POWER QUALITY MONITORING SYSTEMS FOR FUTURE SMART GRIDS

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ABSTRACT

With the manifold increase in the distribution systems, the Power Quality (PQ) monitoring is becoming an important aspect for distribution network operators. Today, compliance of supply voltage with actual standards is rarely controlled and measured in the LV networks.

Verification of product quality compliance for a large number of customers becomes more and more important with the advent of future smart grids. Close link between PQ measurements and network control is an essential requirement for an improved operation of future grids

Thus this paper is going to describe how PQ monitoring will become an important part of the operation and management in future grids in all voltage levels. The biggest challenge we will face is its efficient implementation. Strategies like multilevel PQ monitoring approach, effective integration of PQ functionality to smart meters is discussed in detail. The suggestions on how to simplify set up procedure for PQ modules and technique of Distributed data storage to utilize minimum storage space for storing huge amount of data is also discussed.

INTRODUCTION

The most significant power quality problems that are responsible for poor power quality and are having detrimental effect on industrial& domestic load operation are voltage sags, supply interruptions, harmonics and voltage flickers. Thus electric power quality has become an important issue in the future power grids.

Many market and business forces, including initiatives related to Smart Grid, have increased the need for electric utilities around the world to understand the true performance of their transmission and distribution networks. Current utility practice for PQ measuring and monitoring has focused on a number of key outcomes, including:

- optimizing investment in PQ prevention and mitigation
- benchmarking grid performance internally
- benchmarking grid performance vs. other networks
- defining normal/appropriate PQ performance levels
- understanding the trending of PQ performance
- meeting the needs of the increasing number of customers sensitive to small variations.

MULTILEVEL PQ MONITORING APPROACH

The first step is to define the objective(s) of the Power Quality (PQ) monitoring. The second step is the conceptual phase, which has to cover a lot of aspects, like selection of locations, selection of monitors, transfer storage and processing of data and analysis and reporting of results. During the operation of the monitoring system the results should be evaluated on a regular basis to verify if objectives are still met and to continuously identify potential for optimization of the system.

Selection of Monitoring Locations

Generally, the selection of locations for PQ monitoring depends on utility's objectives, the architecture of the power system, the length of the monitoring period and cost related issues.

The location of monitoring equipment strongly depends on the detailed goals (e.g., increasing the effectiveness of voltage tolerance band management). Another major factor influencing location and costs for a monitoring system is the monitoring duration. For permanent monitoring PQ monitors intended for fixed installation are usually used, while mobile monitors are selected for temporary monitoring [3]. Fixed monitors are usually cheaper than mobile ones, but fix installed systems need a powerful infrastructure that may cause significant additional costs. In some cases a combination of fixed and mobile sitting can achieve a good trade-off between costs and benefit.

Selection of Monitoring Equipment

Continuous evolution of new technologies (sensors, IEDs, software, telecommunication) and standardization of related products are facilitating the acquisition of data required by Advanced Distribution Automation (ADA) applications. The trend towards an integration of PQ functions into IEDs (e.g., smart meter, protection relays, etc.) could significantly reduce costs of future PQ monitoring systems [2]. For example, if an IED with PQ features already exists at a certain site, no separate PQ monitor has to be installed.

Fig.1 shows some examples of IEDs that are suitable or have already PQ functionality included. These IEDs are usually part of other applications, like:

- Smart Distribution Applications using relays, RTUs,etc.,
- Smart Transmission Applications using Phase Measuring Units(PMUs), etc.,
- Advanced Metering Infrastructure(AMI) using smart meters

Fig.1 Relays, controllers and meters, potentially available for PQ monitoring.

In future PQ monitoring systems e.g., for performance analysis or compliance verification it is expected that dedicated PQ monitors are stepwise replaced by new IED's with PQ functions, because it becomes more and more difficult to justify the high costs for a large number of PQ monitors and time effort for their installation and maintenance. The Smart meters, their new requirement and complexities associated with the integration of PQ functionality to smart meters are dealt separately in detail as below.

Transfer and Storage of Data

A powerful and cost-effective PQ system requires effective communication links, smart systems able to communicate with devices in order to download information and verify their availability, as well as robust information systems for gathering and analyzing data with minimal human intervention. These topics will be depicted below.

Communication links

The more robust communication links are, the better reliability will be achieved and the less corrective maintenance will be required. It is also recommended to oversize communication requirements to some extent at the design phase. Otherwise the system may get handicapped and could not grow. Too restrictive cost cutting at certain points may lead to unexpected high costs in the future. For instance the use of IP networks instead of proprietary modem links may be more expensive, but guarantees that the PQ monitoring system can easily be improved and expanded in the future. IP networks, especially those based on the IPv6 standard, seem the natural choice.

