Successful Power Quality Monitoring

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Summary: **Monitoring power quality often seems the solution for power quality problems. However, in order to solve power quality problems something more than simple installation of power quality monitors at the site is needed. This article attempts to dissipate any doubts of engineers about organizing a monitor program to solve power quality problems. It can be organized in three programs: an overall power quality program, the power quality survey and the immunization program. In all three programs, monitoring plays a decisive role. Furthermore, an overview of the main monitor features will be given.**

Key words:
power quality, power quality monitoring, monitorng instruments, power quality survey management

1. INTRODUCTION

When the assembly line stops, or the computer network crashes for no apparent reason, very often the electric power quality is involved. Voltage dips, harmonics, interruptions, high frequency noise, etc. are the most important power quality problems that we find in industrial and commercial installations. Troubleshooting these problems requires measuring and analyzing power quality and that leads us to the importance of monitoring instruments in order to localize the problems and find solutions.

Power quality problems are not only solved by the simple installation of a power quality monitor, there are other aspects to consider, either technology or non-technology aspects. The technology aspects are all very well known and discussed in engineering societies. On the other hand, the non-technology aspects, like managing power quality projects and economic impact of power quality problems, are still unknown. The awareness of these non-technological aspects of power quality helps to apply the most effective solution to the problem, which in some cases can differ from the most appropriate technical solution. In many projects related to finding a solution for power quality problems, monitoring plays a decisive role, and therefore, managing monitoring properly helps minimizing the cost of solving problems.

It is useful to know the relationships behind power quality in order to solve the related problem. First, quality of electric supply depends on both, utility power supply and the loads. Secondly, it must be recognized that electric power is a like one of the raw materials in the production process; better quality will increase the quality of the end-product. Better quality of the end-product helps to justify the costs in power quality solutions. An economic study of the impact of poor power quality is recommendable for every project related with power quality solutions,. Third, technology is good, but knowledge is better. Solving power quality problems not only depends on the technology applied to solve the problem, but a profound knowledge of the power quality phenomena, the applied solution and the electrical installation is needed to find the most effective solution. Trouble shooting and simple fixing measures are short term solutions; knowledge is the only way to find long term solutions. At last, the personal relationship between the maintenance personnel and the company offering power quality solutions is sometimes decisive what kind of solution is applied. In many cases, maintenance personnel do not trust new power quality solutions offered in the market, because they are not sufficiently informed about the different alternatives in the market.

1.1. Benefits of power quality monitoring

There are several reasons to monitor power quality. The most important reason is the economic damage produced by electromagnetic phenomena in critical process loads. Effects on equipment and process operations can include malfunctions, damage, process disruption and other anomalies [1]. The costs caused by the lack of power quality can be identified in:

- costs by product damage due to the process interruption of continuous or batched production;
- the downtime production losses;
- losses by the process restarting;
- increased costs due to lost opportunity in time-critical and just-in-time production.

Monitoring requires an investment in equipment, time and education. In many cases management, production and plant engineers must be sufficiently convinced of the benefits of monitoring. Monitoring is an essential analyzing tool in order to improve the availability of

