POWER QUALITY : MONITORING AND INNOVATION IN PFC AND HARMONIC FILTERING

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SUMMARY

Electricity quality has become a great concern for both energy suppliers and their customers because the increasing use of sensitive devices and the significant consequences of a poor power quality for the competitiveness of the companies.

To maintain the level of disturbances within the limits defined by the contracts, the utilities set up rules for the connection of the customers.

To respect the emission levels, it is in the interest of the industrial and tertiary customers to use monitoring system to measure the power quality in their installation. When a poor quality is detected, the installation of solutions to limit the level of disturbances produced by the devices, equipment and systems is necessary.

The paper will discuss the different aspects of the power quality : voltage dips and interruptions, harmonics, overvoltages, voltage fluctuations, voltage unbalance and the origins of these disturbances.

The paper will describe the interest of the installation of fixed monitoring system in the consumer facilities and how these devices can prevent and detect power quality problems.

The paper will present innovative solutions for power factor correction and harmonic filtering.

The development of hybrid filter is a high performance solution to reduce the disturbances and respect the contractual current distortion limits.

The real time compensation system is an new solution to reduce the voltage fluctuations caused by highly transient or unstable loads and to reduce the switching transients.

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RÉSUMÉ

La qualité de l'électricité est devenue une préoccupation majeure pour les compagnies d'électricité et leurs clients car les équipements sensibles aux perturbations se généralisent et les conséquences d'une mauvaise qualité de l'énergie affectent de plus en plus la compétitivité des entreprises.

Pour maintenir les niveaux de perturbation dans des plages fixées par contrat, les distributeurs d'électricité mettent en place des réglementations de raccordement pour les clients perturbateurs.

Pour respecter ces réglementations ou pour éviter l'arrêt de procédés sensibles, ces clients industriels et tertiaires sont amenés à prévoir des systèmes pour mesurer la qualité d'énergie dans leurs installations et de mettre en place des solutions pour réduire les perturbations.

L'article passera en revue les différents aspects de la qualité de l'énergie : creux de tension, harmoniques, surtensions, fluctuations de tension, déséquilibre et les origines de ces perturbations.

On montrera l'intérêt de système de monitoring fixes permettant une surveillance permanente des installations et comment ces dispositifs peuvent assurer une fonction d'optimisation, de prévention et de détection.

On présentera des solutions innovantes dans le domaine de la compensation d'énergie réactive et le filtrage d'harmoniques

Le développement de filtre hybride est une solution performante de dispositifs permettant de limiter les perturbations générées par les installations et de respecter les limites contractuelles d'émission harmonique.

Les dispositifs de compensation automatique temps réel permettent de réduire les fluctuations de tension créées par des charges à fonctionnement intermittent et suppriment les surtensions transitoires de manœuvre.

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ABSTRACT

Power quality has become a great concern for both energy suppliers and their customers because the increasing use of sensitive devices and the significant consequences of a poor power quality for the competitiveness of the companies. This paper shows the different aspects of the power quality and the interest of the installation of fixed monitoring system in the consumer facilities

A methodology for improving power quality is described.

Innovative solutions for power factor correction and harmonic filtering are presented.

The development of hybrid filter is a high performance solution to reduce the disturbances and respect the contractual current distortion limits.

The real time compensation system is a new solution to reduce the voltage fluctuations caused by large loads with rapid, cyclical or random variations and to reduce the switching transients.

INTRODUCTION

Power quality has become a strategic issue for the following reasons :

- The economic necessity for businesses to increase their competitiveness.
- The widespread use of equipment which is sensitive to voltage disturbance and/or generates disturbances itself.
- The deregulation of the electricity market.

In this context, it is essential for the utility and the customers to prevent and detect power quality problems and to have solutions available to fix them.

The installation of monitoring system is an essential measure to prevent disturbances. The last evolutions of power factor correction and harmonic filtering systems give solution to solve the problems of harmonic disturbances and voltage fluctuations.

MAIN POWER QUALITY DISTURBANCES

Power quality usually involves characterising low frequency conducted electromagnetic disturbances which can be ranked in different categories.

Voltages dips and interruptions

A voltage dip is a sudden decrease of the voltage followed by voltage recovery after a short period of time from a few cycles to a few seconds

Interruptions are a special type of voltage dip to typically within 1-10% of the reference voltage.