Communication protocols

Now a days a plenty of different protocols exist, each of them having its advantages and disadvantages. A compromise has to be found between robustness, payloads, speed and standardization. Protocols that can be used in IP networks are always a good choice. However the main focus of the future development has to be the simplification of interoperability of equipment from different vendors. Easy exchangeability is essential for implementing cost-effective monitoring systems.

Storage and pre-processing of data

As a monitoring system grows, data storage and handling become more and more problematic. Performance of data analysis decreases with increasing size of databases. Highly aggregated indices are stored centralized, while the detailed data remains in the instrument itself (circular buffers) or a concentrator (collects data from a limited number of PQ monitors) and can be accessed if needed (i.e. complaints).

The consequent use of distributed storage and processing approaches in combination with modern technologies, like cloud computing ensures high flexibility and reasonable costs even in case of a significantly increasing data amount.

Analysis and Report of Results

Monitoring systems for compliance verification or performance analysis usually consist of many PQ instruments generating a large amount of data. The data has to be analyzed in an automatic, effective and proactive way with as less as possible involvement of staff. PQ experts should be notified only if a pre-defined event occurs or on a daily or weekly basis by few highly aggregated indices that can be interpreted at a glance. Only in case of abnormalities a deeper view into the data should be required. Therefore new algorithms are needed e.g., to quantify the typical PQ behavior of a site as a basis to identify sudden changes in the behavior. Aggregated indices that are easy-to-interpret even for e.g., staff in control centers will enable the integration of PQ into e.g., SCADA systems.

SMART METERS AND THEIR NEW REQUIREMENTS

The ability of smart meters for bi directional communication of data enables the ability to collect information regarding the electricity fed back to the power grid from customer premises [1]. A smart meter system includes a smart meter, communication infrastructure, and control devices.

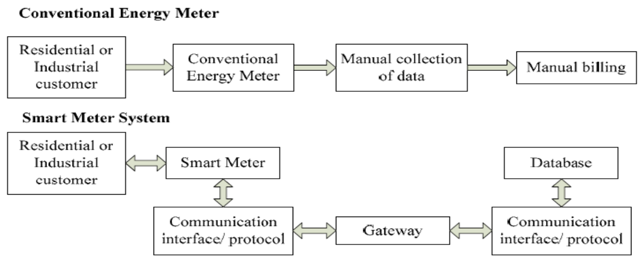

Fig.2 Conventional Meter V/s Smart Meter

Modular and flexible functionality

From an economic point of view it is not wise to integrate the full PQ functionality in each smart meter. A suitable way is a multi-level approach for PQ monitoring functionality integration into smart meters shall be used [4]. The PQ monitoring functionality levels can be classified as:

M-I encloses only the measurement and registration of the RMS values of the voltage and voltage interruptions. Methods have to comply with the relevant standards. M-I guarantees the observation of a basic quality level.

M-II includes the complete functionality of M-I. In addition it covers all main voltage quality parameters according to EN 50160. This includes flicker, voltage unbalance and voltage harmonics with a reduced frequency range. M-II functionality meets most requirements of “normal” sensitive consumers and should be used e.g. for the standard household customers. Currents are not considered in this level.

M-III includes the complete functionality of M-II. In addition different aggregation intervals (shorter and longer than the standard interval of 10 minutes) should be possible. M-III can be used for more individual measurements, e.g. for more sensitive customers with power quality contracts. Currents are still not considered in this level.

M-IV includes the complete functionality of MIII. Furthermore it includes the measurement of current quality parameters. It should cover a higher frequency range to allow measurements behind the actual standards. It should be used for monitoring very sensitive consumers with high power quality requirements and producers. M-IV allows detailed analyses of causes for power quality disturbances and to identify possible sources.

In general it has to be guaranteed that the functionality levels are downward compatible. For transparent information of customers about PQ, an optional human interface module for local visualization of power quality data should be made available.

To guarantee a vendor independent definition of the different M’s a suitable way could be the addition of a new instrument class in IEC 61000-4-30. In addition to the already defined classes A and S, a new class M could be added, which covers the above described four levels of power quality monitoring functionality.

Cost-effective integration of PQ functionality

For a mass roll-out it is only cost-effective to integrate PQ monitoring functionality into the smart meters. In this way already existing hardware of smart meters could be utilized, such as the analog signal conditioning, power supply unit and the communication interface. Especially the co-use of the communication interface and there by the use of the whole communication infrastructure for the PQ data handling creates a real comparative advantage. Altogether this enables a significant reduction of costs related to equipment, installation and operation.

