use multiple steps to accurately track the reactive power demand profile and therefore maintain a power factor near unity for all load conditions. The costs to achieve this at medium voltages would be exorbitant.

The need to maintain the power factor near unity therefore needs to be examined. The objective to maintain the power factor near unity is probably because:

- The kW maximum demand could be at a different time to the uncorrected kVA maximum demand due to the nature of the loads (different power factors) in service at the different times. Therefore on maximum demand based tariffs, the power factor corrected maximum demand would now be at a different time and a power factor near unity will ensure optimised maximum demand at all times.
- On time of use tariffs like Eskom's Megaflex and Miniflex, the reactive power charges are based on the reactive energy across the whole load profile.

The need to maintain a high power factor at all load conditions becomes an economic trade-off between the additional costs of a many PFC steps and the additional savings that may not be achieved with the coarser control that could result in some low power factors at periods of low load (when the PFC banks are switched out to avoid high levels of exported reactive power).

All of the above basically dictates the need to change the control system for MV PFC from "power factor" based control (best suited to low voltage PFC) to "reactive power" based control where the PFC banks are switched based on the reactive power demand from the utility. (Switch the PFC banks based on their direct benefit to the system than (providing a fixed amount of reactive power) rather than a constructed measure such as "power factor").

In our opinion, the objective should not be to maintain the power factor near unity at all times, but rather to reduce the reactive power demand on the system that is stressing the generation and distribution system and limiting the power flow capacity of the generation and distribution infrastructure.

The Megaflex tariff targets 0.96 power factor, at which the reactive power is about 30 % of the real power. Therefore when a single step capacitor bank is installed to achieve 0.96 power factor at maximum demand, the load can reduce by about 30% before unity power factor is reached. The load can reduce further and the supply go leading, which is limited by the quantum of exported vars (and not leading power factor).

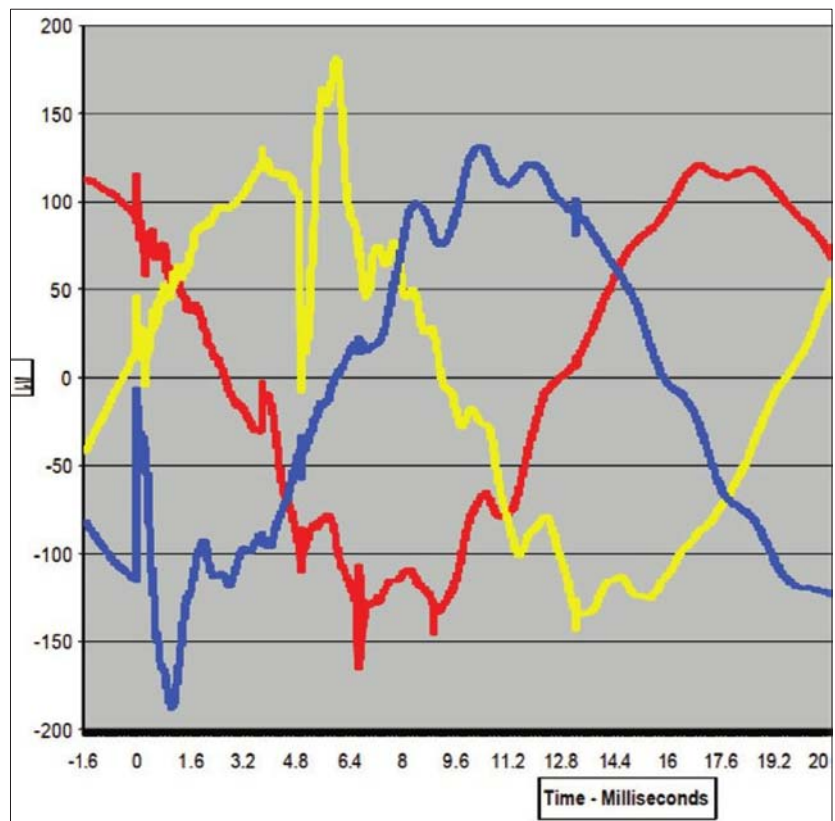


Fig. 3: Typical transients associated with capacitor bank switching (single pole switching).