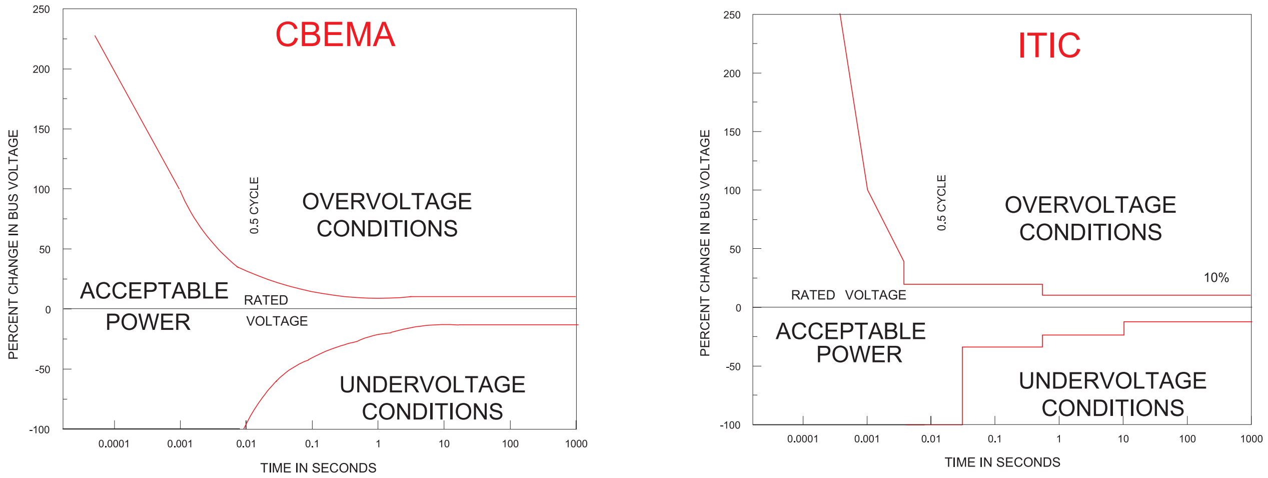

Fig. 1. CBEMA and ITIC curves are used in order to establish criteria for acceptable power quality in industrial plant

power. The investment in monitoring can be justified by its increased availability due to the following:

— preventive and predictive maintenance
— determining the need for mitigation equipment
— ensuring equipment performance
— sensitivity assessment of process equipment to disturbances.

Monitoring can help to identify power quality problems and minimise losses in the production process and increase plant productivity. Monitoring is an essential component of the customer care process for this business.

1.2. What is the difference between measuring and monitoring power quality?

First, measuring is the procedure of quantifying electrical phenomena in magnitudes like Voltage, Ampere. These measurements are realized by measurement instruments, well known, like ampere or volt meters. On the other hand, we need to define limits of power quality magnitudes; those within the measured values are defined as good power quality. Once these limits are defined, measurements can be compared and the level of power quality in the grid can be determined. There is a quantity of power quality parameters defined, for example in the standard EN 50160 which shows the most important parameters of voltage quality in distribution networks.

Monitoring power quality differs from simple measurement as a time component is added to the measurements; thus, we can determine when a power quality problem occurs. That means we record the electrical quantities for a defined period then they exceed a defined limit in order to analyze them afterward. This is necessary because most of the power quality problems are temporary, and they appear and disappear. Stored data can be analyzed after the power quality event, and sometime this is the only way to truly determine the cause and the nature of the power quality phenomena.

2. POWER QUALITY PROGRAM

When power quality problems occur in industry, monitoring may be useful to determine the cause of the lack of power quality, but it should be a part of a whole power quality program. Monitoring is an important part of the program, but it should go with a power quality program. The following list summarizes its principal parts [3, 4, 5]:

1. Secure a commitment. The first task is to obtain internal support for the program. Engineering, production and management must be convinced of the benefits of this program.

2. Assemble a team. A team of persons coming from different plant division should be assembled.

3. Obtain participation and cooperation of the electric utility. An important part is to obtain the participation of the electric utility. Usually, the utility is interested in collaborating in order to improve customer satisfaction.

4. Establish a power quality specification. It is needed to specify the lack of power quality, defining limits for the measured magnitudes. The limits refer to the process, which suffers the consequences of power quality problems. For example, the CMEBA and ITIC curves can be taken as basis for the voltage dip analysis.

5. Establish a communication process with the electric utility. Events in the power system that lead to interruptions etc. should be expressed to the customer by the utility through a defined communication process. For example, restarting a production process should be delayed, when more grid side disturbances are expected.

6. Establish a monitoring project and execute a power quality survey. This part deals with monitoring power quality and recording event data. The organization of this survey is described in a later section.

