A Framework for Implementing Continuous, Iterative Power Quality Management

by Vanya Ignatova and Chuck Hoeppner

Executive summary

Power quality problems are one of the major causes of unscheduled downtime and equipment malfunction and damage. This paper presents a power quality management framework–based on continuous and iterative monitoring, analysis and corrective actions–that improves power quality performance. The framework can be applied to standalone or integrated energy / power management programs and will result in reduced unexpected downtime, extended equipment lifetime, and improved operating conditions.

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Introduction

Power quality is an area of growing concern for end users due to the frequency and financial impact of power quality issues: 30 – 40 percent of all unscheduled downtime today is related to power quality problems. In the Industry sector, for example, the cost of poor power quality can reach four percent of annual turnover and is often equivalent to the total balance payable on a facility's energy bill.[1]

Worldwide user surveys show that complaints about power quality-related disturbances– harmonics, voltage dips, flicker, and so on–are increasing every year. This is due to the number and variety of power quality disturbances, growing equipment sensitivity, and an increasing user awareness (see **Table 1** on the following page).

Today, an end-user electrical installation is exposed to a high number of various power quality problems; 80 percent of these disturbances are generated by user-owned equipment. In industrial facilities, for example, such disturbances can be caused by non-linear loads like arc welders or variable speed drives, capacitor switching, or large motor starts. In commercial buildings, electronic equipment like computers, printers, and servers may also generate additional power quality disturbances.

The other 20 percent of power quality disturbances come from the energy provider, as even the most advanced transmission and distribution systems are not able to guarantee 100 percent energy availability. Modern transmission and distribution systems range between 99.9 to 99.99 percent availability, depending on redundancy level, geographical location, and voltage level of the network. Even with 99.99 percent energy availability, the equivalent interruption time amounts to 52 minutes every year.

What is power quality?

In an ideal three phase power system, voltages are at nominal magnitude and frequency, perfectly balanced and with a perfect sinusoidal waveform. Any disturbance on one parameter (magnitude, frequency, waveform, or symmetry) is classified as a power quality problem. There are a variety of power quality disturbances – voltage dips, harmonics, transients, etc. – all of which can have negative impacts on the electrical system and equipment, such as power outage, device damage, failure, overheating, degraded performance and reduced equipment life.

At the same time, the end user's electrical installation is much more sensitive to power quality problems than it was in the past. A modern network includes large and growing amounts of electronic equipment and switching devices. These can generate power quality problems and simultaneously are far more sensitive to power quality events. As a result they fail more often.

Finally, the increasing number of power quality-related user complaints are also due to growing user awareness. Today users are much more aware of the impact poor power quality can have in terms of downtime, equipment damage, and overheating. They expect a higher quality of electrical supply and pay more attention to the power quality problems generated on-site.

While a variety of solutions to manage power quality challenges exist, a lack of clear and understandable power quality management approaches persists. This generates a barrier for facilities that want to improve their power quality, as they lack the knowledge to address critical aspects of their power quality performance –including measurement, monitoring, documentation, reporting, analysis, preventive, and corrective actions. The aim of this paper is to establish a systematic and sustainable approach to manage power quality within a facility.

[1] J. Manson, R.Targosz, *"European Power Quality Survey Report", Leonardo Energy*, 2008

