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Web- and Event-Based Power Quality Monitoring Systems Provided by Application Service Provisioning Model

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ABSTRACT

This paper presents web- and event-based power quality data management systems developed in a research project at Tampere University of Technology (TUT), Finland.

The web-based system consists of meters with power quality functions (Quality Guard), a remote reading system, a database developed for managing measurement data, and a web-based application for power quality monitoring. The system is implemented by using application service provisioning (ASP) model.

The event-based power quality monitoring system is implemented as an expansion board to be attached along with Quality Guard. The main idea is to inform automatically if some abnormality in the distribution network occurs.

1. INTRODUCTION

In modern information society requirements and expectations associated with power quality have become increasingly important. Reasons for that are increased requirements for power quality by network utilities, customers and regulators. Many industrial and commercial customers have equipment that is sensitive to power disturbances. Therefore, it is more important to understand the quality of power being supplied. Also regulation models, laws, and guidelines relating to network business provide requirements for developing power quality management.

Electricity is not anymore a luxury article like few decades ago, but it has become a necessity and a part of our everyday life. Even short interruptions and voltage sags can be harmful when the amount of computers, programmable logics etc. in industry and as well in households have increased rapidly. In Europe, the standard EN 50160 gives the main characteristics of the supply voltage at the customer's supply terminals under normal operating conditions with regard to frequency, magnitude, waveform and symmetry of the three phase voltages.

So far continuous power quality monitoring in larger extent is not yet very common, but the situation is changing quite rapidly. Power quality measurements are mainly carried out temporarily based on customer reclamations. Solutions for continuous power quality monitoring either do not exist or they are expensive and complex. New IT-technologies and advancement in measuring equipment provide more sophisticated power quality monitoring systems. Reference [1] describes a low-cost smart web sensor, which is designed and implemented to acquire, process and transmit data over 802.3 network and to construct dynamic HTML pages. Reference [2] presents a web-based multi-channel power quality monitoring system, which consists of PQ meters, data transmission and displaying in the Internet. Reference [3] depicts a concept of database management system to store power quality data and a web-based user interface of the system.

Web-based applications have many advantages compared to ordinary applications and they offer an easy way for power quality monitoring. In addition to usability and functionality, web-based applications offer possibility for electricity utilities to outsource their operations where the service is

provided using application service provisioning (ASP) model. Power quality monitoring is one example of implementing outsourced service using ASP model where the service provider takes care of supply chain of the power quality information in total and allows customer to focus on core business and leave technological solutions into provider's responsibility.

Tampere University of Technology (TUT) has going on research projects on power quality data management and new business models in network utilities. In these research projects a target is on one hand to define and demonstrate power quality monitoring functions as a part of integrated automation systems, and on the other hand power quality issues are considered from the point of view of network planning and operation including basic analyses, measurements, outage reporting, and also issues of distributed generation. A wider concept for power quality monitoring is presented e.g. in reference [4].

This paper introduces a power quality data management and web-based monitoring system, which is suitable for both temporary and continuous power quality monitoring. The developed web-based system consists of power quality meters (Quality Guards), their remote reading software, database server and structure, web application for presenting and analysing data, web server, and client (i.e. web browser). In addition to power quality monitoring functions, functions for energy consumption and building automation (i.e. water and heat consumption, state information, and temperatures) can be implemented in the system. Suitability of developed system for distributed generation is described in detail in reference [5].

The paper also presents an event-based power quality monitoring system which uses the same Quality Guard meter as mentioned above. The system is based on a Field Programmable Gate Array (FPGA) device and a development board built on its features. The main task of the device is to gather measurement data from the Quality Guard and analyze it looking for deviations from the power quality standards or user defined limits. The main idea of the event-based monitoring is that the system informs automatically if some abnormality occurs. This kind of function can also be used for many other purposes than just power quality monitoring, e.g. for condition monitoring and in fault situations of LV network.