7. Establish an immunization program. In this part a process for event analysis, root cause analysis and corrective action should be realized. A principal description of an immunization program is exposed in a later section.

8. Set improvement targets. Business losses can be reduced by improving power quality or immunizing processes. An evaluation of long term improvement actions, taking into account these business losses, should be done.

9. Establish a process to evaluate the power quality program. It is necessary to evaluate the effectiveness of this program periodically and if required, continue the program, redefine targets or terminate this program.

3. MANAGING MONITORING PROJECTS

When managing a monitoring project, significant questions will arise depending on the targets established previously [4]:

1. Why measure? This question clarifies the monitoring objectives as they determine the choice of measurement equipment, the triggering thresholds, the methods for collecting data, the data storage and analysis requirements, and the overall level of effort required.

2. What kind of power quality parameter do we want to measure? Power quality includes a wide variety of conditions on the power system. Important disturbances can vary in duration from very high frequency impulses (lightning strokes), to long-term overvoltages and interruptions. Standards, like IEC 61000 and EN 50160, and grid codes define the power quality parameter to be measured. The IEC 61000-4-30 defines the methods for measurement and interpretation of results for power quality parameters in 50 Hz systems and is part of the standard IEC 61000 of electromagnetic compatibility.

3. Where should the measurement equipment be located? Power quality monitoring can be very expensive due to the number of possible monitor locations. It is very important, therefore, to carefully select the monitoring locations based on the monitoring objectives to minimize the involved costs. For example, for trouble shooting applications, the monitor should be placed as near to the sensitive load as possible. On the other hand, for overall power quality monitoring, the monitor is located at the power entrance. Often, the monitor placement is limited by the access to the power lead, especially for current metering.

4. How should the measurement be carried out? The physical organization of the measurement should be carried out carefully; the number of monitors needed should be defined along with the kind of current clamps required. Also, the accessibility of the measurement point should be determined.

5. What kind of equipment should be used for the measurement? The instrument can be separated into two main types: power quality monitor and power quality analyzer. Power quality monitors are instruments equipped with memory and the ability to record power quality parameters over some period of time by triggers. Modern monitors can self adjust thresholds to capture the most relevant events and also ignore non-relevant events. On the other hand, power quality analyzers are instruments that measure and analyze real time data, sometimes only harmonics. The analyzing results will not be recorded.

Monitors and analyzers on the market enclose a wide range of features, and it is not easy for custumers to choose the right instrument for the required application.

6. How long should we measure for? Often it is important to define the period of monitoring depending on the event expected to take place and the available budget. In critical processes, permanent monitoring is also applied.

After clarifying these six questions, the survey is developed by the following steps:

1. Planning the survey. All involved persons of the monitoring survey should participate in the survey planning and agree on a schedule for the monitor installation, the monitoring period, the communication process and the de-installation of the monitor.

2. Preparing for the survey. Appropriate monitoring instruments and current clamps should be available. The staff using the monitor equipment should have received sufficient training on the instrument in order to avoid human errors.

3. Inspecting the site. The optimal monitoring location may not be easily accessible and therefore the possible location should be decided by a site inspection. Modifications in the electrical cabinet or programmed power interruption may be necessary. Furthermore, during the inspection, the most significant electrical and non-electrical data of the installation should be collected for further analysis.

4. Installing the monitor. The installation should be done according to the security code, in particular when the installation is done without interruption. Isolating gloves, protective goggles and a helmet are indispensable in order to prevent accidents during the monitor installation.

5. Monitoring the power. In this part, the monitor is installed for the agreed monitoring period. It may be necessary to discharge the monitoring data from the monitor periodically, if a lot of power quality events are expected and the monitor memory is limited. Furthermore, the trigger levels should be chosen with care, because very high levels could fill the memory with unimportant events without significance. It is recommended to check the memory one hour after the installation of the monitor and readjust the trigger levels.

6. After the monitoring period, the deinstallation of the instrument is done, respecting the security code. If the event expected to take place, is not recorded, a decision to prolong the monitoring or abort the survey must be done.