Plug-in interface for the PQ-module

The PQ functionality should be integrated into an as small as possible module that is simply plugged into the smart meter. The smart meter has to provide a simple hardware interface for analog signals (voltages and currents) and for data communication between PQ-module and smart meter. These interfaces should be standardized to allow easy interchangeability of PQ-modules of different M’s and PQ-modules as well as smart meters of different vendors. That will reduce the maintenance cost and speeds up maintenance time.

Communication interface for data exchange

Power quality monitoring produces a tremendous amount of data. Today each vendor uses proprietary interfaces to his Power Quality Instruments (PQIs) and their own setup software and data handling software.

For data exchange some vendors implement in their analysis software an interface for manual data export on file basis. Furthermore it is not unusual that even one vendor provides different interfaces and setup software for different PQIs within their own product portfolio. As a result for the data handling becomes time consuming and error prone.

This is not acceptable for efficient PQ monitoring in future grids. Another drawback of this is the missing comparability of measured and aggregated PQ parameters. To guarantee a reliable and cost-efficient treatment of PQ data, international standards are necessary. This could be either standards for file formats or, which would be better, standards direct for the communication interface.

Zero-configuration approaches for setup

Today the setup of PQI is a complex and time consuming process. As mentioned before each vendor uses their own setup software with own philosophy. Different setups of different PQIs may finally lead to incomparable measurement data.

PQ-modules for smart meters should not need an individual setup. They have to provide a useful and unique standard setup out of the box. Depending on the local measurement conditions and based on the standard set up, the PQ-modules have to find their optimal settings and the measurement data have to be comparable. In general only for a few selected smart meters an individual, manual setup should be necessary. To identify the measurement location, the PQ-module should use the unique identification of the smart meter.

Intelligent data management and distributed data storage

PQ monitoring produces a huge amount of data. A scalable, multi-level approach for data storage is proposed for handling of this huge amount of data. The classical approach which exist today stores measured data nearly exclusive in one central storage site. The number of hierarchy levels varies. The data, depending on the number of devices and performance of communication links are transferred in to the central database.

Most of the data shall be stored in the PQ-module of the smart meter itself. Only high aggregated information should be continuously transferred to a central site. The data transfer should be initialized by the smart meter (push-principal) following an approach that randomizes the send time of individual smart meter to avoid a simultaneous transfer request of a huge amount of meters [4]. To optimize the traffic, different storage levels in combination with data concentrators could be introduced. Data should be step-wise aggregated according to a specific time period schema. All information is available for a certain time (first period), e.g. to respond to or to analyze customer complaints.

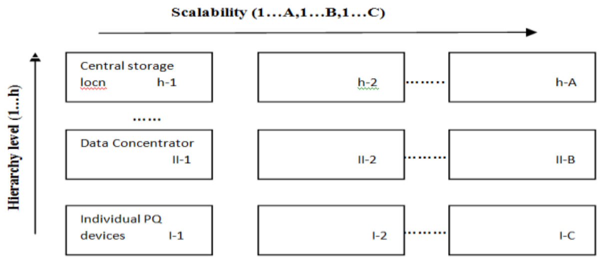

Fig.3 Principle scheme of scalable approach (PQ-Device can be a PQI, PMD or smart meter with PQ-functionality)

After the first time interval is lapsed, the storage and buffer system starts to aggregate the information depending on the elapsed storage time. Finally after the last period the data is deleted. Under normal operating conditions of the measurement system no action from the user regarding data management should be necessary.

For an individual measurement campaign the Distributed Network Operator (DNO) and/or the involved consultants should specify the requirements for data storage carefully already in the planning stage. Only by this way inadequate, non-sustainable storage solutions can be avoided.

ISSUES WHILE INTEGRATING PQ FUNCTIONALITY TO SMART METERS

Communication issues

Currently PQIs and Power Monitoring Devices (PMDs) use a wide range of different communication protocols. The protocols are used to send single items of information. MODBUS, IEC 60870-5-10x, DNP, ZMODEM, FTP, HTTP are some important protocols

The authors suggest implementing several protocols at once. For instance, short-frame protocols could still be used for online monitoring and integration into a SCADA system. At the same time suitable protocols for file transfers shall also be provided by the PQ device.

Usually files are generated on a daily or monthly basis. It would be advisable to provide flexible intervals for generating these files, ranging from minutes up to months. This can avoid reading one file multiple times.

Integration Issues

It's neither practical nor economically feasible to change all PQIs at the same time when its technology becomes obsolete. Within DNOs it's quite common to have cohabitation between ancient and very new devices. Therefore, it's a mandatory for the DNO to be able to integrate old and new equipment in a sustainable manner. Nevertheless, our proposal is to develop a future standard covering among other things an open communication standard. After establishing such a standard, integration of smart meters with PQ-modules from different vendors with already existing PQIs isn't an issue anymore.