Voltage dips and short interruptions are mainly caused by faults on the transmission or distribution networks or on the installation itself and switching of large loads. Long interruptions are the result of the definitive isolation of a permanent fault.

Harmonics

Harmonics measure the distortion of a signal. A distorted periodic waveform can be broken down into a fundamental plus harmonics.

Harmonics are mainly produced by non-linear loads.

Main sources of harmonics are :

- Industrial loads such as power electronic equipment (drives, rectifiers, inverters) or loads using electric arcs: (arc furnaces, welding machines, lighting).
- Domestic loads with switching mode power supplies (television sets, computers, fluorescent lamps...).

Overvoltages

Refers to a voltage having a peak value which exceeds the limits defined in a standard or specification.

Overvoltages are of three types:

- Power frequency overvoltages generated by an insulation fault, ferroresonance, faults on alternator regulator, tap changer transformer or overcompensation.
- Switching overvoltages produced by rapid modifications in the network structure such as opening of protective devices or switching on capacitive circuits.
- Lightning overvoltages.

Fig. 1 Characteristic waveforms of disturbances

Voltage variations and fluctuations

Voltage variations are variations in the rms value or the peak value with an amplitude of less than 10% of the nominal voltage.

Voltage fluctuations are a series of voltage changes which are characterised by the frequency of variation and the magnitude.

Voltage variations are caused by the slow variation of loads connected to the network. Voltage fluctuations are mainly due to rapidly varying industrial loads such as welding machines, arc furnaces or rolling mills.

Unbalance

A 3-phase system is unbalanced if the rms value of the phase voltages or the phase angles between consecutive phases are not equal.

The unbalanced voltage is produced by LV loads connected between phase and neutral, or single-phase loads such as welding machines and induction furnaces.

OBJECTIVES OF POWER QUALITY MEASUREMENT

Contractual application

Within the context of a deregulated market, the parameters of power quality must be defined and the values compared with contractual limits.

Corrective maintenance

Even where best practice is observed right from the design phase, malfunctions may occur during operation because disturbances may have been ignored or underestimated or the installation may have changed.

Optimising the operation of electrical installations

To achieve productivity gains, correct operation of processes and sound energy management are required, both of which are factors dependent on Power Quality.

ADVANTAGES OF PERMANENTLY INSTALLED MEASUREMENT DEVICES

When using portable apparatus, the duration of the measurements must be representative of the operating cycle of the factory. It must always be assumed that the disturbance will recur.

It is also preferable to use devices installed permanently in the distribution system.

- A visit by an expert is necessarily limited in time, whereas permanent measurements at different points in the installation provide an overall view of system operation and cover all the situations.
 - Measurement devices installed in the distribution system prepare and facilitate troubleshooting by experts.
 - Permanently installed measurement devices detect any occurrence of disturbances and they indicate the operating conditions when the incident occurred.
- Measurement and detection devices that are built into the electrical distribution equipment offer very optimised solution.

For example, an analysis at the main low-voltage switchboard level can commonly be carried out by the incoming device and/or the measurement devices built into each outgoing device.

Fig. 2: Some measurement communicating products (Merlin Gerin brand).

The products of the Power Logic System range and the latest generation of Masterpact circuit breakers fitted with Micrologic P trip release (see fig. 2) can be used for continuous monitoring of the installation. They will carry out prevention and detection by recording each occurrence of disturbance. The data can be displayed locally or remotely via an Internet connection.

PROBLEM ANALYSIS METHODOLOGY

Corrective maintenance is generally the consequence of incidents or malfunctions during operation requiring troubleshooting in order to apply corrective measures. Selection of the best solution, from both the technical and economic point of view, requires an in-depth study of the installation carried out by experts in the field of disturbances in electrical distribution systems and equipped with powerful analysis and simulation equipment.

The usual steps are:

- Data collection (type of load, single-line diagram...)
 - Search for symptoms
 - Examination of the installation
 - On-site measurement to detect and record the event where the problem originated.
 - Identification of origin :
Simulation with a computer model of the measured phenomena, can provide a precise explanation of their causes.
 - Definition and choice of mitigation solutions
- The choice of solution is often made by comparing the cost with the potential lost earnings in case of disturbance.
- Implementation of the final solution .
 - Verification of the performances via measurement.