7. Analyzing monitoring and inspection data. The most difficult part is analyzing and interpreting the data collected during the survey. Several kind of analysis can carried out with this data: RMS analysis, waveform analysis, trend analysis, transient analysis, harmonic analysis, etc. Monitor manufacturers offer special software in order help the user to visualize the data and some software are able to generate reports automatically. Nevertheless, the right interpretation of the results of these tools can only be carried out by an experienced engineer.

8. Defining corrective solutions. The next logical step is to perform an immunization program, following the steps described in the next section.

4. IMMUNIZATION PROGRAM

As the process becomes more automated, the sensitivity to power quality problems, in particular to voltage dips, increases. In many cases, the failure of one element due to the dip (sensors, static converters, bus controllers, remote racks, etc.) causes the entire production to stop because the automation chain acts as a propagation stream. Restarting the processes can be difficult due to the raw materials accumulated, which must be removed before. The proposed method [5] takes into account quantity and quality aspects, as well as the heterogeneity between the productive branches or different technologies involved. Depending on these technologies, different actions are needed to correct the sensitivity to dip voltages. Basically, there are two families of immunization techniques: to stop the plant with a controlled stop and try to restart after the dip, or to keep the plant working during the dip.

The steps to characterize the problems and, when possible, solve them, are:

1. Analyze the process. This activity has technical and management components. The technical component is the basis for identifying the origin and streaming of dip disturbances due to monitoring as well as to analysis of the production process. The management component is the basis for evaluating the economic impact of the disturbance. Sometimes it is useful to monitor the power supplies and to compare the results with the overall production plant monitor.

2. Identify the critical parts. As a result of the previous step, we can identify the critical parts. These are the parts that have a major contribution to production losses, or that indicate the origin of disturbance, or both. Due to the high level of plant complexity; the critical parts should ranked according to their importance.

3. Choose the immunization technique. Basically, there are two families of immunization techniques: to stop the plant with a controlled stop and try to restart after the dip, or to keep the plant working during the dip. In both cases, the process controls ("brains") of the plant must be on, so UPS or other techniques must be used to assure this. To implement any one of the two immunization techniques we need to combine a set of the following immunization tools in a coherent form:

i. Timed under-voltage relays
ii. UPS "process brains" feed
iii. Time and level protection sets
iv. Special programs in "brains"
v. "Ride through" features in static converters

4. Estimate the attainable theoretical level of immunity. In the case that parameters for a good plant characterization are known, the calculation of the attainable immunity level is possible.

5. Simulate and/or test the proposed actions. If a correct simulation is possible, in addition to the attainable immunity level, other useful information can be obtained, like relay protection set points, speed changes, temperature changes, peak torques, etc.

6. Project the concrete case. As result of the previous steps, a project plan for every case can be realized. It includes changes in the wiring scheme, or, the new programs and the new set points, installation of immunization equipment, etc.

7. Estimate costs. Execution cost, operation cost and maintenance cost must be estimated.

8. Make the decision. The plant management, after considering cost estimation and future benefits due to fewer production losses, must decide if the immunization projects will be executed. The final decision to immunize the plant and the strategy to be applied is always taken in accordance with economical parameters such as payback time.

5. GENERAL FEATURES OF MONITORING INSTRUMENTS

There are different types of monitoring instruments available in the market, sometimes their characteristics are not easy to compare. In order to choose the right instrument, it is necessary to analyze the monitoring needs first, for example, type of disturbance to be monitored, monitor period, requested accuracy. In function of these needs, the selection of monitor can be realized more objectively. The following list describes the general features of power quality monitoring instruments [2, 4].

