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Importance of measurement: The Impact of Power Quality in Energy Efficiency

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ABSTRACT

To implement sustainable and green initiatives in a building it is vital to have a means of measuring and verifying its performance. This is done by the introduction of intelligent utility and energy metering to the facility that would become its "eyes and ears". The principle is "you cannot control what you cannot measure".

Looking closer at the power side, the inefficiencies caused by power quality issues such as power factor and harmonics have often been easily overlooked due to the traditional focus on equipment performance optimisation, rather than on the quality of power which is essential for the operation of any electrical equipment.

This paper analyses power factor and harmonics problem areas and offers practical approaches for improvements.

INTRODUCTION

World energy consumption has risen 45% since 1980. Energy demand is anticipated to be double by 2030. More than ever, global warming is at the top of the agenda. Environmental concerns and public opinion on climate change is driving continued actions by legislators, opinion leaders, and special interest groups and is forcing utilities and industry to respond. CO2 emissions should be halved to avoid global warming acceleration. Both issues place a major challenge on the generating capacity of all utilities and on us as electricity end users[1].

Energy efficiency becomes more than a cost issue today. It becomes part of the journey to ensure energy availability and preserve the environment in the future.

Many organisations put energy efficiency at the top of their agenda as part of a green initiative and sustainable development strategic plan. Increasing efficiency has significant impact on energy savings.

The effectiveness of energy efficiency is described in Figure 1, where a small saving at consumer level realises a big saving at the power plant.

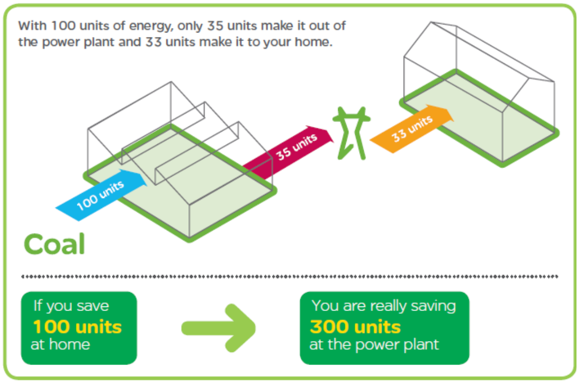

Figure 1. Power generation and consumption proportions

An easily overlooked area in energy efficiency is power quality. This is due to the traditional focus on equipment performance optimisation, rather than on the quality of power which is essential for the operation of any electrical equipment.

Most utilities have specific policies for billing for reactive energy. Price penalties are applied if the active power / apparent power ratio is not within the guidelines.

Power Factor Correction solutions modify and control the reactive power to avoid utility penalties, and reduce overall KVA demand. These solutions result in lowering utility power bills by 5 to 10%.

Harmonic Filtering solutions are a means to reduce and eliminate the harmonics. They increase the service life of equipment up to 32% for single-phase machines, up to 18% for three phase machines and up to 5% for transformers[2].

An improvement plan for power factor correction and mitigation of harmonics improves the energy efficiency of any electrical installation much like the bumps and holes in a road impeding the progress of an automobile. Distorted voltage in AC distribution systems has a very negative impact on operating costs and drives up expenses.

The plan needs to be part of a life-cycle process and this illustrated in Figure 2.