SOLUTIONS FOR HARMONIC MITIGATION

There are three different types of solutions that may be used to attenuate the effects of harmonics :

- Reducing generated harmonics currents.
- Modifying the installation.
- Installing filters in case of the preventive measures are not sufficient.

Passive filter

This involves connecting a low impedance by-pass to the frequencies to be attenuated using passive components (inductor, capacitor, resistor). Several passive filters connected in parallel may be necessary to eliminate several components. Passive filters are generally configured to remove one or two specific harmonics (generally 5th and 7th). An inherent benefit is power factor correction.

Fig. 3 : passive filter principle

Active filter

This consists in a power electronic device neutralising the harmonics emitted by the load through analysis of the harmonics consumed by the load, and subsequently restoring the same harmonic current with the appropriate phase.

Fig. 4 : active filter principle

A new solution : Hybrid filter

This consists of an active filter and a passive filter which is tuned to the predominant harmonic frequency (e.g. 5) and supplies the requested reactive energy. The active compensator is dedicated to the other harmonic orders. As a consequence, the active filter is rated only for a fraction of the total harmonic current. The control is specifically designed to prevent interaction between passive and active components. By combining those two elements within one enclosure, they provide benefits over either element alone :

- Cost-effective high power filtering of one specific harmonic via the passive elements means a smaller, thus lower cost active element.

- Broadband filtering of all other harmonics via the active element.
- 3rd harmonic filtration via the active element.
- Low cost power factor correction via the passive element.

Fig. 5 : Hybrid filter principle

Hybrid filtering combines the best attributes of both active and passive filters. This solution allows a high level of performances, since a large number of harmonic orders are covered. The use of a passive filter dedicated to the predominant harmonic order allows for applications over a wider power range.

With the reduction in size of the active section and the natural supply of reactive energy, the hybrid technology offers an optimum economical solution for the most demanding high power installations.

Application example

Description of the installation

Ski-lifts are powered by an MV/LV transformer (800 kVA).

The connected loads are the chair lifts together with other loads such as payment booths, ski-pass validation systems, the official timing system for competitions and a telephone network.

Problems encountered

When the chair lifts are running, the sensitive equipments (payment booths, timing system, etc.) connected to the low voltage network powered by the MV/LV transformer are subject to disturbances. The measurements taken at the site showed a high harmonic voltage distortion (THDU = 9%) from the MV power system as well as harmonic pollution from the chair-lift feeder. The resulting distortion of the supply voltage (THDU = 12%) disturbed sensitive loads.

Solution

The objective is to ensure the simultaneous reactive compensation and neutralisation of harmonics likely to disturb the installation.

The solution chosen was to install a hybrid filter consisting of a passive filter tuned to the order of the dominant harmonic (H5) which provides the required reactive power (188 kvar), and an active filter rated at 20 A is dedicated to the elimination of all other harmonics.

a

b

Fig. 6 : Spectrum showing the effectiveness of a hybrid filter:[a] in voltage [b] in current

After commissioning, measurements show that the device reduces the magnitude of the harmonics over a wide frequency spectrum in both current and voltage (see fig. 6) and reduced the voltage distortion factor from 12.6% to 4.4%. It also increased the power factor of the installation from 0.67 to 0.87. This solution solved all of the problems as no malfunction was subsequently detected.

Fig. 7 Merlin Gerin hybrid filter

SOLUTION FOR VOLTAGE FLUCTUATION MITIGATION

Fluctuations produced by industrial loads may affect a large number of consumers supplied from the same source. The fluctuation magnitude depends on the ratio between the impedance of the device generating the disturbance and the impedance of the power supply. The solutions are:

- Changing the type of lighting.
- Installing an uninterruptible power supply.
- Modify the device generating the disturbance.
- Modify the network.
- Connect a reactance in series with the load.

- Use a real time reactive compensator.

This device which provides ultra-rapid reactive compensation is the best solution for industrial networks containing unstable loads.

Dynamat Real time reactive compensation

Dynamat systems represent a step forward in power factor correction and harmonic filtering technology. Solid State switching elements replace standard electromechanical contactors to provide high speed response to load fluctuations with transient-free capacitor switching.