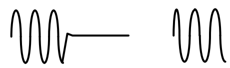
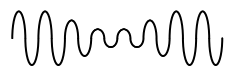
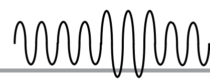
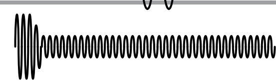
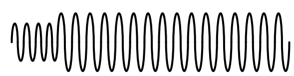
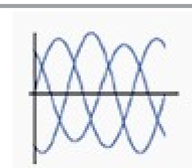
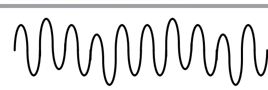
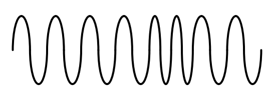
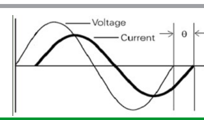
Disturbance category	Waveform	Effects	Possible causes
Transients		Equipment malfunction and damage	Lightning or switching of inductive / capacitive loads
Interruption		Downtime, equipment damage, loss of data possible	Utility faults, equipment failure, breaker tripping
Sag		Downtime, system halts, data loss	Utility or facility faults, startup of large motors
Swell		Equipment damage and reduced life	Utility faults, load changes
Undervoltage		Shutdown, malfunction, equipment failure	Load changes, overload, faults
Overvoltage		Equipment damage and reduced life	Load changes, faults, over compensation
Harmonics		Equipment damage and reduced life, nuisance breaker tripping, power losses	Electronic loads (non-linear loads)
Unbalance		Malfunction, motor damage	Unequal distribution of single phase loads
Voltage fluctuations		Light flicker and equipment malfunction	Load exhibiting significant current variations
Power frequency variations		Malfunction or motor degradation	Standby generators or poor power infrastructure
Power Factor *		Increased electricity bill, overload, power losses	Inductive loads (ex. motors, transformers...)

Table 1
Common disturbances that impact power quality

** not defined as PQ problem from Standards perspective, but considered as a PQ problem from End User perspective.*

Power quality management

This paper presents a framework for implementing, maintaining, and improving power quality with the aim of achieving continuous power performance improvement. The recommendations presented are suitable for any facility – whatever its size, sector, or geographical location.

Power quality management requires the establishment of a power quality policy, as well as baseline, planning, and management reviews. Measurement, analysis, and improvement of power quality as a continuous process are mandatory tasks in order to achieve sustainable results.

Key steps in the power quality management include the following:
:

1. Measurement and monitoring
2. Results interpretation and analysis
3. Corrective and preventive actions

Measurement is the first and fundamental step in the power quality management. The measurement is used to detect and understand power quality problems, but also to verify that the implemented corrective action is working. What, where, and how to measure are the fundamental questions addressed by this white paper.

Analysis consists of the interpretation of the measured results and the design of proper corrective solutions. Analysis usually requires skilled professionals who are experts in power quality. Analysis might also be performed (or at least facilitated) by power quality monitoring software.

Corrective actions may impact design architecture, equipment choice, or settings. They may also require the installation of additional power quality correction or protection equipment. An overview of the power quality correction equipment and guidelines for their selection are provided at the end of this paper.

Measurement and monitoring

In the business world, a popular adage states that you can’t manage what you don’t measure. This principle also applies quite well to power quality management.

What to measure?

A number of different power quality disturbances affect the magnitude, the waveform, the frequency, or the phase balance of the supplied voltage or current (see **Table 1**). All of them can have a negative impact on the electrical system and equipment. However, the most frequent and the most impactful power quality disturbances should be analyzed more deeply and with higher priority.

Several power quality studies were conducted to evaluate the major power quality disturbances. In the United States, study results concluded that voltage dips, voltage swells, transient over-voltages (due to capacitor switching), harmonics and grounding-related problems are the most common power quality problems (see **Figure 1**)

