PQMS – Power Quality Monitoring System: Improve Power Systems Through IEDs

Renan Bernardes and Fernando Ayello
Schweitzer Engineering Laboratories, Inc.

PQMS – POWER QUALITY MONITORING SYSTEM:
IMPROVE POWER SYSTEMS THROUGH IEDS

Renan BERNARDES
Schweitzer Engineering Laboratories – Brazil
renan_bernardes@selinc.com

Fernando AYELLO
Schweitzer Engineering Laboratories – Brazil
fernando_ayello@selinc.com

ABSTRACT

This paper discusses a new concept in power quality monitoring through the use of digital multimeters specially designed for use in circuits with nonlinear loads, together with other intelligent electronic devices. These devices allow utilities to monitor and analyze relevant disturbances in the distribution system. Interconnected equipment on a high-speed communications network provides the basis for an electrical power quality monitoring system. This system is a powerful tool for evaluating and minimizing the costs of interruptions, maintenance, and any other influencing factors that may negatively impact the power system.

INTRODUCTION

The question of power quality has been widely discussed due to the increase of electrical loads in industrial facilities and in service and residential sectors, which has led to an increase in the load sensitivity to power disturbances.

The objective of this paper goes beyond concepts and definitions to describe the basic philosophy of a system created to monitor electrical power quality, perform a true inspection of the power system, and assist utilities in making decisions related to cost reduction and solving power quality problems.

It is interesting to note the degree of importance given to certain events in the electrical system. Obviously, the more serious the disturbance, the greater the interest is in analyzing and detecting the causes. To better understand the power quality question, the disturbances are classified into three types:

Power outages in large areas

The consequences of large disturbances attract attention, but little can be done after these events except to analyze them to avoid repeating the problems.

Power outages in localized areas

Localized power disturbances, which we can call normal or expected, are simple and generally eliminated through the correct response of the protection system.

Small disturbances occur with greater frequency than large disturbances; thus, the analysis and investigation of them are fundamental to avoid larger problems in the future. The analysis of these disturbances can also help to optimize corrective actions by maintenance teams.

Hidden disturbances without power outages

Hidden disturbances that do not cause power outages have the following characteristics:
- Do not involve forced interruptions of power
- Are not perceived by system operators
- Do not cause the relays to trip
- Affect maintenance
- Occur repetitively

Unlike the disturbances that cause interruptions in electric power and are easily identified, hidden disturbances are not detected by humans or conventional supervisory systems, but should be investigated for three reasons:
- May affect service life of electrical equipment
- May cause production stoppage—even without the occurrence of a power outage
- May provide valuable information to avoid a more serious disturbance involving power outages, damages, or equipment failures

These disturbances are best investigated by specialists, using appropriate tools that log disturbance data. Some examples include excessive levels of harmonics in a power transformer, successive voltage sags in a medium-voltage feeder, and a high number of neutral overcurrent element pickups. With the knowledge gained through analyzing hidden disturbances, we can avoid future interruptions and also plan to use existing feeders and equipment for expansions and to improve equipment efficiency.

A Power Quality Monitoring System (PQMS) can be used to continuously improve the electrical power system and consequently reduce the costs cited above because it helps identify, assess, and correct potential problems.

DEFINITIONS

A PQMS centralizes and structures the information collected from various parts of the power system, obtaining relevant information at the exact instant in which problems occur. It is made up of intelligent electronic devices (IEDs) distributed throughout the power system and located at strategic points in the distribution substations. These devices must have a high data-processing capacity to satisfy functional requirements.

The system consists of various IEDs (meters, protective relays, and communications processor), one or more remote workstations (microcomputers), web-based software, and an Ethernet communications network. For efficient analysis, the information must be centralized and structured for power quality monitoring.

This type of data system has the ability to detect and record disturbances, as well as the waveforms of harmonic distortions above a given level, monitor the load profile of a feeder and its participation in the maximum demand peak, record the power consumption measurements of several circuits, and obtain tables of various metered electrical quantities at points of interest.