Data Storage Issues

One problem that becomes evident with increasing number of devices is how data of PQIs is stored and handled. In contrast to simple meters or PMDs, PQIs may generate hundreds of variables at a time. Moreover, depending on their configuration, the data amount of a single PQI may vary in wide ranges.

Traditional ways of storing information in relational databases systems (RDBSs) do not seem adequate, at least without creative solutions. Many commercial software packages just rely on RDBSs with high reputation and wrongly assume the underlying design doesn't matter. It's quite common to store data in very simple tables consisting of time stamps, variable id and value as exemplarily shown in Table I.

Start	End	PQ Parameter id	Value
01/10/14 10:50	01/10/14 11:00	301	123678
01/10/14 11:00	01/10/14 11:10	301	123781
…	…	…	…

Table 1 TRADITIONAL WAYS OF STORING INFORMATION IN RELATIONAL DATABASES

Another important drawback of RDBSs is scalability. Even though some kinds of clustering can be developed, they usually require constant maintenance work and do not scale well at all. It's quite common to implement just vertical scaling based on more powerful computers.

However, it doesn't mean that certain RDBSs are not able to handle the structures mentioned above. It only means that most probably the size of data tables will be limited to a few thousand devices atmost for reasonable handling.

Analysis issues

Under normal operating conditions only highly aggregated information should be transferred to a central site. The fast availability of this information is important for managing customer complaints. The DNO should always be informed of the event before a customer calls the service center. The above described data handling strategy ensures that communication infrastructure and storage systems as well as the stuff analyzing the data will not be overloaded.

If the DNO intends to monitor the PQ status of a whole network with many sites online, new indices with following properties are necessary:

• Comparability between different PQ-parameters, sites and networks

• Direct relation between individual PQ-index and the margin between actual levels and specified limits (DNO planning levels or limits given by standards), which quantifies the quality reserve

• Clear and easy-to-understand indices, tables and graphs, especially in case of many sites

Our proposed PQ indices are based on normalization and aggregation and are derived from the methodology in [5]. They are global indices which characterize installation distortion and unbalance, respectively, with a single value. The advantage of going with Unified Power Quality Index (UPQI) is that the relevant information can be concentrated, avoiding non relevant and dispersed information. A case study conducted for PQ monitoring and data analysis using UPQI is as shown below

Case Study

The analysis given below has been carried out using the data monitored from 415V distribution feeders of 3 different sites. The measurements such as Voltage Sag, Swell, Interruptions & Harmonics taken over 10 min for each feeder, sufficient to give useful results for continuous disturbances. It was observed that harmonics was the major power quality issues in all the 3 Sites.

Site Indices & UPQI

Indices are calculated as quotient of the measured level and the set limit. The normalized & consolidated indices measured on each feeder for 3 sites as shown in Table-2. The overall PQ index for each site has been determined & indicated by single index for each site Known as UPQI [5][6]. UPQI been defined as

1. If all the consolidated disturbance indices are less than 1, UPQI equals the maximum of the indices.
2. If one or more of the indices exceeds 1, UPQI equals 1 plus the average of the Exceedances.

TABLE 2

	Sites		
Harmonic Indices	1	2	3
Feeder -1	1.65	0.0	1.11
Feeder- 2	0.55	0.0	1.12
Feeder -3	1.16	0.0	1.26
Feeder- 4	1.12	1.24	0.0
UPQI	1.31	1.06	1.16

In Support of UPQI, site 1 is worse than site 3, it is noted that:

1. Site 1 exceeds the allowable limits for three of its disturbance indicators with maximum deviation from set limit as related to site 3.
2. If the problem to the customer is in proportion to the total amount of exceedance, site 1 is worst because its total is 1.65 while that for site 3 totals 1.26. The Site 3 is worst as related to Site1, thus it is estimated as the site having majority of PQ Disturbances.

Thus by using UPQI, Sites with poor power quality could be easily ranked to determine the priority for PQ improvements. The data Analysis using UPQI reduces raw data generated by PQ instruments into Single indices. The single indices generated can be integrated to Site indices. By using indices data management &data Analysis can be done in an effective manner.

CONCLUSIONS

Monitoring PQ will become an important part of the operation and management in future grids in all voltage levels. Proper Planning is required in the initial stages itself. Costs for PQ devices and for their operation including maintenance, communication links, IT infrastructure, data analysis etc. have to be adequate.

Future PQ monitoring systems have to provide benefits for the DNO. A simple accumulation of a huge amount of data, which becomes more and more difficult to handle, is definitely not enough. On the other hand the individual analysis of single sites has to be superseded by global approaches covering the network as a whole. PQ monitoring should become actively integrated into the day-to-day network operation business and should be considered in new concepts for smart grids.

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