Reactive power compensation is typically performed by a dedicated controller which measures the system power factor, compares it to a set target and energises capacitors via electromechanical contactors. Standard system response to a load fluctuation will be 5-10 seconds because the operation of capacitor steps is deliberately time delayed to reduce the number of operations as well as to enable the capacitors to discharge.

The new Dynamat system utilises electronic switching elements and a special controller capable of reacting within one cycle (20 milliseconds) to load fluctuations. Capacitor switching is transient-free and electronic switches have a virtually unlimited life. Due to absence of moving parts and transient overvoltages, the service life of the equipment is improved.

The extremely rapid response of the Dynamat system makes it ideal for reactive compensation of highly cyclical loads and particularly welders. The system can minimise the negative effects of these loads providing near instantaneous reactive compensation, reducing flicker and providing voltage sag support.

Fig. 8: Dynamat Real time reactive compensator [a] principle,[b] practical implementation

Application of real time reactive compensation

Dynamat system is ideally suited for industrial facilities with power quality or production problems resulting from loads such as welders, inductive heat treating equipment, injection moulding machines, rock crushers, mining conveyors, heavy stamping machines, elevators

or other highly cyclical loads. These facilities benefit from improved power factor, increased system capacity, lower power losses and reduced voltage sag and flicker. A real time reactive compensator is suitable in any application where standard control is too slow to track rapid load fluctuations. In addition, transient-free switching allows for use in sensitive environments with loads which cannot withstand transient overvoltages (PLCs, computer systems, etc.).

Figure 9 : Voltage, current and reactive power before and after application of Dynamat compensator

Application example

Description of the installation

A car equipment manufacturer's plant is supplied by a 2000 kVA transformer.

It manufactures exhaust assemblies from steel plate using spot welders and seam welders.

Problems encountered

- Visual and nervous fatigue in personnel, due to the fluctuation in brightness of lamps (flicker) when welding equipment was in operation.
- Noise pollution and premature mechanical ageing of equipment caused by vibrations mainly in the transformer and the main switchgear.
- Inability to add equipment for fear that the installation would be overloaded.
- Annual penalties of 5k Euro for exceeding the reactive power consumption limit (0.75 power factor).
- Defective parts caused by welding faults appeared at the end of the manufacturing process.

All these factors reduced company productivity.

Solution

The measurements taken during the operation of the welding equipment showed a nominal voltage of 584 V, voltage dips of 5.8%, current peaks of 2000 A, and reactive power peaks of 1200 kvar (see fig. 10).

The problems clearly stemmed from voltage fluctuations caused by the operation of welders which vary rapidly and frequently and which consume significant reactive power.

A voltage dip of 6% produces a reduction of 12% in the power available for welding. This was the reason for the large number of defective welds.

The solution chosen was to connect a real time reactive compensator of 800 kvar (this power was deemed sufficient to maintain the voltage at an acceptable level for all processes in the plant under all load conditions).

	Before	After
Voltage (V)	584	599
Voltage dip		
■ Depth (%):	5.8	3.2
■ Duration (cycle)	20 to 25	10 to 15
Current		
■ Average	1000	550
■ Peak	2000	1250
Reactive power (kvar)	600 – 1200	0 – 300
Power factor	0.75	> 0.92
THDI (%)	5 – 12	4 – 12

Fig. 10: Improvements due to the real time reactive Compensator

The results of implementing the solution are :

- A reduction in current peaks to 1250 A and the addition of loads without modification of the installation, with improved installation efficiency through reduction of joule losses.
- A reduction in reactive power peaks to 300 kvar and an increase in the power factor to over 0.92, thus avoiding power factor penalties.
- An increase in the nominal voltage to 599 V and a reduction in voltage dips to 3.2% (see fig. 10).
- Visual and nervous fatigue in personnel due to the flicker was also eliminated.
- Welding quality improved, as did productivity.

CONCLUSION

Power Quality has become a strategic issue for consumers. In the present economic context, the consequences of electrical disturbances become more and more serious.

However, problems of disturbance should not be regarded as insurmountable, as solutions do exist. Monitoring of the installations and innovative power electronic devices such as hybrid filter or real time reactive compensator can contribute to power quality improvement.

Employing specialists to define, implement these solutions while observing best practice will provide users with the right quality of power supply for their requirements.

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