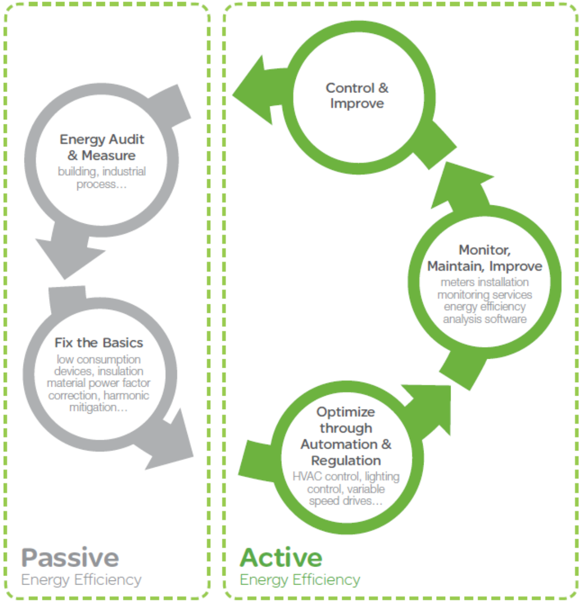

Figure 2. Energy Efficiency Life-cycle Process

BACKGROUND

Most utilities charge for peak electrical demand on each month's electrical bill. The charges are normally based on a two part tariff, where in the customer pays for the active energy (KWh) plus the reactive energy (KVARh) consumed OR active energy (KWh) plus the KVA maximum demand.

Reactive energy consumption and KVA maximum demand are interlinked and most utilities offer an incentive to their customers to operate their system at a higher operating efficiency.

Power factor correction systems, commonly known as capacitor banks, improve the overall electrical efficiency of the electrical network and are implemented to reduce the KVARh consumption / minimise KVA maximum demand charges.

Table 1 illustrates the increase in operating efficiency at improved power factor levels.

	Transformer power efficiency (kVA)				
Cos Phi	250	400	630	1000	1600
0.5	125	200	315	500	800
0.7	175	280	441	700	1120
0.9	225	360	567	900	1440
0.95	238	380	598.5	950	1520

Table 1. Efficiency versus power factor

In addition to the conventional way of responding to a reactive power demand, some applications demand dynamic reactive power (VAR) compensation. Lack of timely and adequate VAR compensation can lead to voltage fluctuations and flicker in the electrical distribution system, impacting equipment operation as well as product quality.

Over the recent years, power electronic devices have been adopted for various process control related application and their apparent energy saving benefits.[3] However, these power electronic devices tend to introduce a significant amount of harmonics into the electrical distribution systems thereby reducing the energy efficiency and reliability of the network.

A proper power factor correction plan and an effective harmonic mitigation strategy can contribute to the following improvements:

i. Reduced overloading of the electrical system thereby releasing useable capacity

ii. Reduced system losses and demand power

iii. Reduced risks of outage

iv. Extended equipment lifetime

POWER FACTOR BASICS

AC Power flow has three components:

Active Power (P) is the power needed for useful work such as turning a lathe, providing light or pumping water. It is expressed in Watt or KiloWatt (kW).

Reactive Power (Q) is a measure of the stored energy reflected to the source. It is expressed in var or Kilovar (kVAR).

Apparent Power (S) is the vector sum of both the active and the reactive components. It is expressed in Volt Amperes or in KiloVolt Amperes (kVA).

The relation between the various power components is illustrated in the power triangle shown in Figure 3.

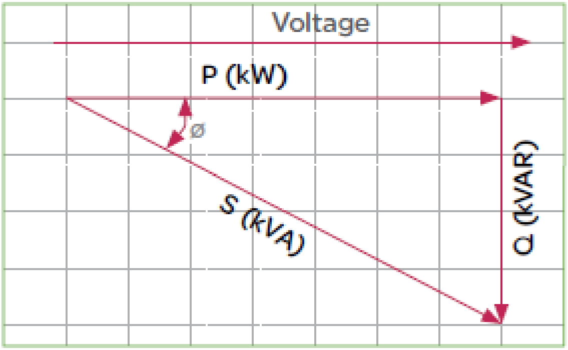

Figure 3. Power Triangle

From Figure 3, it is apparent that the active power component is in phase with the applied voltage while the reactive component occurs at 90º out of phase with the voltage.

The equation that defines this relationship is: $(kW)^2 + (kVAR)^2 = (kVA)^2$

Power factor (PF) is, in fact, a measure of efficiency. When the PF reaches unity (as measured at the utility power meter the electrical system in the plant is operating at maximum efficiency. Depending on the local utility rate structure, a PF below target PF may result in higher utility power bills than are necessary (provided a two part tariff is in force).