2. 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: [3]

- Fairness (Only Internet connection and browser needed.)
- Supporting cross-platform architecture.
- Supporting 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 and operates a software application. The ASP also owns, operates and maintains the servers that run the specific application. An ASP employs the people needed to maintain the application, and also makes the application available to customers everywhere via the Internet, either in a browser or through some sort of thin client. The ASP bills for the application either on a per-use basis or on a monthly/annual fee basis. More detailed description of ASP is presented in reference [6].

The ASP model has evolved because it offers some significant advantages over traditional approaches. Especially for small businesses and start-ups, the biggest advantage of an ASP is the low cost of entry and short setup time. Furthermore, the ASP model, as with any outsourcing arrangement, eliminates head count. IT headcount tends to be very expensive and very specialized, so this is frequently advantageous. Moreover, the ASP model also eliminates specialized IT infrastructure for the application as well as supporting applications and licences. Another important factor leading to the development of ASPs has been the growing complexity of software and software upgrades. Distributing huge, complex applications to the end user has become extremely expensive from a customer service standpoint, and upgrades make the problem even worse. The ASP model eliminates most of these headaches with short implementation time and updates.

3. POWER QUALITY MONITORING AS ASP

Power quality monitoring is a process of gathering, analyzing and interpreting raw measurement data into useful information. The process of gathering data is usually carried out by continuous measurement of voltage and current over an extended period. The process of analyzing and interpretation has been traditionally performed manually, but recent advances in signal processing and artificial intelligence fields have made it possible to design and implement intelligent systems to automatically analyze and interpret raw data into useful information with minimum human intervention. [7]

Concentration on core businesses is at present a trend among Finnish distribution companies and same kind of development can be found in other countries, too. Companies are outsourcing their functions and only the most important business (i.e. managing the network assets) is left to the distribution company. For example, construction and maintenance are more often given to another company providing this kind of services. One example of future trends could be outsourcing power quality data management and monitoring where the advantages of web applications are undeniable. It is possible for an ASP to offer power quality monitoring as a service straight to the network utility or by an operator providing wider concept of services for network utility.

When a distribution company is buying the power quality monitoring services from an ASP and power quality data is collected to ASP-company's database server. The data is accessed through the Internet and power quality reports can be made with the web application in the user interface of a web browser. The distribution company benefits from easy-to-use power quality monitoring applications, which do not spend the company's human resources like ordinary applications with all the maintenance and updating tasks do. On the other hand, the ASP-company benefits from fewer application and database updates when all the applications and databases are located in the same place.

4. THE CONCEPT OF WEB-BASED POWER QUALITY DATA MANAGEMENT AND MONITORING SYSTEM

Web-based functions of the power quality data management and monitoring system presented in this paper consists of power quality meters (Quality Guards), their remote reading software, database server, web application, web server and client (i.e. web browser). A lot of effort in research has been put on new system development technologies and optimising the structure of Power Quality Database (PQDB). Purpose of the system development has been to illustrate and demonstrate a power quality monitoring system suitable for web-based outsourced service. Also issues of system scalability and data security are examined. Fig. 1 illustrates the system architecture of the system.

Quality Guard (EDHSRML) is a commercial product of MX Electrix Oy, which is a Finnish energy and power quality meter manufacturer. Quality Guard is a fairly cheap smart kWh-meter with power quality monitoring functions. Quality Guard is remotely read by using phone line or GSM modem. Measuring functions are implemented by using sparse sampling methods described in reference [8]. Most of the power quality quantities described in standard EN 50160 can be measured with Quality Guard. In addition to this, data on powers and currents can be measured.

