Power Quality Monitoring System with a New Distributed Monitoring Structure

Dong-Jun Won†, Il-Yop Chung, Joong-Moon Kim***, Seon-Ju Ahn**, Seung-Il Moon**, Jang-Cheol Seo*** and Jong-Woong Choe*****

Abstract - Power quality monitoring is the cornerstone for power quality analysis, diagnosis and improvement. The measurement of power quality (PQ) evolves from instantaneous metering to continuous monitoring. Furthermore, recent technologies enable us to construct more flexible, reliable, rapid and economical power quality monitoring system (PQMS). Therefore, this paper presents an improved PQMS with a new distributed monitoring structure. The proposed PQMS consists of a PQ meter, PQ analyzer and GUI. The PQ meter only collects raw data and the PQ analyzer performs power quality analysis. It has several advantages compared to conventional structures in economic efficiency, modularity, speed, etc. PQ monitoring algorithms to catch steady-state trends and to detect PQ events are also adapted to the proposed structure. Using the proposed structure and monitoring algorithm, a prototype PQMS is constructed and real-time testing is performed.

Keywords: detection, distributed monitoring, event, monitoring, power quality

1. Introduction

In the past, power quality was the ability of utilities to provide electric power without interruption. In recent years due to an increase in critical load and electronic devices, customers require a greater level of power quality than ever before, so power quality has become an important concern to customers as well as to utilities and facilities. Power quality is different from reliability in that it treats very short-duration events with a few cycles or seconds. New PQ problems such as sag, swell, harmonic distortion, unbalance, transient and flicker can impact customer operations, causing malfunctions and costs on lost production and downtime. To avoid these malfunctions and unnecessary costs, many facilities and large customers have been required to install a PQ monitoring system [1, 2].

The deregulation in power systems is based on competition between the participants, who enter into contracts according to their own interests. In this case, electric power traded in the market is considered as a product that has price and quality. As a matter of course, the quality of the electric power must be measured and evaluated. These facts increase the need for a PQMS [3].

Recent PQMS demonstrate further high-tech functions than previous systems. Developments in electronic devices and communication accelerate this tendency. Ethernet communication, graphic user interface (GUI) through web-browser and statistical analysis will be the basic functions for the future PQMS [4]. In addition, the PQMS will be installed on a large-scale for PQ analysis and diagnosis. In this case, the conventional PQMS structure that calculates and processes raw data in one device cannot have economic efficiency. Therefore, the requirement for an improved PQMS arises.

For these reasons, this paper presents a new PQMS with an improved realization of the distributed monitoring system. Firstly, the new trends in PQ monitoring are investigated. Through these investigations, an appropriate structure is proposed and the advantages of the proposed PQMS are explained compared to the conventional PQMS. A PQ monitoring algorithm is developed and implemented in this system. A prototype system is constructed and various power quality events are analyzed using this prototype.

2. New trends in power quality monitoring

2.1 Evolution from metering to monitoring

As stated in the introduction, PQ measurement is the starting point to solve PQ problems. PQ measurement systems have many variations in their structure, price and function. Though it is somewhat difficult to classify all the PQ measurement systems into several groups according to their characteristics, they can be classified as in Table 1.

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Table 1 Classification of PQ measurement system according to their objectives

Char. / Group	Objective	Measurement
Meter	Instantaneous	Voltage, Current, Power, etc.
Analyzer	Periodic, Reactive	V, I, P, etc., Harmonics, Waveform, Event
Monitor	Continuous, Proactive	Above contents + Statistics + Indices

The meter group measures the instantaneous values of the measuring point, such as RMS values. Typically, it is portable and has a simple display panel. The analyzer group measures periodically changing values and mainly performs harmonic analysis, waveform capture and event detection. The devices of this group are for portable use and the objective of them is the troubleshooting of the PQ problems.

The last group, known as the monitor group, is installed at one point permanently to capture not only its steady-state parameters but also PQ events. Furthermore it provides the statistical results and some PQ indices. The devices of the monitor group calculate PQ parameters continuously so that they provide long-term trends as well as short-term events. Nowadays most PQ measurement systems are developing from meter or analyzer systems into monitoring systems.