POWER FACTOR CORRECTION

The circulation of reactive power in the electrical network has major technical and economic consequences. For the same active power P, a higher reactive power means a higher apparent power, and thus a higher current must be supplied.

The consumption of reactive power over time results in reactive energy (kVARh).

In an electrical network, the reactive energy can be supplied in addition to the active energy as shown in Figure 4.

Figure 4. Reactive energy drawn by the load from the network

Hence, there is a great advantage in generating reactive energy at the load level in order to prevent the unnecessary circulation of current in the network.

This is carried out by the connection of capacitors, which produce reactive energy in opposition to the energy absorbed by loads such as motors. Figure 5 provides an illustration of this.

The power generation and transmission networks are partially relieved, reducing power losses and making additional transmission capacity available.

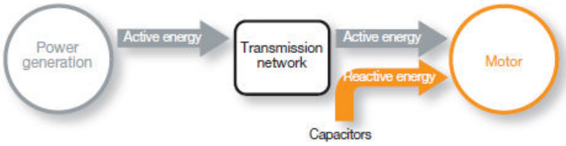

Figure 5. Reactive energy supplied closer to the load

CHALLENGES OF DYNAMIC REACTIVE POWER

Certain applications demand reactive power to be delivered in real time. The conventional PF controllers do not respond to such real time reactive power requirements.

The solution for such an application is to employ thyristor switches to switch the capacitors at the voltage zero crossing in conjunction with real time PF controllers which can turn ON and OFF capacitor stages within 2 cycles (40 ms).

Back-to-back thyristor switching of capacitors at zero current leaves the capacitor charged with either a positive or a negative full charge on the capacitor. The fine control allows the switching on of the capacitor when the system voltage equals the charged capacitor voltage[4].

This action eliminates voltage fluctuations and flicker in the electrical distribution system, as demonstrated in Figure 6.

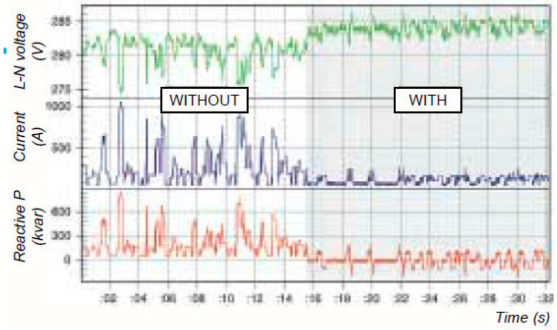

Figure 6. Variation in the network parameters without and with a dynamic reactive compensation system

CHALLENGES OF SYSTEM HARMONICS

Application power factor capacitors used to be straightforward. Today, with the proliferation of harmonic generating loads such as variable speed drives, soft starters, electronic ballasts etc. attention must be paid to the proper selection of power factor correction equipments due to the following reasons.

The first is the fact that the reactance of a capacitor bank decreases with frequency, and the bank, therefore, acts as a sink for higher harmonic currents. This effect increases the heating and dielectric stresses[4], thus reducing the life of the capacitor.

The second and potentially more serious concern is network resonance. When capacitors are added to the network, they set up a parallel resonance circuit between the capacitors and the network inductance. Harmonic current components that are close to the parallel resonance point are magnified[4] (see Figure 7).

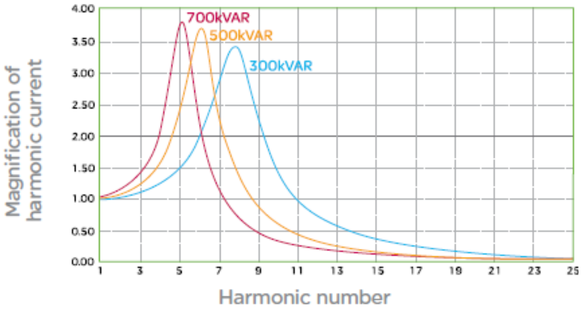

Figure 7. Example of amplification of harmonic currents when different stages of a capacitor bank are switched on

The magnified harmonic currents can cause serious problems such as overheating of transformers, motors, cables, thermal tripping of protective devices, logic faults of digital devices and drives. Higher harmonic levels can cause vibrations and noise in electrical machines (motors, transformers, reactors). The life span of many devices can be reduced by elevated operating temperature.