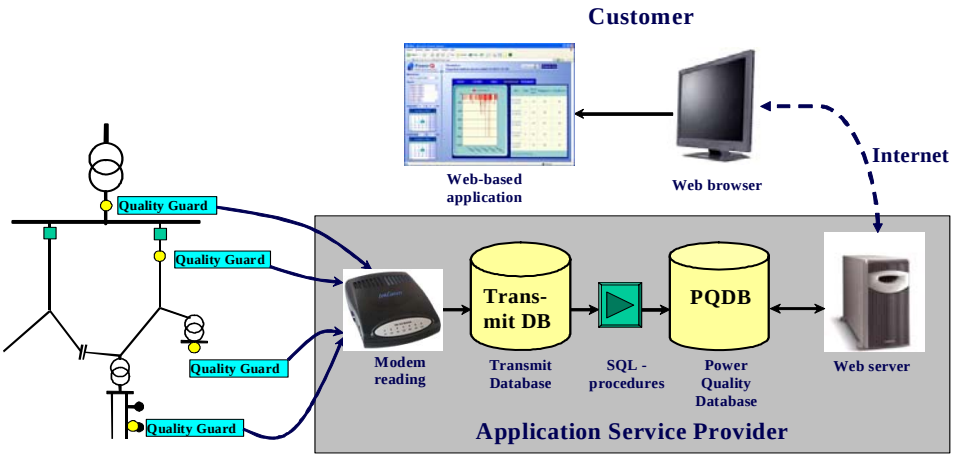

Fig. 1 System architecture of the web-based power quality monitoring system

Quantities measured by Quality Guard are:

- Voltage level, current, real power, total reactive power, fundamental frequency reactive power, apparent power, DC offset, total harmonic distortion (THD) of the supply voltage, and power factor for each of the three phases
- Total real power into both directions
- Total capacitive and inductive reactive power
- Total apparent power
- Frequency of the supply voltage
- The ratio of the negative- and zero-sequence components to the positive-sequence component
- Harmonics of voltage (3., 5., 7., 9., 11., and 13.)
- Maximum values of total harmonic distortion (THD) of voltage, DC offset and power factor

Quality Guard records also timestamp, length, minimum/maximum value and rms value of voltage dips and swells, and starting and ending times of interruptions. In addition to this, external pulse inputs, quantities for energy consumption and building automation (i.e. water and heat consumption, state information, and temperatures) can be delivered with Quality Guard.

The recording density can be set as some seconds, minutes or hours. Maximum of 24 quantities can be measured at a time and measured values are stored in memory of Quality Guard. With recording density of 10 minutes and 24 measured quantities the memory of Quality Guard can store data of approximately three days period. Setup and remote reading of Quality Guard are carried out by modem or serial port of the meter using Transmit-system or EQL Online application.

Transmit-system is a remote reading system of Quality Guards consisting of remote reading and timer applications, and Transmit database. With timer applications, remote reading can be set to launch automatically, e.g., once a day. Measurements are stored into Transmit database, which is a relational database requiring MS SQL Server. Each measured value generates one row in a certain table

in the Transmit database consisting of name of measuring point, quantity, recording density, time stamp, measured value and profile. Because of this structure, the size of the table grows rapidly, which reduces its suitability for database applications. For this reason, it has been necessary to develop a database called Power Quality Database (PQDB) with a new database structure. The structure of PQDB is suitable for long-time data saving and for applications to use. Each measuring point has its own table where each measured value with same timestamp is stored in same row. Data of voltage dips/ swells and interruption is also stored in PQDB. Measurements are transferred from Transmit database to PQDB by automatically called stored procedures of MS SQL Server.

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 new Microsoft .NET architecture. Graphical user interface of the web application is presented in Fig. 2.