2.2 Functions of the PQ monitoring system

Recent PQ monitoring devices are largely divided into two types. One is the device that is based on the traditional watt-hour meter or digital protection relay where the PQ analysis algorithm is inserted. The other is the device that mainly deals with PQ parameters and events. The main function of the former is the calculation of electric parameters such as V, I, P, energy etc. Protection parameters such as overvoltage, undervoltage and interruption are also calculated. Harmonic analysis is performed if the user requests that function. The latter follows the IEEE or IEC standard to classify PQ events and displays the results with their own panels or PC connected through serial communication. They measure power quality, store results and analyze the results for future use.

Table 2 Classification of PQ monitoring devices according to their functions

Contents / Kinds	Main functions
1st generation	Electric parameters (Main)+ Power quality (Options)
2nd generation	Power quality parameters and events + Serial communication + Display
3rd generation	Power quality + Ethernet communication + Statistical analysis + Web-browsing

Lately PQ monitoring devices are developing into monitoring systems that continuously measure the power quality of a point and analyze power quality trends. These monitoring systems will provide such functions as high-speed communication with internet networks, statistical analysis through uninterrupted measurements and display with web-browser. In the near future, they may also include the functions of power quality diagnosis.

3. An improved PQMS structure

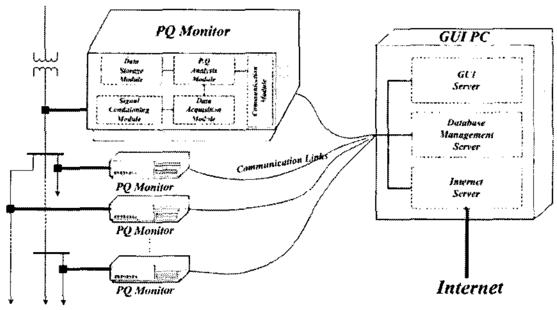

Fig. 1 Conventional PQMS structure

The structure of the conventional PQMS is shown in Fig 1. It consists of a PQ monitor and GUI PC for display. The PQ monitor performs measuring, processing and communication. The PC displays the results via the graphic user interface (GUI). As stated in the previous section, PQ monitoring requires a large-scale system with multiple meters in order to analyze power quality and diagnose PQ problems. For example, one monitor is insufficient to find the source of sag or harmonic distortion and it takes more than one monitor to diagnose the PQ problems. Therefore, it becomes more important to construct large-scale PQMS, which is referred to as a '*distributed monitoring system*'. In the distributed monitoring system, the price for installing the PQMS becomes a critical factor. In the conventional monitoring structure, the price of the PQ monitor is relatively high, which can be a penalty factor for system integration [5-8].

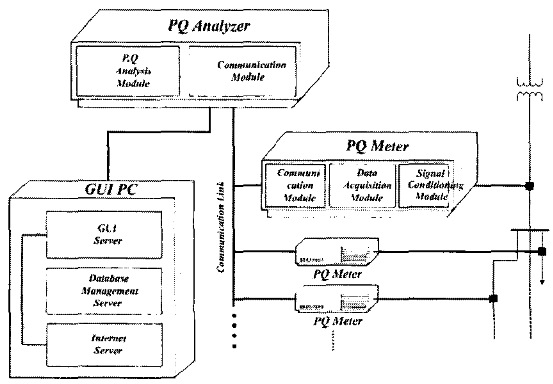

Fig. 2 Proposed PQMS structure

For this reason, a different structure is proposed here. It is shown in Fig. 2. The components of the proposed system are somewhat different from those of the conventional structure. In this structure, the PQ meter has its own function that only collects raw voltage and current data. It does not perform any manner of calculation. Instead, it transfers the sampled raw data directly to the PQ analyzer. For large amounts of raw data that cannot be transferred through conventional serial communication, they are transferred via Ethernet communication.

The PQ analyzer receives raw data from several meters simultaneously via the switching hub and Ethernet, and performs PQ analysis. Further related details will be explained in chapter IV. GUI is implemented in client PC and displays the results of the PQ analysis. It has a user-friendly interface allowing it to be easily handled. The advantages and disadvantages of this new structure are listed in Table 3.