The solution for such an application is to de-tune / tune the capacitor bank depending on the harmonic order and harmonic generation characteristics of the load.

Figure 8 shows the network impedance of a capacitor bank, tuned to the 5th harmonic frequency.

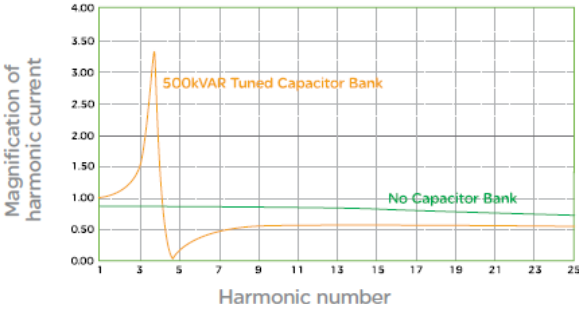

Figure 8. Example of the introduction of a tuned capacitor bank tuned to 250Hz

The selection of a correct de-tuning frequency is a very important point that needs to be taken into consideration. An incorrect selection of the de-tuning frequency could lead to amplification of system harmonics.

The capacitor reactors combination should be tuned below the lowest harmonic present in the electrical network[5].

CHALLENGES OF HARMONICS MITIGATION IN A DYNAMIC ENVIRONMENT

There are various harmonic mitigation methods that can be used to address harmonics in the distribution system. They are valid solutions depending on circumstances, and have their pros and cons.

Line reactors / DC bus chokes / isolation transformers

The use of line reactors is the simplest form to reduce harmonic current caused by non-linear loads; typically converter-based devices (see Figure 9). Inductors or isolation transformers, installed ahead of the load, can also reduce the harmonic current content by up to 50%.

The limitation of this solution is that the reduction in harmonic levels would not be adequate to comply with harmonic regulations.

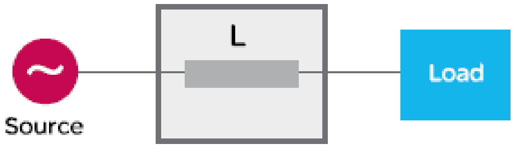

Figure 9. Line reactor connection

Tuned harmonic filters

A tuned harmonic filter is a type of passive filter. It is called passive because it consists of passive elements such as inductors and capacitors.

Figure 10 is a typical tuned harmonic filter circuit. Inductor (L) and capacitor (C) provides low impedance path for a single (tuned) frequency.

This type of filter is very application specific. It can only mitigate a single frequency, and can inject leading reactive current (kVAR) at low load conditions. But it is economical if you only need to deal with a dominant harmonic in the facility.

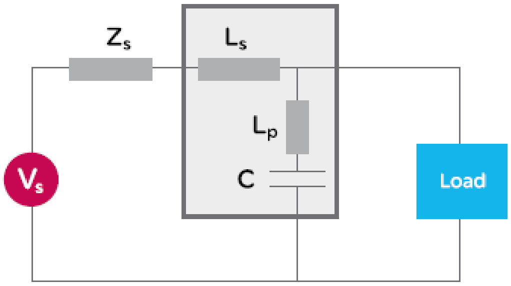

Figure 10. Typical Harmonic Filter circuit

Broadband filters

As the name indicates, a broadband filter is designed to mitigate multiple orders of harmonic frequencies. The similarity and the difference of its circuit from the tune filter are visible (see Figure 11). Both inductors (L) could have an impedance > 8%, which means a 16% voltage drop across the filter. Its physical dimension is normally very large, and it generates quite high heat losses (> 4%). However, broadband filters have their limitation and are not suitable for certain harmonic load applications.

