ENERGY EFFICIENCY IMPROVEMENT THROUGH OPTIMIZATION OF THE POWER FACTOR CORRECTION

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ABSTRACT

In a context of higher energy costs, dwindling resources, increased world demand and growing concerns about climate protection, power factor correction appears to be one of the easiest and most effective measure to improve energy efficiency. But, most of users have a poor knowledge about Power Factor Correction and the advantages of such systems are not fully exploited.
This paper will remind the positive impacts of Power Factor Correction (PFC) on the environment. The different solutions where PFC systems can be installed on electrical networks will be discussed. An example will illustrate the different advantages of using Power Factor correction systems.
Recommendations to push users to install power factors correction will be given.
Optimal use of capacitor banks through better control and maintenance can improve the benefits and the savings.
Development of communication towards users about the benefits of power factor correction is one action to expand the use of these systems.
The evolution of regulations to force the users to install equipment will be one of the most efficient method to take the maximum advantage of the potential of PFC.

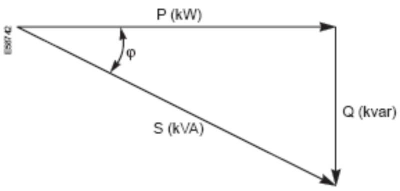
INTRODUCTION

Rising public awareness for environmental protection, coupled with commitments of EU countries to reduce their emissions of greenhouse gases create increase interest in measures to improve energy efficiency
Power factor correction is a simple, mature and inexpensive technology but it is often overlooked and full use of the potential for energy savings is not made.

PRINCIPLE AND ADVANTAGES OF POWER FACTOR CORRECTION

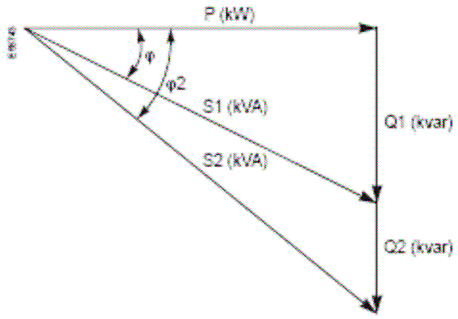
Nature of reactive energy

All inductive devices, such as motors, that operate on AC systems convert electrical energy into mechanical work and heat. This energy measured by kWh is referred to active or wattfull energy. In order to perform this conversion, magnetic fields have to be established and maintained in the machines. These fields are associated with another form of energy to be supplied from the power system, known as reactive energy or wattless energy.
The apparent power S, which must be available and transmitted on the systems, is the vector addition of the active power P and the reactive power Q.



Effects of reactive power

Circulation of reactive energy has major technical and economic consequences. For the same active power P, the following figure shows that for a higher reactive power, a higher apparent power and thus a higher current must be supplied.



Thus, due to a higher supplied current, circulation of reactive energy on distribution networks results in:
- Investment costs because generators, transformers, power lines, switchgear, cables must be sized for greater power ratings than if the load only need active power.
- Additional power losses proportional to the square of the current
- Reduced equipment life due to temperature rise of the main components : cables, transformers,
- Increased voltage drops along the transmission and distribution lines.

For these reasons, reactive energy must be produced as close as possible to the loads, to prevent the unnecessary circulation of current in the network. This is what is known as "power factor correction". The universal solution to produce reactive energy is to use power capacitors.

To take this additional losses into account and avoid overrating the network, electrical utilities make additional charges for reactive energy if this exceeds a certain threshold. Usually a certain target power factor cos ϕ of 0.9 to 0,95 is specified.

Economic and technical advantages

The main advantage for users to install PFC systems is the reduction of electricity costs by the avoidance of power factor penalties or reduction of the supply capacity charge. But PFC systems can also optimise the rating of installations and networks (lines, cables, transformers) or release electrical system capacity with the meaning of a reduction in investment costs.
By reducing reactive current, capacitor banks provide a reduction of current dependant system losses and then a mitigation of the active power consumption.
For example, with a cosϕ of 0,7 corrected to a cosϕ of 0,9, the system losses due to reactive currents can be reduced by 40%.
Additional benefits of PFC are the extended equipment life, voltage regulation improvement and the management of the power quality of the system by the control of harmonics.

Environmental benefits

By providing reactive energy near the loads, PFC systems reduce currents in transmission, distribution network and in customer's network and thereby decrease energy losses. As shown hereafter, a PFC system can give a reduction of 30 % to 40 % of losses depending to the level of the level of compensation .

It has been calculated [3] that the potential of savings in the European Union is about 48 TWh corresponding to 19 Mt CO2. That quantity represents 2,5 % of the objective of the energy efficiency action plan of the European Commission which aims to reduce the direct cost of the energy consumption by over €100 billion annually by 2020, avoiding around 780 million tons of CO2 per year.

With PFC, additional transmission capacities are made available that will allow the connection of renewable energy generation. A load relief of 10 % to 15 % could be achieved in industry and buildings sectors.