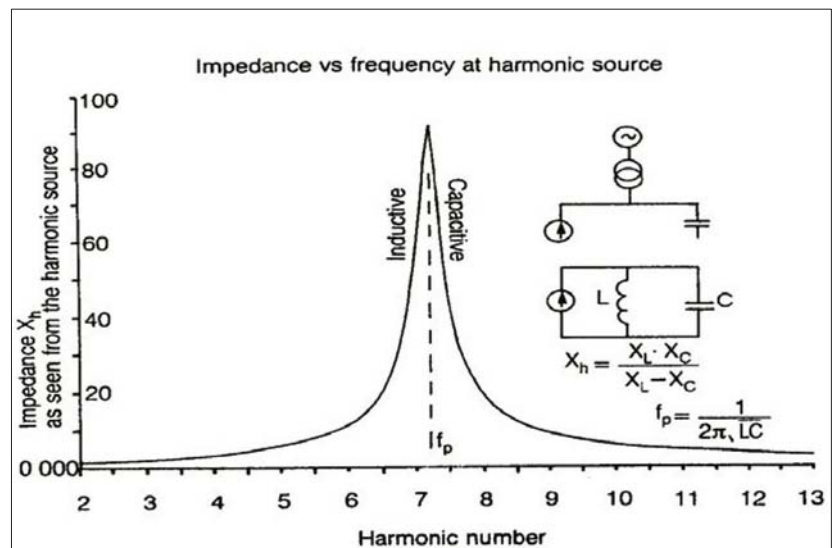


Fig. 4: Impedance vs frequency plot with a capacitor bank installed.

Therefore a single step capacitor bank can normally compensate for most loading conditions in a typical industrial or mining load.

Myth 4: Frequent switching of multi-step capacitor banks is technically acceptable

Switching capacitor banks is associated with switching disturbances that can have a detrimental effect on sensitive electronic loads. In today's world, the proliferation of sensitive electronic loads is increasing

all the time. When a capacitor bank is switched in, the supply system effectively sees a short circuit while the capacitor bank is charged up. This is because the impedance of a capacitor is inversely proportional to the frequency – therefore a step change (effectively infinite frequency) of the voltage across the capacitor sees an effective zero impedance at the point of switch-on.

Fig. 3 shows how the voltage dips at switch on, followed by high frequency recovery

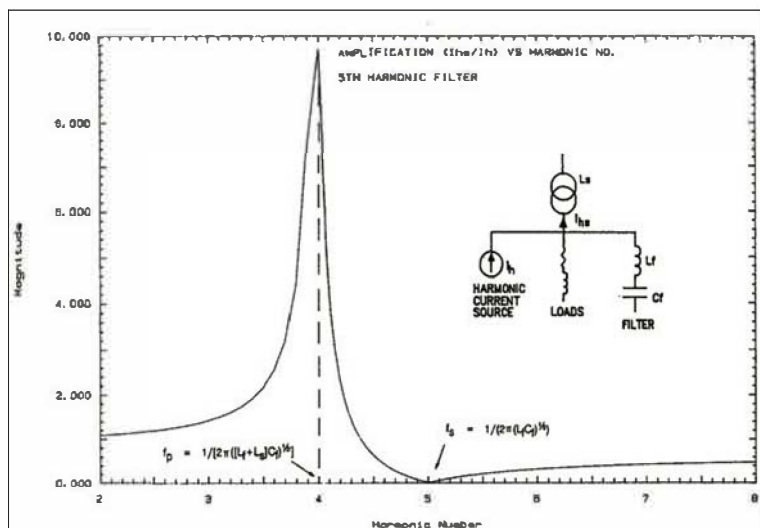


Fig. 5: Typical Impedance vs frequency plot of a 5th harmonic filter.

existing high harmonic levels, but rather to avoid PFC capacitor banks introducing unacceptable high harmonic levels due to harmonic resonance between the capacitor banks and the supply impedance.

Harmonic currents normally follow the path of least resistance – normally back to the source. By installing a capacitor bank, the system impedance introduces a peak at the "resonance point". The harmonic voltages at each frequency are therefore the product of the harmonic current and the impedance at that frequency. Therefore the installation of a capacitor bank can result in unacceptably high harmonic voltages near the resonance point because of the amplification of the impedance at that point.