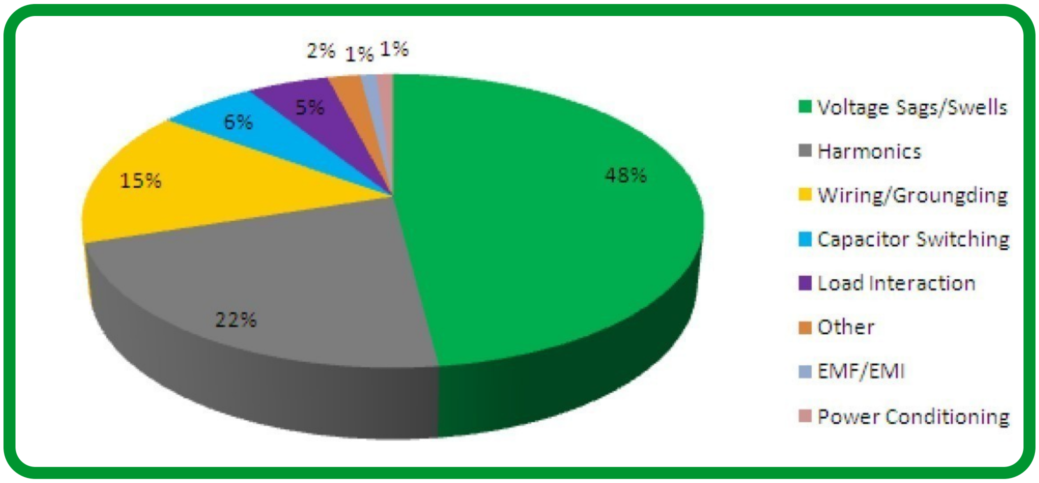


Figure 1
Most common power quality issues (U.S.)

Another power quality study conducted by the Leonardo Power Quality Initiative among various end users in the EU-25 countries concluded that the power quality disturbances with highest economic impact are voltage sags, interruptions, harmonics and transients (see **Figure 2**).

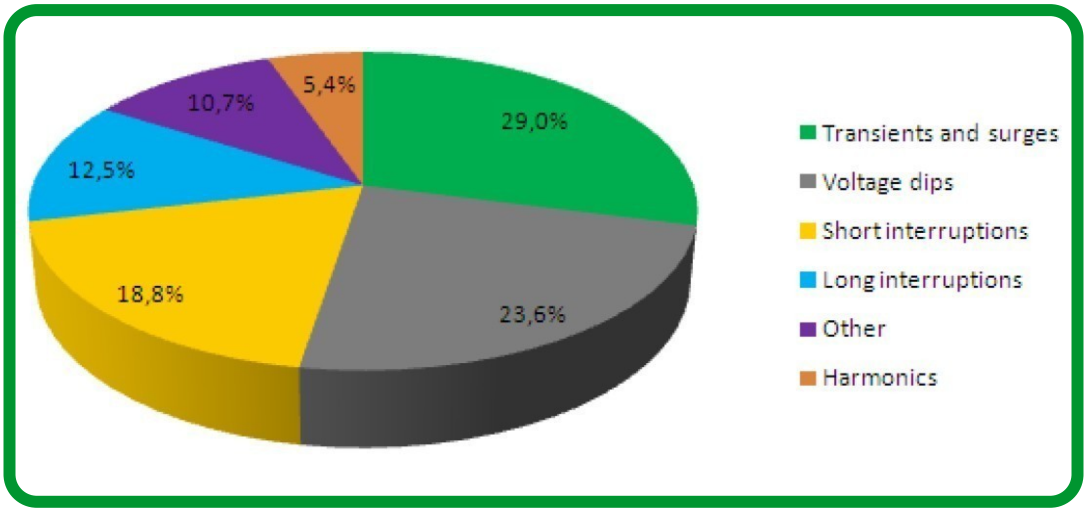


Figure 2
Power quality disturbances with highest economic impact in EU-25 countries

Each facility has its own specific power quality issues, depending on the installed loads, equipment, and the quality of supplied energy. However, based on the above international survey results and the rich group experience of hundreds of power quality audits and analyses realized every year around the globe, we recommend the systematic monitoring of the following power quality problems:

- Harmonics
- Power factor
- Voltage dips and interruptions
- Transients
- Imbalance (specifically in motor applications)

How to measure

Measurement can be performed over a short period of time, or on a more permanent basis, over extended periods of time.

A temporary power quality monitoring system allows detection of steady-state power quality problems – current and voltage harmonics, unbalance and voltage fluctuations. Such an approach is flexible and can be connected to strategic areas in order to investigate a specific problem on certain equipment or in a particular part of the installation. However, while a temporary power quality monitoring system can detect main power quality issues like voltage sags, interruptions, and transients, should these events happen outside of the usual two week measurement period, the system will not be able to analyse these events. This approach has the disadvantage of failing to provide a continuous improvement solution.

A permanent power quality monitoring system detects and records all power quality disturbances on an ongoing basis. It allows the display of power quality recorded data and the analysis of that data in real time. Even though an installation of this type of system may require maintenance, a permanent installation provides the greatest benefits as it enables continuous measurement, which improves system power quality and achieves sustainable results.