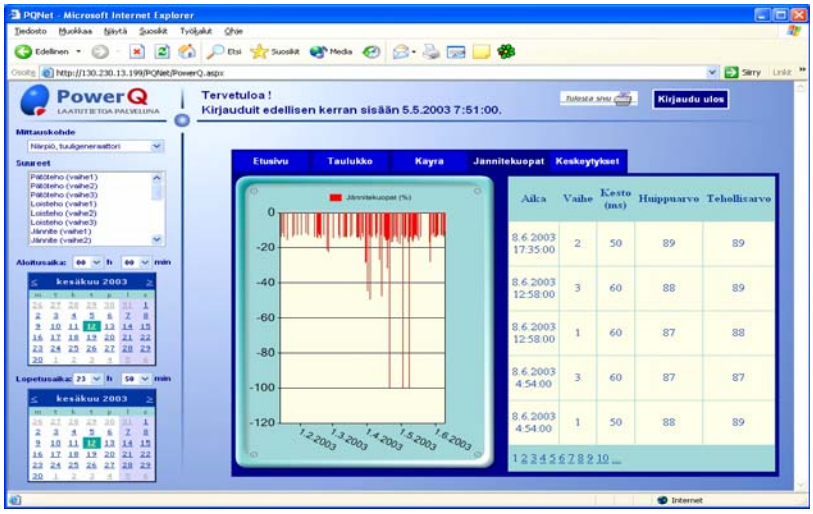

Fig. 2 Graphical user interface of the web application for presenting power quality data

Functionality of the web application consists of:

- Presenting measurement data graphically in chart and grid mode.
- Presenting voltage dips/swells in grid mode.
- Presenting pulse measurements (e.g. water and heat consumption) and energy consumption calculated from power measurements.

User is entitled to see and use only data and functions that are authorized for the user. Access to one network utility's data can be limited to persons in this network utility only or to certain customers. Consequently, power quality data of various network utilities can be stored safely to the same database system. Also, some functions can be limited to some authorized users only. Authorization is carried out using login page that creates a cookie enabling access to main page for 30 minutes. After this time, browser has to be re-opened and new login is required.

The latest function for power quality monitoring system is executing instantaneous measurements reading from the web application. Reading is implemented as a windows application that connects to the Quality Guard, carries out reading of instantaneous measurements from the meter's registry and stores them into database, from which the measurements can be presented in the web application. In this function, the remote reading software of the Quality Guard (Transmit) is not needed.

Openness and scalability of the Power Quality Database (PQDB) provide solid base for further development of the system. Because of scalability, interfaces for other measuring equipment can be implemented to covering i.e. modern relays, analysers or some other remotely readable meters cheap enough to be installed to every customer. In addition to this, a target for further development is to integrate power quality data to other information systems in network utility. Power quality data can be utilised i.e. in condition monitoring, network calculation, network planning and investment decisions. Using data from power quality monitoring for condition based management of transformers is presented in reference [9].

5. EVENT-BASED POWER QUALITY MONITORING SYSTEM

In addition to the web-based power quality monitoring system there has also been under development functions for event-based power quality monitoring system at TUT. The system is constructed to be used along with the same Quality Guard meter as mentioned earlier in this paper. However, it is not the only metering device to which this concept can be implemented with as the function itself is based on a versatile reprogrammable expansion board that is discussed next.

A function of event-based power quality monitoring system has been demonstrated using an Altera® Nios® Development Kit that includes a well featured development board. The board contains several useful features including an Ethernet connector but in this case the main focus is on two RS-232 DB9 serial ports. More detailed information about the board can be found from reference [10]. The heart of the board is an Altera Cyclone™ FPGA device. The device details are described in reference [11]. FPGA devices are usually very flexible and easy to program and the Cyclone FPGA doesn't deviate from this line.

In general FPGA devices can be programmed in many ways. They can be used as plain logic to implement pure hardware function or as in more advanced way to implement a complete hardware system which is the case most of the times. The main use of FPGA devices has always been in the system prototyping sector as they are thought to be slow and lack in performance compared to Application Specific Integrated Circuit (ASIC). The performance cap between ASIC and FPGA has narrowed significantly as more powerful FPGA devices are constantly developed. Today FPGA devices offer very considerable choice for manufacturers as the solution for the ever growing need of integrated circuits and tight deadlines.

After the selection of the used platform the development process of the event-based power quality monitoring system continued by creating the System On Programmable Chip (SOPC) design. The SOPC design is built using Intellectual Property (IP) blocks which each integrate certain mega macro to the system. IP block can be for example CPU core, memory controller, timer etc. After construction the generated SOPC block can be added to the system design. System is then compiled using specific software that generates a netlist of the design to be loaded in the target device i.e. Cyclone FPGA. This completes all the necessary steps that are required of the board to make it ready for the software development.