DIGITAL MULTIMETERS

Introduction

Digital multimeters are the basis of the PQMS and must satisfy specific requirements for correct power quality monitoring. For optimum PQMS benefits, the following features must be available:

- **True RMS measurements.** Measurements, to at least the fiftieth harmonic, allow for the comparison between the true RMS and fundamental values.
- **Inclusion of new measurement quantities.** Measurements that traditionally were not specified and used in electrical installations, such as harmonic distortion, power distortion, K-factor, peak factor, and voltage unbalance, flicker, sag, swell, and interruption should be considered for inspection of electric power.

Multimeters are in use continuously and must be installed permanently on the most important circuits, such as the utility incoming circuit for an important consumer or on busbars and feeders with special loads, such as arc or induction furnaces, converters, etc. Temporary installation of portable multimeters, even for relatively long periods (one month), is not reliable because the phenomenon to be monitored may not occur during this period.

General features

To meet the minimum requirements for a PQMS, the multimeters should provide:

- **RMS operational and demand metering.** Electrical quantities used for operational purposes such as currents, voltages, power, and demand should be measured with high accuracy. Additionally, the meter must be able to monitor the consumed demand for each feeder.
- **Revenue metering.** As an option for interconnections between utilities that use revenue and power quality meters, the following energy readings would be available with 0.2 accuracy: active energy, reactive energy, and apparent energy, as well as bidirectional readings of active and reactive energy.

- **Power quality.** The multimeters must also provide various measurement quantities that allow power quality monitoring of a circuit in compliance with IEC (International Electrotechnical Commission) standards [1]. The main parameters to be measured and recorded are:
    - Voltage sag, swell, and interruption (VSSI)
    - Harmonic distortion to the fiftieth order
    - Voltage fluctuation
    - Voltage unbalance
    - Power factor
    - Frequency variation
- **Control functions.** The meter should also provide control through contact inputs and outputs and user-programmable logic (with Boolean operation, analog compare, trigger, remote control logic, etc.). This tool is useful for controlling and protecting capacitor banks, transformers, and harmonic filters.

Disturbance monitoring

Multimeters must be able to monitor disturbances continuously by incorporating waveform visualization for problem analysis. They may be requested by the PQMS operator (through the software application) or in response to an alarm condition detected by the multimeter itself or from an external trigger. Fig. 1 shows the graph generated by a multimeter during voltage sag. The voltages and currents for the three phases are shown. Note that the event in question resulted in load shut-off (currents decreased to zero).

For VSSI, it is important to know the instant, the voltage magnitude, and the duration of the events. Also, it is necessary to alarm the events that cause interruptions. The meter must be capable of sending all this information through a communications network for later analysis.
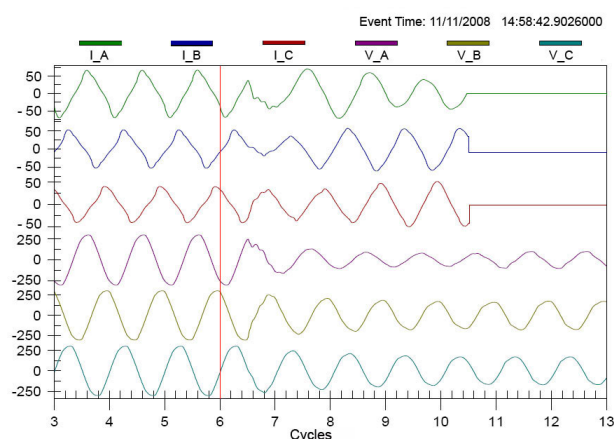

Fig. 1. Model of voltage sag for currents and voltages for all three phases

These phenomena occur frequently in electrical installations of industrial plants. Thus it is possible to diagnose equipment problems caused by VSSI, identify vulnerable areas, and then take corrective actions.