Where to measure?

To perform power quality measurements, a system should be equipped with power quality metering devices. These devices should be able to capture and record short-term power quality events, provide current and voltage, continuous disturbance measurements, and power quality compliance evaluations.

Power quality metering devices usually have a higher cost than power meters with more basic functionality, thus it is important to place them in strategic places within the electrical installation, or on sensitive loads. For example, placing a power quality metering device on the main incomers allows monitoring of the power supply quality and detects whether the disturbances are coming from the energy provider or are being generated on-site. Also, a key for continuous improvement of power quality and power system health is to collect and connect the information of all available sources into a single system, and provide tools that evaluate, analyze, report, and alarm on power quality issues.

Power quality analysis

Analysis includes the interpretation of recorded data and the evaluation of power quality's impact on the electrical installation and equipment. The analysis can be performed on a regular basis (for example, once per month) or ad hoc (when there is a problem caused by a potential power quality disturbance).

Analysis is usually performed by skilled and experienced professionals, with specific competencies in power quality, electric installation and equipment, who are capable of correlating power quality disturbances with equipment damage, malfunction, or electrical installation downtime.

Because electrical and maintenance engineers in a facility plant are not always power quality experts and may have difficuties exploring and benefitting from power quality data, the current trend is to embed increasing analysis and expertise capabilities into power quality monitoring systems. Such systems can provide meaningful dashboards and appropriate widgets to analyse power quality problems. For example, a trend graph (see **Figure 3**) should be used to analyse steady state power qualitity disturbances (harmonics, unbalance, power factor, etc.) where exceeding recommended limits on a regular basis can lead to issues such as equipment overheating or failure and network overload.

Figure 3
Analysis of continuous power quality disturbances

For power quality short-term disturbances or events such as voltage sags, swells, transients and interruptions, it is recommended to use statistical widgets, pie charts or counters (see **Figure 4**). Relevant information will include the number of events for a given time period, breakdown per type of event, per origin (downstream or upstream) and per estimated impact (likely impact or no impact). This type of information can help electrical engineers to evaluate the operating conditions of the electrical installation and detect if a power quality problem is at the origin of a power outage or equipment failure.

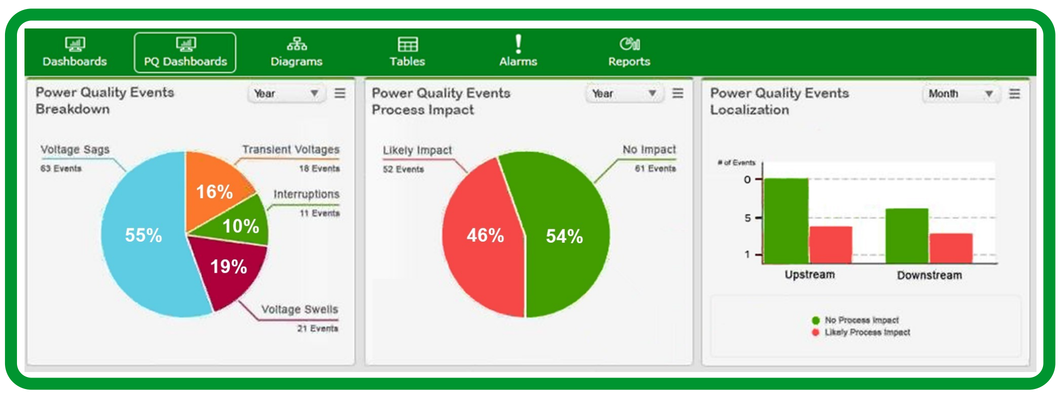


Figure 4
Analysis of power quality events

A power quality monitoring system can also simplify the power quality analysis. For example by associating green- yellow-red color code indicators to each power quality problem, or by an automatic root cause power quality analysis in case of electrical installation outage or equipment issues overall analysis is simplified. Such a system also addresses the cost aspects of power quality, estimating losses due to poor power quality. "Putting a price tag" on power quality issues makes it easier to perform the cost-benefit analysis, and facilitates return on investment evaluations of power quality monitoring systems.