PFC contributes also to the optimisation of the ratings of network components and the extension of equipment life meaning to a reduction of raw material depletion.

Global effectiveness

Power Factor correction with capacitor banks is a mature and reliable technology : PFC systems use high quality capacitors with safe protection systems and service life of low voltage capacitor banks is around 15 years.
The installation of PFC systems is straightforward and does not disturb the productivity of the users.
PFC systems are cost effective and attractive for the customers provided that an appropriate fee for reactive energy is charged by utilities.

In comparison with other measures for reducing CO2 emission (use of speed drives, renewable electricity,…), PFC appears to be one of the easiest and most effective measure to improve energy efficiency.

PFC already contributes to reduction of primary energy consumption, but PFC offers further potential and a widespread use is absolutely necessary to meet commitments of Kyoto protocol in reducing emission of greenhouse gases.

INSTALLATION

Since capacitors reduce reactive power flow from the source on out to the capacitor location, the ideal location is as near the load as possible. This will have the greatest effect on network losses reduction and load relief of installation.

By the penalties, the users are incited to install PFC systems but only to reach a target cos ϕ at the point of common coupling. Whereas the compensation at the level of voltage where the energy is consumed presents the advantage of reducing the losses of Low Voltage (LV) and Medium Voltage (MV) lines but also those of the distribution transformers.
However, the whole of the reactive load is usually not compensated by the consumers. It is then necessary to add additional correction by capacitors installed along the distribution lines and at HV/MV primary substations.

PFC system locations

The actual location of capacitor banks depends on the size and location of the various loads. The distribution of the capacitors depends of load locations and operating conditions on each feeder to obtain the maximum benefits.

The basic types of power factor correction stated below should be distinguished :

- Individual correction (LV or MV)
- Group correction (LV or MV)
- Central correction (LV or MV)
- On high voltage network (HV)

Individual power factor correction
Individual correction should be primarily applied to large motors operating continuously, such as pumps and compressors. With such loads the power factor can be improved with a fixed capacitor bank up to a displacement power factor of 0.95.

The advantage of individual compensation is that the reactive power is compensated for right at the point of its origin, the supply lines being released.

Group correction

With one capacitor bank, a large group of small inductive consumers can be compensated. Such a system is particularly favourable in the case of a group of small motors as the installed power of the bank is reduced compared to an individual compensation.

Normally the consumption of the power of such group is variable. For this reason the capacitor banks are divided in several steps controlled automatically by a power factor relay.

Central correction

A group correction system for a total plant is normally connected to the main busbars of the installation. This provides a high displacement power factor at the point of common coupling but reactive energy still flows in all the conductors downstream the point of connection.

Transmission and distribution network

As said previously, even if reactive energy is correctly compensated on the MV and LV levels, the inductive behavior of the lines and the transformers of HV and MV powers network results in a power factor reduced to these levels of voltage and can lead to the installation of capacitor bank on MV and HV systems.

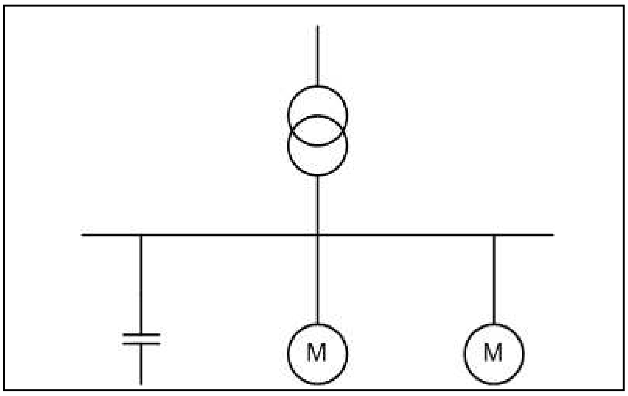
Optimisation of PFC use

For users, the full potential of the PFC can be exploited by adopting some measures :

- For low voltage loads, the solution of LV automatic capacitor bank is to be recommended as it constitutes a technico-economic optimum for the customer.
- Benefits in loss reduction can be increased by installing automatic LV capacitor banks defined to a higher power factor than the target cos ϕ specified for avoiding penalties. It allows a quite full compensation without any risk of overcompensation .
- Benefits in using PFC systems can be improved while using capacitor banks even in the period when there is no charge for reactive energy.
- The use of capacitor bank monitoring device with advanced power factor controller including communication feature make the management of the power factor correction easier in large sites with several transformers.
- The use of capacitor bank with detuning reactors limits the propagation of the harmonic currents on the distribution network and contributes to the improvement of the power quality and to the reduction of losses.

Example

As an example, we take an industrial company with two low voltage motors supply by one transformer 800kVA / 400V three phases.



We studied the benefit effects brought by the PFC according to the reactive energy tariff of France and Spain.