Industrial process interruptions due to abnormal voltage supply conditions result in high operational costs, such as production losses, equipment damage, reduction in process quality, and delays due to the time lost in restarting the production process. Industrial customers want and need reliable monitoring systems to maintain power quality.

After interruption or shut down of a power system without PQMS, it is very difficult to determine the cause of the disturbance, especially if it originated in remote circuits (other points in the installation or other customers' or their utility's systems). Fig. 2 shows a voltage sag experienced by an industrial customer due to a fault on another feeder.
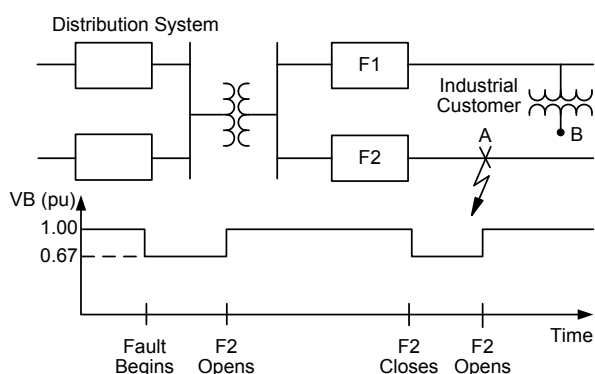
Fig. 2.   Voltage sag in an industrial facility (Point B) due to a short circuit in the distribution system [2]

The monitoring capacity of multimeters can:

- Identify VSSI and other power quality phenomena for later analysis
- Compare the sensitivity of equipment installed in the power system with the pertinent standards
- Distinguish between equipment failures and power system problems
- Aid in determining the cause of a problem
- Precisely distinguish a power outage condition from a voltage sag condition
- Provide data for equipment specification
- Verify the customer's protection settings
- Justify the purchase of power conditioning equipment

OTHER IEDs

A complete PQMS should be composed of sets of IEDs and not just multimeasurement devices. A combination of multimeters with system IEDs allows monitoring of all system points.

The integration of meters and protective relays allows the association of some disturbances with the operation of the protection system. For example, voltage sag can be associated with a short circuit if the events occurred at the same time.

Protective relays have particular monitoring functions specific to each type of equipment, thus contributing to system power quality monitoring. Table 1 summarizes the types of IEDs that aid in monitoring the main power quality problems in electrical system equipment.

Table 1.   Functions of the IEDs in a PQMS

IED	Functions
Meter	Monitoring of sag, swell, interruptions, unbalance, flicker, harmonics, power factor, and frequency
Protective relay	Monitoring of batteries, transformers, generators, breakers, and auxiliary services
Data concentrator and server	Database, data retrieval from devices, and power quality indicator calculations
Satellite synchro-nized clock	Time synchronization
Computer with PQMS software	Practical and easy remote analysis and diagnosis through database access

For general feeder protection, the relay is able to monitor the dc auxiliary power supply, providing an alarm for dc undervoltage or overvoltage. It also monitors the circuit breaker, checking contact wear per pole and equipment coil.

For a power transformer, its own differential relay also monitors the thermal conditions, the ageing factor, and the service life.

Fig. 3 shows a typical distribution substation, considering all devices needed for the PQMS. Most, if not all, of these devices already exist in the utility's substations.
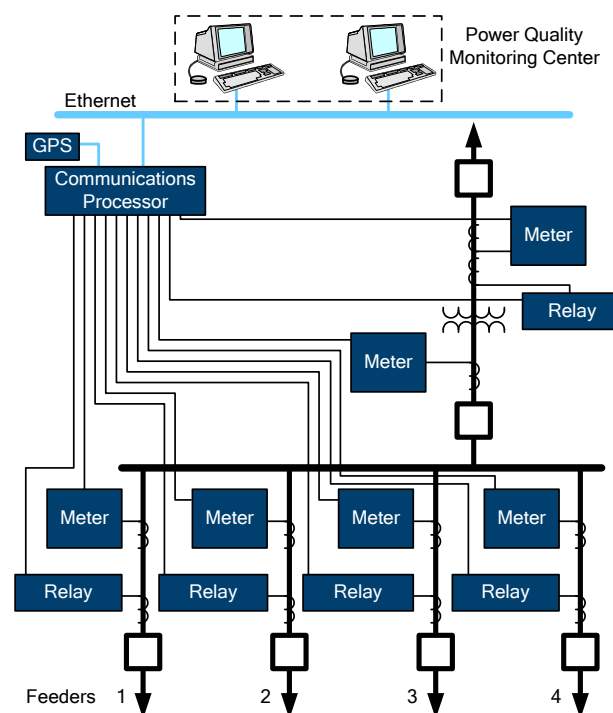