Corrective and preventive actions

Based on the interpretation of results and conclusions, different solutions can be considered. They may include equipment for the mitigation of power quality disturbances, settings modification, design and architecture modification, or even selection of equipment that is less sensitive to power quality disturbances.

Overview of recommended power quality equipment

Each power quality problem requires specific corrective equipment. **Figures 5**-**8** illustrate common equipment solutions that address the main types of power quality problems and power factor issues.

Transients
To protect against transients, end-users may use transient voltage surge suppressors.

Figure 5
Transient voltage surge suppressors protect an electrical network from damaging power surges and spikes.

Voltage sags and Interruptions
To protect equipment from interruptions, end-users may use uninterruptible power supply devices (UPS) and other energy storage systems. Back-up generators or self-generation equipment is necessary to manage sustained interruptions. Other solutions include the use of static transfer switches and dynamic voltage restorers with energy storage.

Figure 6
UPS equipment is used to manage sustained interruptions

Harmonics
The equipment recommended for harmonic mitigation is the active filter due to its flexibility and high correction performance. Alternative solutions include passive filters, multi-pulse arrangement transformers, or harmonic correction at the equipment level – for example harmonic filtering integrated to variable speed drives.

Figure 7
Active harmonic filters inject harmonic current to cancel the harmful harmonic current in an electrical distribution system

Power factor
To reduce power factor and increase efficiency, it is necessary to produce reactive energy as close as possible to the loads. The easiest and most common way of generating reactive energy is to install capacitors on the network.

Figure 8
Network capacitors are specially designed for use in networks with frequently switched loads and harmonic disturbances.

Monitoring power quality equipment

In the past, power quality correction devices were considered “set and forget”. After installation there was no specific follow-up of the equipment efficiency and operation. End users today require remote monitoring of power quality correction equipment to verify the efficiency of the corrective actions and to monitor the operating status and the operating conditions (see **Figure 9**). End users expect to be alarmed when an equipment indicator is out of range and anticipate an equipment failure.

Figure 9
Power monitoring software can verify operating status of equipment and alarm end users when their operation moves outside of normal parameters.

Conclusion

The different types of power quality disturbances, their impact on equipment and electric installation, as well as possible mitigation solutions are well known in today's business world. However, there are no standards, recommendations or guidelines on how to implement correction, management, and continuous improvement of power quality within an electrical network.

Power quality management methodology is designed to improve power quality on a continuous basis, increase electric installation uptime, and optimize equipment performance, efficiency and lifetime. The three fundamental and specific steps for power quality management (measurement and monitoring, results interpretation and analysis, corrective and preventive actions) are meant to be iterative, and provide a framework through which each facility can set and engage in improving power quality. Doing so will reduce unexpected downtime and optimize equipment life and operating conditions.

For those that want to address the power quality to improve their uptime, energy efficiency and asset management, consider the following short and long term steps:

Within the next few weeks: Plan a project roadmap. As a starting point consider monitoring the power quality at plant level, or critical areas with sensitive loads.

Within the next 6 months: Analyse the results and their impact on your equipment and installation. Assess the power quality correction technologies. Identify an initial project with reasonable investment that can result in positive results over a relatively short period of time (for example, an immediate opportunity to deploy power quality equipment for a particular device or process).

Within the next 12 months: Plan methods for expanding power quality to a broader areas of the installation. Collaborate with internal stakeholders and/or seek out expert services organizations that have the technical expertise and global presence to support a long term infrastructure integration project.

About the authors

Vanya Ignatova (PhD, Power Quality) is the Power Quality Marketing Expert for Schneider Electric, working on power quality solutions creation for Industry, Critical Buildings, and Utility applications. Vanya received her PhD from Institut National Polytechnique de Grenoble in 2006, receiving the award for the year's Best PhD from the Laboratory of Electric Engineering. She joined Schneider Electric in 2006 as an Electrical Engineering Expert, and since 2010 has specialized in Solutions Offer Creation for energy management and power quality.

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