— *Enclosure options: handheld, portable and fixed*. The choice of the enclosure option depends on the user's requirement. The handheld and portable options are more dedicated for engineering and trouble shooting applications. The fixed install option is more often used by utilities, industrial plants and equipments that are integrated in a power quality monitoring system.
— *Enclosure protections*. The environmental limits for the power quality monitors are usually specified by the manufacturers. The IP (Ingress Protection) rating also must be specified by the manufacture, instruments could have a similar NEMA rating too.
— *Power supply.* The power supply of a power quality monitor is also an important consideration. Supply voltage and frequency, battery back up during power failure or separate supply should be checked.
— *Memory.* The memory options for the recorded events can be hard disks, floppy disks, internal RAM and PCMCIA memory cards.
— *User interface.* The instrument – user communication is usually realised by built-in displays, external viewing devices or personal computers. The user – instrument communication is done by keypads, keyboards or by a personal computer. The personal computer options require a connection interface from the instrument to the personal computer. Many instruments allow remote monitor operation and real-time displaying of the signals.
— *Software and data analysis tools.* The software and data analysis tools supplied with most power monitors have a variety of functions and data manipulating abilities.
— *Printer.* The printer can be installed internally, with a direct connectaion or connection by a personal computer.

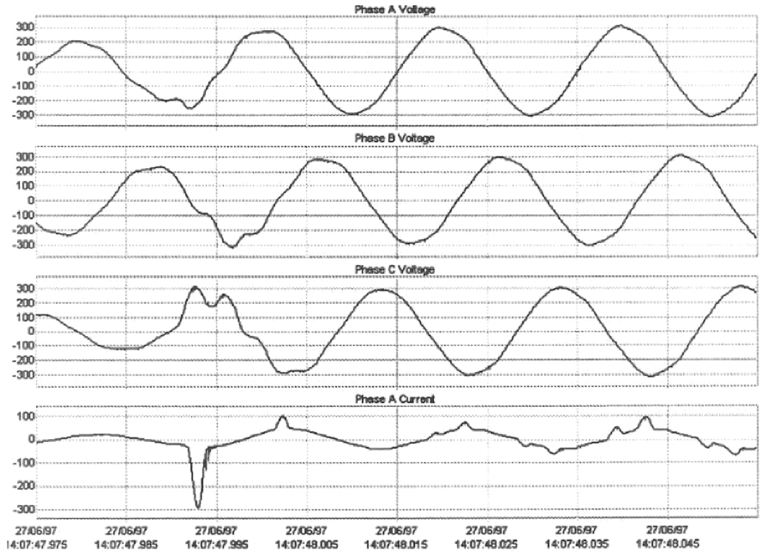

Fig. 2. Inrush peak current after voltage dip of a power supply

— *Accessories*. Leads, probes, sensors, current clamps, frames, handles and carrying cases are typical accessories supplied by the manufacturer.
— *Warranty*. Manufacturer or supplier may provide a warranty for a year or more.
— *Update ability*. The update ability of software and hardware (optional modules or cards) is an important deciding factor in the purchase of the monitor.
— *Maintenance and calibration*. Power quality monitor requires periodic maintenance and calibration. This is an important factor for the life time costs of monitoring and should be considered.
— *Accuracy*. The accuracy of a power quality monitoring is specified by the manufacturer
— *Resolution*. The resolution of an instrument is a measure of the detail of the digital sampled data after the analogue digital converting process, and it is represented in bits. The larger the number of bits, the finer the resolution with which the sampled data is captured.
— *Sampling rate*. It defines the rate at which the input channels are sampled and should state in samples per cycle. For detecting transients, high sampling rates in the MHz are necessary.
— *Voltage withstand*. Manufacturers may specify the voltage withstand of the monitor and the complied standards.

5.1. Signal Input/Output

The following list describes the signal input and output interface of power quality monitoring instruments.

— *Input channels.* The input channels are the main analogue inputs to which the voltage current transducters are connected.

— *Analogue inputs/outputs.* Analogue inputs can, for example, monitor additional parameters while analogue outputs are used, for example, as signals to other monitors.
— *Digital inputs/outputs.* These types of inputs and outputs are mainly used to trigger other monitors.
— *Communication and networks.* Internal and external modems via RS232, Ethernet and direct PC connection (USB, RS232, RS485, and Infrared) are provided with the monitor instrument. Many instrument manufacturers allow the user to download information or operate the monitor via internet.

