COMPREHENSIVE SOLUTION FOR USING DISTRIBUTION AUTOMATION EQUIPMENT IN VOLTAGE QUALITY MONITORING

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INTRODUCTION

In consequence of technological development, more diversified functionality can be integrated into distribution automation equipment (e.g. remote readable energy meters, protection relays, etc.) installed at primary substations, secondary substations or at customers sites to provide potential for developing data analysis and management, e.g. for power quality monitoring. The main function of this equipment remains the original but the measurement data can be used also for power quality monitoring enabling also development of voltage quality evaluation functions.

Measuring equipment of the presented system consists of protection relays with disturbance recorder and TCP/IP communication gateway, distribution transformer condition monitoring units with SMS communication, and advanced remotely readable energy meters with power quality monitoring functions. Power quality data provided by various measuring equipment is converted into unified and open format and stored into relational database called PQDB. A web-based application with analysing and reporting functions is developed to present power quality data via Internet as an application service provisioning (ASP) business. Also, the use of measuring data in network planning and operation purposes in the utility level and possibilities in network business regulation is discussed.

As a practical example, power quality monitoring system based on existing advanced measuring equipment in a middle-sized Finnish rural distribution utility is presented.

BACKGROUND

In recent years, market environment in the field of electrical distribution has experienced relatively radical changes. Distribution business has in many electricity utilities changed from municipality owned business towards capitaly controlled privatized business. To ensure adequate level of power quality in this business environment, regulation models for electricity markets are developed and commissioned. The purpose of regulation models is to encourage distribution utilities to intensify operations and to perform adequate investments to network assets to ensure quality of supply.

Structure of quality of power distribution is presented in figure 1. In Europe, voltage quality is defined in the standard EN 50160, which gives the main characteristics of the supply voltage at the customer’s supply terminals in public low voltage and medium voltage electricity distribution systems under normal operating conditions. The object of the standard is to define and describe the characteristics of the supply voltage concerning frequency, magnitude, wave form and symmetry of the three phase voltages. [1] In addition, there are some national regulations and recommendations.

In many European countries, quality of power distribution is a significant part of the electricity market regulation model. Voltage quality is regulated based on definitions in SFS-EN 50160. So far, quality of power distribution in efficiency determination of regulation model is mainly consisting of time and/or number of interruption, and quality of service and quality of supply voltage is not taken into account. Regulators are currently considering affiliation of voltage quality in power quality parameter in efficiency determination of regulation model.

At the moment, voltage quality is usually monitored temporarily at customer sites based on customer reclamations, not comprehensively and continuously over the entire distribution network. Reasons for that are complexity and expensiveness of systems and measuring equipment and investment not being economically arguable based on present regulation models and legislations.

Power quality monitoring including continuous voltage quality monitoring in larger extent could however give important information for various operations of distribution utility. In addition to power quality management, network operation benefits from more detailed information provided for real time state and fault management of the distribution network. Also, valuable information for network planning, customer service and condition management is provided. Furthermore, it is possible to develop efficiency determination of regulation model with voltage quality parameter included to power quality parameter.

The Institute of Power Engineering at Tampere University of Technology has actively been developing a comprehensive power quality management system in the past years together.
with distribution utilities and several different equipment and data system vendors. [2, 3, 4] The developed power quality monitoring concept is implemented and demonstrated in a Finnish middle-sized rural electrical distribution company Koillis-Satakunnan Sähkö Oy.

IMPLEMENTATION OF COMPREHENSIVE POWER QUALITY MONITORING SYSTEM

The Institute of Power Engineering at Tampere University of Technology has strong over 20 years tradition in developing information systems for distribution utilities. Lately, a web-based data management system for comprehensive and continuous power quality monitoring has been developed. The system is implemented to meet also the demands of application service provisioning (ASP) model. The main effort in research has been put on developing and defining optimal database structure for storing large number of power quality data provided by different kinds of measuring equipment so that the data is easily managed and effectively available for data-access applications. Also, functions for data analysing and presenting in web-based application have been developed. Figure 2 presents the concept of the developed power quality monitoring system.