The PFC is made of an automatic capacitor bank (350 kvar for Spain, 300 kvar for France) connected directly at the low voltage side of the transformer in order to reach the target power factor and avoid chargeable reactive energy .

The table attached shows the results.

	Spain	France	unit
Imput datas			
Active energy costs	0,08347	0,08797	€/kWh
Reactive energy costs	0,02535	0,01700	€/kvarh
Mean operating time	1600	1600	h/year
Months when reactive energy is charged	12	5	months/year
Cosine target	0,95	0,92	-
Mechanical power of the motors	500	500	kW
Displacement power factor	0,75	0,75	-
Mechanical efficiency of the motors	0,8	0,8	-
Power assessment without PFC			
Total active power of the loads	625	625	kW
Total reactive power of the loads	551	551	kvar
Total apparent power of the loads	833	833	kVA
Load factor of transformer	104	104	%
Active losses of the transformer	10,7	10,7	kW
Power assessment with PFC			
Necessary minimum reactive power of the PFC	346	285	kvar
Total active power of the loads with PFC	625	625	kW
Total reactive power of the loads with PFC	201	251	kvar
Total apparent power of the loads with PFC	657	674	kVA
Fundamental current with PFC	948	972	A
Load factor of transformer with PFC	**82**	**84**	**%**
Active losses of the transformer with PFC	6,7	7,0	kW
Total active energy consumed	1000000	1000000	kWh
Total reactive energy consumed without PFC	881917	881917	kvarh
Total active energy consumed with PFC	321917	401917	kvarh
Pay back period			
Reactive energy saving with PFC	560000	480000	kvarh
Cost saving reactive penalties	14194	3400	€
Investment cost including installation	6125	5250	€
Payback period	**0,4**	**1,5**	**years**
Active losses saving with PFC			
Losses in PFC	0,5	0,5	kW
Active power saving	3,6	3,2	kW
Active energy saving	5704	5146	kWh
Cost saving active losses	**476**	**453**	**€ / year**

From a technical point of view, to supply the overall loads, the PFC gives a solution to optimize the rating of the transformer (apparent power). Indeed, the needed apparent power decreases by around 20%. The transformer is thereby relieved and some active power is still available.
The reduction of the current in the lines naturally induces the decreasing of active losses in the cables and the transformers by more than 30%.

Economically, the PFC cancels the penalties of reactive energy imposed by the supplier according to the power supply tariff (3400 to 14194 €). In addition, the saving due to losses reduction can be estimated at 450 € per year (by taking in account the losses inside the PFC).
Here, we show that on average, the payback period of capacitor banks is about 0,5 year in Spain and approximately 1,5 years in France.

This example illustrates the great importance of the tariff to develop the implementation of PFC systems in industrial companies. Without any charge from the supplier, PFC systems are not considered enough attractive for the final consumer even if the saving in active energy is consequent. Without any direct charge, the savings are also more difficult to demonstrate to decision makers.
It shows also the difference between the different countries and suggest that the best practices can be adopted at the European level.

RECOMMENDATIONS

PFC is not as developed as it can be because companies and decision makers are not aware of the problem and the potential of the solutions.

Today, we see that most of the communication on the energy efficiency and environment friendly products is mainly focus on the energy production means such as windmills or solar.
We suggest to move the focus of communication on the users of energy explaining how they could have a positive impact on the environment with simple and well-proven solution like PFC capacitor banks.
For that reason, actions can be implemented :

- Make campaigns to inform users about the benefits of capacitors banks (environment friendly, energy savings, energy bill savings and fast return of investment).
- Promote tools explaining in an educational way this subject to the users. For that purpose, Schneider Electric has developed a training kit to show the principle and interest of PFC and harmonics filter (Harmocer and Harmocem tools boxes).
- Add information in the program of the students at school and university.
- Develop installation software including losses calculation and environmental assessment.

Utilities and network operators have a major role to encourage the extension of PFC.
The best way to convince the customers to use the energy with efficiency is to give them a fast return on the investment they will make.

For that, power suppliers should :

- Increase the price of reactive power
- Increase the target Cos Phi (for example, Turkey will move from 0.95 to 0.98 in 2008).
- Charge reactive energy all over the year and not only during peak hours.
- Apply reactive energy charge to small and medium users.

Politicians should also support the expansion of PFC with appropriate measures :

- Define standard and regulations to push users and utilities to implement PFC systems.
- Add tax incentives for the installation of capacitor banks, following the energy end-use efficiency European directive.
- Promote harmonization between the countries at European and international levels.

CONCLUSIONS

PFC already contributes to reduction of primary energy consumption, to the mitigation of CO_2 gas emissions and thereby to the prevention of climate change. But PFC offers further potential and a widespread use is necessary to meet the Kyoto commitments.
A better use of PFC systems, communication to make this measure aware and an increase of the target cos ϕ level should contribute to the expansion of the power factor correction for benefits of the users and the environment.

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