As mentioned before this system is meant to be used as an additional expansion board for the Quality Guard, smart kWh-meter. A separate module of a meter feeds measured data in serial form to its output port one packet in every 100 milliseconds. This packet contains total of 49 quantities described previously in this document and voltage dips.

The main idea of the event-based monitoring is that the system informs user automatically if some abnormality at the metering point occurs. The main task of the board which is attached to Quality Guard -meter with serial cable is to gather measurement data fed by meter using software only and analyze that data. Some basic floating-point arithmetic operations are also required so that the data can be transformed into understandable form. Analyzed data is collated with value limits set to the

board by user. These limit values can be either the ones defined by power quality standard EN 50160 (limits in Europe) or any other desired by user. The only restriction to these limit values is that they have to be within the quantity range of the Quality Guard – meter. Depending of the collation result the board sends information to user. The system architecture is presented in Fig. 3.

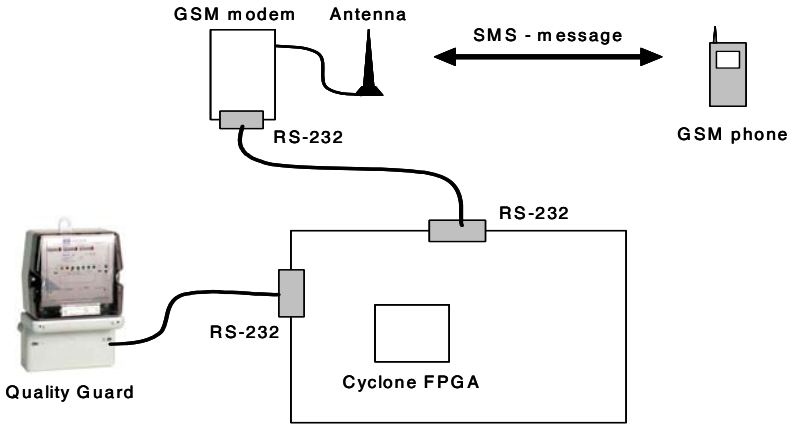

Fig. 3 System architecture of the event-based power quality monitoring system

Human intervention with the event-based monitoring system is arranged through GSM-modem and done by SMS-messages. It's a reasonably easy way to offer user complete control of even the most advanced settings. The used Nios platform and the board itself is very flexible environment and depending of the abstraction level software can be developed in such way that even hardware settings can be parameterized and altered by SMS-message. Also user identification is possible to apply. SMS is however not the only way to arrange communication with the board. As mentioned in the beginning of this chapter the board contains Ethernet connection. This offers a possibility to connect the board to Local Area Network (LAN) or directly to Internet. Through this it might even be possible to program the board for continuous power quality monitoring that offers new data in every 100 milliseconds.

This kind of system could also be used for other purposes than power quality monitoring. For example condition monitoring of transformers [9] or fault detection in LV networks could be implemented using Quality Guard and presented expansion board. As the board is easy to reprogram, Quality Guard is not the only metering device it can be used with. Depending of the metering device's features and output ports, the board can be attached to it by serial cable, network cable or flat cable. Of course a new meter needs a new SOPC system and software but the main idea remains the same.

6. CONCLUSIONS

In this paper solutions and service models that network utilities can use in power quality data management and monitoring were presented. One goal in our research was to develop a system consisting of remote data reading, database structure for data storage and management, and a web application for presenting and analysing power quality data. Other goal was to develop an event-based monitoring system as an expansion board that is flexible and easy to implement into various environments.

One big challenge in our research has been to test these systems in real working environment. The real working environment usually brings out new problems that were not considered in the

research environment and that is why these kinds of applications should always be tested in an environment they will actually be used in the future.

Concentration on core businesses is at present a trend among distribution companies. Application service provisioning (ASP) model gives new possibilities for distribution companies to monitor power quality continuously using outsourced service provider. The development and commercialising of these applications is about to start by a company (PowerQ Oy) founded by the researchers.

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