Measurement equipment

Recently, measurements carried out in the electricity distribution network have become increasingly common, accurate and real-time. In consequence of technological development, more diversified functionality can be integrated into distribution automation equipment installed at primary substations, secondary substations or at customers sites to provide potential for developing data analysis and management, e.g. for power quality monitoring. The main function of this equipment remains the original but the measurement data can be used also for power quality monitoring enabling also development of voltage quality monitoring and analysing functions. Power quality monitoring system being developed in the research project of the Institute of Power Engineering at Tampere University of Technology includes protection relays, distribution transformer condition monitoring units, advanced energy meters and additional expansion devices to kWh-meter.

Protection relay. Modern protection relay usually includes function for disturbance record, which gives important information about behaviour of the electrical network during disturbances. During last few years, disturbance recorder is usually included in every new protection relay installed into distribution network. In addition, modern protection relay stores information of events including voltage dips/swells, outages, state information of e.g. feeder breaker operations, etc. Also, measurements voltage and current including e.g. variation, distortion and unbalance can be carried out in some extent.

A product of a Finnish protection relay manufacturer VAMP Oy, VAMP 255 feeder manager, is used in development of carrying out power quality monitoring from primary substations. In VAMP 255, communication can be implemented using local area network (LAN) with TCP/IP protocol. This enables fast and real-time operation of analysing software gathering the measured data from the relay independent of SCADA communication. The primary function of the relay remains the original, but measurement

Figure 2. Architecture of comprehensive power quality monitoring system
data can also be utilised in power quality monitoring.

**Distribution transformer condition monitoring unit.** Some important distribution transformer stations are equipped with condition monitoring units focusing mainly on load and current information measuring. In some cases, also temperatures and voltages are measured. This data can be utilised also in power quality monitoring.

Wimotec Oy is a Finnish manufacturer focusing on distribution transformer condition monitoring equipment and wireless remote monitoring solutions. The monitoring unit, WIMO transformer station controller, is equipped with GSM modem enabling SMS communication with Wimo-Control server of the distribution transformer monitoring system (DTMS). DTMS is implemented as an ASP-service located in Seinäjoki in Finland providing distribution transformer condition information to the customers via Internet. DTMS contains also function for simplified power quality report consisting of trends, voltage dips/swells and outages that can be obtained to other systems using http-query.

**Intelligent kWh-meter.** Quality Guard is a product of a Finnish energy and power quality meter manufacturer MX Electrix Oy. It is a fairly cheap intelligent and remotely readable kWh-meter with power quality monitoring functions. A more detailed description of characteristics of Quality Guard and remote reading system Transmit is presented in reference [4].

Quality Guards can be installed at customer sites as energy meters or at primary substations with current and voltage transformers. Load measurements can be delivered to existing energy management system as pulse measurements and the power quality data can be delivered to power quality monitoring system with modems using GSM or phone line. Quality Guards are also suitable for temporary power quality measurements based on customer reclamations.

A Finnish energy meter and energy management system manufacturer Enermet as developed new generation remotely readable kWh-meter with power quality monitoring functions. Heat consumption) of the measuring equipment.

**Expansion device to kWh-meter.** The basic aim of development is to develop an easily installable expansion device cheap enough to be installed to almost every customer. This device can be attached to a kWh-meter with pulse output. In addition, it is supposed to have analog inputs for currents and voltages and a special communication terminal enabling remote reading through a phone line.

Expansion device is designed to perform power quality functions based on analog measurements of voltages and currents. At the beginning, functions for voltage variations, voltage unbalance, voltage dips/swells and outages are planned to be implemented. The main advantage of the device is converting the existing kWh-meter to a remotely readable kWh-meter. Consequently, there is no need to change the existing and well-working meter into expensive new one and cost caused by meter reading is decreasing. In addition to this, information of power quality can be obtained at the same time from the customer site with a reasonable cost.

**Power quality database (PQDB)**

Traditionally, measuring equipments have a specified remote reading system and data storing format. For this reason, it has been necessary to develop a relational database called Power Quality Database (PQDB) with a database structure enabling measurement data from different measuring equipment to be stored into unified database structure. Consequently, development of interface between data store of measuring equipment and the PQDB required.

Issues of openness, scalability, effectiveness, size and security are taken into account while developing PQDB. The structure of the database should be open to enable open analyzing application development for different parties. PQDB has to be scalable from small scale short term power quality monitoring of one measurement point to large scale long term comprehensive power quality monitoring of various network utilities. Nevertheless, effectiveness has to be remained independent of number of measurement points and length of measurement period. Also, the size required by database has to be optimized, since power quality monitoring provides vast quantity of measurement data. Nowadays, issue of data security has to be taken very seriously into account.