Fig. 3.   Integration of IEDs in a typical substation

Another important IED is the computational platform, in which the data from all the system IEDs are concentrated for manipulation and calculation. This platform also interfaces with the PQMS software application.

PQMS SOFTWARE APPLICATION

A PQMS must be able to support an unlimited number of workstations (microcomputers) and use a high-speed LAN (local-area network) or WAN (wide-area network). Each computational platform connected to the LAN/WAN must have equal access to the information supplied by the IEDs throughout the installation. With this arrangement, the electrical measurement quantities, event records, analog data records, alarms, waveform visualization, etc., can be obtained in a centralized manner. Operating in a client/server environment allows data to be shared and visualized on any network computational platform. Each user can have access to all existing IED information.

The screen of a typical PQMS user interface should provide clear and practical visualization of the metered and registered quantities according to international standards [3]. Fig. 4 shows a demonstrative software screen containing short-term, long-term, and steady-state events. More information on events and alarms, such as time of occurrence, duration, and severity, can also be obtained from the software.

Fig. 4.   PQMS illustrative screen showing power quality indicators

The values stored in the historical database can be manipulated and visualized in a practical, objective manner in accordance with the user's interests. One can see measurement reports, check when certain events were recorded, and determine which alarms were generated during time periods indicated by the user.

The user can perform additional tasks such as automatic data transfer to other applications.

PRACTICAL EXAMPLES

The application of the PQMS can alert technicians to the real day-to-day problems that go unnoticed and provide ways to propose alternative measures to minimize system operation and maintenance costs, for example:

- A cracked insulator in an overhead distribution system caused a small leak of current to ground. The component was substituted.
- A customer with an arc furnace that generated voltage flicker in a big area, disturbed many people. The meter provided all the information to define which filter/static compensator should be used.
- Tree branches near overhead distribution wires can cause voltage sag (Fig. 5). The PQMS helps to detect this problem to avoid future events and interruptions.
- A power transformer with excessive overheating exploded due to nonlinear loads (Fig. 5).
- A historical database can be used to plan for future expansions, reducing the costs of investments.

Fig. 5.   Trees near distribution lines and a power transformer after an explosion

CONCLUSIONS

The PQMS is a tool that provides innumerable benefits, allowing utilities to provide better power quality, therefore attracting and keeping new customers. The main benefits are:

- Reduced losses and costs in the distribution system
- Reduced number of interruptions and power quality problems
- Specific monitoring of select customers
- Improved monitoring of factors that may negatively impact the power system
- New tools to detect disturbance from customers
- Optimization of distribution equipment (through monitoring of transformers, capacitors, etc.)

REFERENCES

[1] *Power Quality Measurement Methods, Part 4-30 Electromagnetic Compatibility (EMC): Testing and Measurement Techniques – Power Quality Measurement Methods*, IEC Standard 61000-4-30, Oct. 2008.

[2] Kagan, N., "Conceitos Gerais em Qualidade de Energia," proceedings of ABINEE TEC, Anhembi, São Paulo, Brazil, 2007. Available: http://www.tec.abinee.org.br/2007/arquivos/s1601.pdf.

[3] *IEEE Recommended Practice for Monitoring Electric Power Quality,"* IEEE Standard 1159-1995, June 1995.