To avoid the harmonic resonance effects of installing a capacitor bank, we normally include a series reactor with the capacitor bank, which effectively detunes the capacitor bank into a harmonic filter. Tuning the filter to near the 5th harmonic normally has the lowest risk of amplifying other harmonics while maintaining the costs at an acceptable level.

A detuned filter normally introduces a low impedance at the tuning frequency (to filter off the harmonic currents) and a peak below the tuning frequency. Where the fault level is low (supply impedance high), there is a risk of amplifying the 3rd harmonic. In these cases, a 5th harmonic filter would not produce acceptable harmonic performance and a 3rd harmonic or damped 5th harmonic filter will be required. (A damping resistor is included in a filter circuit to reduce the magnitude of the peak and trough.)

Conclusion

The installation of MV PFC equipment will provide economic benefits to customers as the utilities, driven by Eskom, implement additional low power factor penalty charges. The law of diminishing returns however applied to MV PFC, in that there is a finite saving available, but the costs to achieve those savings increase significantly for each additional R1 saving near the margin.

Single step PFC installed as 5th harmonic filters will normally provide the best technical performance with the lowest risk of introducing unacceptable transients and harmonics, while generating sufficient savings to provide payback periods of the capital costs of the order of 18 months to 2 years. A detailed design study is however recommended to ensure that the proposed design and equipment to be installed will provide the expected results in each customer's particular network.

Contact Dale Pudney,
HV Power Systems
dale@hvpowersystems.co.za ♦

oscillations (and overshoot). The larger the capacitor bank is, the higher the inrush will be, and therefore the larger the dip impact will be.

Frequent switching of many capacitor bank steps will have many such switching transients, which are known to cause problems on industrial and domestic equipment. The inrush current (making current of the circuit breaker) also has a derating effect on the supply circuit breakers or contactors, reducing their useful life in terms of number of operations.

Whilst we are not aware of formal studies that have been done to determine the actual reduction in life, one circuit breaker manufacturer we work with believes that this reduction can be up to half of the rated number of operations. In order to reduce the amount of switching disturbances that are associated with PFC capacitor banks, one can either:

- Reduce the number of switching operations; or
- Reduce the depth of the dip (smaller capacitor steps or include an additional impedance in the circuit).

However, we have already determined that smaller capacitor bank steps will result in exorbitant costs for the total installation cost that cannot typically be justified in terms of the available saving.

IEC80671 requires MV capacitor to be able to withstand certain switching transients and bases the capacitor life on 1000 switching operations per annum (say three times per day). Therefore, more frequent switching can also have a detrimental effect on the life of the capacitor.

Myth 5: Inrush current limiting reactors eliminate switching disturbances

We know that to reduce the dip that is associated with capacitor bank switching,

we need to include an additional impedance in the circuit. This is normally done with a series reactor, which creates a voltage divider effect on the MV busbars, between the mostly inductive supply impedance and the impedance of the series reactor. Current limiting reactors however are normally not sufficient to reduce the switching transient; only the inrush current to within the inrush current rating of the capacitors (100 times the rated continuous current).

To calculate the depth of the dip caused by the capacitors at switch on, we calculate the voltage divider ratio. Let's assume that we have an 11 kV system with a 15 kA fault level – the supply impedance will be about 0,4 Ω. If we install a 3 Mvar capacitor bank with a current limiting reactor (say 50 μH), the reactor will have an impedance of about 0,016 Ω. In this case, the voltage dip at each switch on will be about 96%! If, however, we install the PFC as a 5th harmonic filter, the series reactor (5,7 mH) will have an impedance of about 1,8 Ω. Therefore with the PFC as a 5th harmonic filter, the voltage dip at switch on will be reduced to about 19% and the impact on the nearby equipment is dramatically reduced. (A 3rd harmonic filter will have a dip of only about 7%, but the additional costs are normally not justified by this reduction of the dip from 19 to 7%.)

Therefore, current limiting reactors have almost no impact on the voltage dip and transients associated with capacitor bank switching.

Myth 6: Harmonic filters are only required where there are high harmonic levels

We often hear "we don't need harmonic filters because there are no big harmonic loads". Or the existing harmonic levels are not high. The reality is that most harmonic filter banks are installed, not to reduce