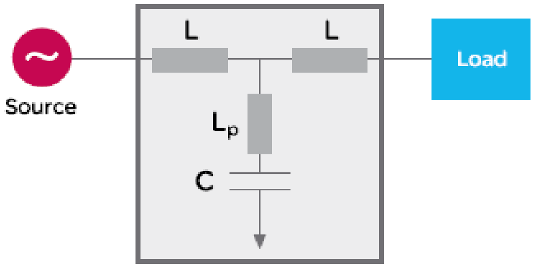

Figure 11. Typical Harmonic Filter circuit

Multi-pulse transformers / converters

The 12 or 18 pulses variable speed drive (VSD) has been developed to address the harmonic issue caused by common 6 pulse VSD. Figure 12 is a typical concept of 12 pulse VSD. The input is connected to the transformer's primary winding and the outputs are connected with two separated phase-shifted secondary winding to two sets of rectifiers. This configuration reduces the current harmonic distortion to a 10% range (12 pulse).

For the 18 pulse VSD, an additional secondary winding and a set of rectifiers are added in to the scheme. The 18 pulse VSD is replacing the 12 pulse as the prevailing choice in multi-pulse solutions. However, it is normally very bulky, has larger heat loss and a higher operating cost when comparing to other solutions.

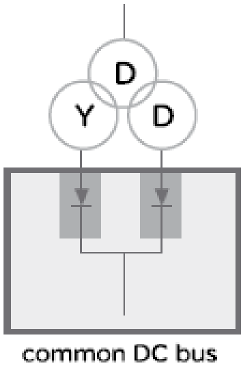

Figure 12. Multi-pulse arrangement

Active harmonic filter

The concept of an active filter is to inject, at any time, a harmonic current of the same amplitude as that of the current produced by the non linear load and is in opposition of phase[6].

Figure 13 illustrates how the harmonic current generated by an active harmonic filter is injecting into the system to cancel harmonic from a non linear load.

An active harmonic filter is a highly-effective device that cancels multiple order harmonics in the distribution system. It is installed as a parallel device and scaled via paralleling multiple units. It can handle different type of loads, linear or non-linear. It addresses harmonics from a system point of view and can save significant cost/space in many applications.

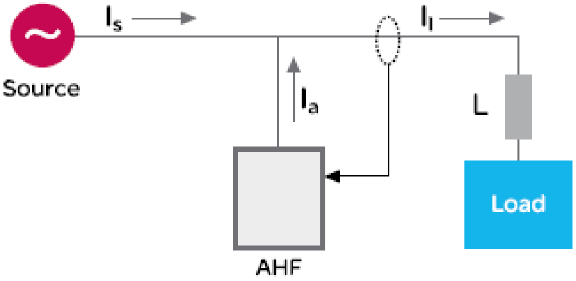

Figure 13. Active Harmonic Filter circuit (AHF)

REACTIVE ENERGY PENALTIES AND INCENTIVES

Utility regulations would go a long way in influencing the design of an installation. Penalties for poor power factor and exceeding harmonic limits would force consumers to adopt a proper power factor improvement plan and mitigation of system harmonics thereby improving the efficiency of the electrical network.

Incentives should also be given to consumers who abide by the utility regulation.

CONCLUSION

Power Factor and harmonics, because of their impact on energy efficiency, are important issues to consider for the management of electrical installations. Multiple approaches have been analysed and explained so that performance of electrical systems can be optimised.

Solutions for Power Factor Correction and harmonic mitigation have been presented in a practical way, answering questions frequently asked by electrical installation designers.

Power factor correction and harmonics mitigation both provide immediate benefits in terms of reduced power losses and reduced electricity bills. In addition, both of these best practices encourage the use of total system capacity in electrical installations thereby increasing payback on investment.

ACKNOWLEDGEMENTS

Schneider Electric

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Focused on making energy safe, reliable, and efficient, the company's 100,000 employees achieved sales of more than 15.8 billion euros in 2009, through an active commitment to help individuals and organisations "make the most of their energy."

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