**Internet-based reporting system**

Data stored in PQDB is analyzed and presented by using web-based application. Implementation of the application is carried out using Microsoft Visual Studio.NET application development tool and C# programming language, which are parts of the Microsoft .NET architecture. Functionality of the web application consists of:

- Presenting measurement data (including disturbance record, trend measurements, voltage dips/swells and outages) graphically in chart and grid mode.
- Presenting state information data of I/O inputs (e.g. state of circuit breaker) and pulse measurements (e.g. water and heat consumption) of the measuring equipment.
- Calculating and presenting report of quality based on classifications and standard SFS-EN 50160 defined in Finnish national recommendation for evaluation of power quality in electrical distribution network.
- Administration tool for user management.

User is entitled to see and use only data and functions authorized for the user. In addition to utility personnel, access to data of certain measuring points of distribution utility can be given to certain customers. Furthermore, power quality data of various distribution utilities can be stored safely to the same database system.
IMPLEMENTATION AT KOILLIS-SATAKKUNAN SÄHKÖ OY

Koillis-Satakunnan Sähkö Oy (KSS) is a Finnish middle-sized rural distribution company consisting of 8 primary substations and about 3600 km of distribution network. KSS has a strong history during last decades of co-operation with Tampere University of Technology offering a real demonstration environment for information system development related to power distribution. Earlier stages of development at KSS are described in [2] and [3]. In recent years, KSS has been demonstration environment for comprehensive power quality monitoring system development. The system consists of VAMP 255 protection relays, Quality Guards and Wimotec distribution transformer condition monitoring units.

VAMP relays are installed as feeder managers at four primary substations that are also equipped with broadband connection. Disturbance records, voltage dips/swells and events are monitored with automated collecting solution. Quality Guards are installed at every primary substation and at the end of the longest feeders also to be utilised e.g. in voltage regulation based on tap changers. Some Quality Guards are circulated in the distribution network based on certain sequence, e.g. one week installation at certain customers. These are also used in power quality monitoring in case of customer complaints and for investment focusing on the most deteriorated LV networks alongside with calculations of the network information system. Also, some new generation energy meters from Enermet are installed. A demonstration of Wimotec distribution transformer monitoring system is installed at four distribution stations.

Power quality database (PQDB) and web-based reporting solutions are installed at KSS’s own servers. Data provided by power quality monitoring system is used in practise e.g. in overvoltage protection planning by replacing surge arresters with spark gap with metal-oxide surge arresters near primary substations based on voltage dip data provided by power quality monitoring system in order to prevent problems caused by deep voltage dips.

POWER QUALITY MONITORING AS APPLICATION SERVICE PROVISIONING (ASP)

The development of advanced Internet technologies has had influence on trends in software production. Using the Internet techniques in application development gains the following benefits: [5]

- Fairness (Only Internet connection and browser needed.)
- Supporting cross-platform and open system architecture.
- User-friendly and consistent human-machine interface.
- Minimization of installation time and maintenance efforts.
- Maximization of system scalability.
- Supporting multi-media, video conferencing, etc.
- Providing relational database access.

A company supplying software applications and/or software-related services over the Internet is called application service provider (ASP). An ASP owns, operates and maintains servers and software applications and employs the people needed to maintain the application. The provided application is available to customers everywhere via the Internet. More detailed description of ASP is presented in reference [6].

At present, concentration on core businesses is a trend among distribution utilities. For example, network construction and maintenance are more often outsourced to service providers. One potential future trend could be outsourcing energy measurements, also power quality data management and monitoring, when the advantages of web applications are undeniable. Power quality monitoring as ASP can be provided directly to the distribution utility or by an operator providing wider concept of services for distribution utility.

CONCLUSION

Experiences in system development and demonstration indicate that it is possible and reasonable to utilise existing distribution automation equipment in developing comprehensive solution for power quality monitoring including voltage quality monitoring. Based on information of problems in power quality observed by developed system, more precise power quality measurements can be carried out using special power quality analyzers. This forms a basis for utilising power quality data in network planning and operation purposes in the utility level and possibilities to observe voltage quality in network business regulation.

REFERENCES