5.2. Functions

The following list describes the functions of power quality monitoring instruments.
— *Data capture by present thresholds.* Parameters to be measured are usually captured when the disturbance exceeds a present threshold (event logging) or at repeated set time intervals. The thresholds and time intervals are set up by the user. By event logging, the captured waveform is usually logged one or more cycles before and after the event to provide a full picture of the event.
— *Data capture by self-adjusting thresholds.* The monitor can set its own thresholds by an established steady state norm. This method allows the detection of small deviations and trends.
— *Externally triggered data capture.* Many monitors provide the feature to be triggered externally.
— *Manual data capture.* For a snapshot of the present situation many monitors provide a manual trigger function.
— *Data logging and time interval recording.* With data logging, the parameters are continuously monitored and can be captured at set time intervals established by the user.
— *Waveform capture.* Some power quality monitors have the ability to capture waveforms (mainly voltage and current). These captured waveforms can de viewed by built-in displays or can be downloaded to a PC. Often, the instruments provide functions such as harmonic analysis and wave form analysis.
— *Time synchronisation.* Some power quality monitors have the option of time synchronisation by an external time signal or a radio signal.

5.3. Firmware

Some meter manufacturers periodically provide new releases of monitor firmware. Firmware releases, typically provided free of charge by manufacturers, are sometimes used to correct errors in the metering algorithms or to enhance the existing feature set of your meter without purchasing new hardware.

6. STANDARD IEC 61000-4-30

The aim of this standard is to define measurement methods which make the comparison of the monitoring results available, no matter which instrument is used. The first version of the standard IEC 61000-4-30 was published in 2003 [IEC].

Measuring parameters defined in this standard are power frequency, nominal voltage, flicker, voltage changes, voltage dips and swells, voltage transients, imbalance, harmonics, interharmonics and signalling voltages. It also specifies measurement uncertainties for voltage, current and frequency as well as for derived values; even through uncertainties of connected current and voltage transducers are not considered.

On of the most important parts of this standard is the specification of measurement intervals and their aggregation as well as the time-clock uncertainty.

Two different classes of measurement performance are defined in this standard:
— **Class A performance**: This class of measuring instruments is recommended for contractual measurements between network providers and customers to verify compliance with standards or resolving disputes.
— **Class B performance**: This class of measuring instruments should be used for statistical surveys, trouble-shooting applications, etc. where high accuracy is not necessary.

This standard brings about two different product lines for monitor manufactures: high-end product with class A and low-end instruments with class B.

The technical requirements of class A measurement devices are very high, the required accuracy of voltage and current is 0.1% and the aggregation of the measurements results requested is very strict. Therefore class A instruments are definitely more expensive than class B instruments and there are very few manufactures offering them. Moreover, there is no authorized test laboratory for this standard; mostly the certificates are given by firms and laboratories on their own self-reliance.

For trouble-shooting applications, were the accuracy is less important than the type of disturbance and the location of its source, class B instruments or existing measuring instruments may be adequate. Also for measurements according to the standard EN 50160, class B devices are adequate.

7. CONCLUSION

The success of planning and executing a power quality program is dependent upon a profound knowledge of technology as well as the non-technological aspects, like management and organization of monitoring projects.

In this paper, three different programs for power quality improvements were presented: an overall power quality program, designated for an overall power quality improvement of the plant; a power quality survey, focussed on determining and locating the source of the power quality problem by inspecting the site, planning and executing a power quality monitoring program; and lastly, an immunization program with the objective of immunizing industrial processes to disturbances. In all three programs, their correct management plays a decisive role, and helps to achieve the required results.

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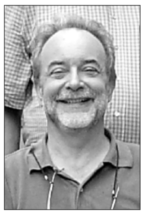

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