Table 3 Comparison between conventional system and proposed system

Characteristics \ Structure	Conventional	Proposed
Meter price	High	**Low**
Overall system price	High	**Low**
Applications	Limited	**Various**
Upgrade	Difficult	**Easy**
Maintenance	Difficult	**Easy**
Modularity and flexibility	Not good	**Good**
Real-time display	Slow	**Fast and precise**
Amount of data communication	**Small**	Large
Efficiency	Not Good	**Good**

As shown in Table 3, the proposed structure is very economical and competitive when the PQMS is installed on a large-scale. For example, if 10 measurement sites need to be monitored, then 10 PQ monitors are required in conventional systems. But in the proposed system, 10 PQ meters and one PQ analyzer are needed. Because of the low cost of the PQ meter, multiple meters with one analyzer in the proposed structure are much more economical than multiple PQ monitors in conventional structures. In addition, the proposed structure can adopt many useful applications of the PC-platform because PC-based applications and solutions are widespread. Furthermore, upgrade and maintenance is easier and faster because PC technology rapidly develops by itself. Because the proposed system has the ability to transfer raw data, real-time display at GUI is quicker and more precise than in the conventional systems. It means that this system can act as an oscilloscope.

The only disadvantage of this system is that its communication burden is relatively heavy. This is because this system transfers raw data. However, current communication technology, that is, Ethernet communication, is adequate to overcome this disadvantage leading to better efficiency in the future.

4. PQ monitoring algorithm

4.1 Algorithm structure

PQ monitoring falls into two categories. One is event, which includes instantaneous RMS voltage variations (e.g. sag, swell, interruption) and transients. The other is steady-state trends such as overvoltage, undervoltage, frequency, unbalance, harmonic distortion and flicker [9-13].

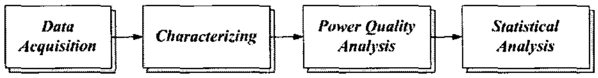

Fig. 3 PQ monitoring process

Fig. 3 presents the process of PQ monitoring. It is composed of four steps. At the first step (Data Acquisition) the line voltages and currents are measured, sampled and converted to digital signals. At the second step (Characterizing), the basic characteristics such as RMS values of voltage and current, harmonic components and frequency are calculated using various signal processing algorithms. At the third step (PQ Analysis), the basic characteristics are analyzed and PQ events are detected. Finally at the fourth step (Statistical Analysis), the PQ trends and events are analyzed in a statistical manner and PQ indices are calculated. A/D converters are used to convert line voltages and currents into digital signals. At

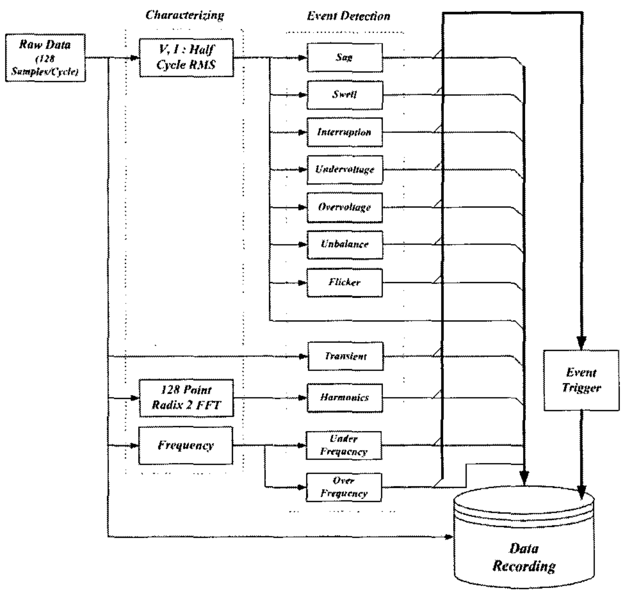

Fig. 4 PQ monitoring algorithm

this time, the sampling frequency and resolution of A/D converters decide the accuracy of the raw data. To measure up to the 50th harmonic components, sampling frequency need to be more than 6kHz (i.e. 100 samples per cycle). The most recent high-efficiency monitoring devices employ Fast Fourier Transform (FFT). For efficient filtering, they use a sampling frequency of 7.68kHz (i.e. 128 samples per cycle) and 12~16bit resolution. These processes are shown in detail in Fig. 4.

4.2 PQ event detection

PQ events are classified into 11 events in this system. They are listed in Fig. 4. Firstly, in RMS variation, the RMS values of voltage and current are calculated at every half cycle. The type of PQ event is defined according to the magnitude and duration of the event. After that, the duration, magnitude, starting time, clearing time, and the mean value of the event are calculated. In case of unbalance, the unbalance factor is calculated. In the event of flicker, flicker indices such as P_{st}, P_{lt} are calculated once every 10 minutes (P_{st}) or 2 hours (P_{lt}). In the case of transience, the MAVSA index that uses the squared value of the voltage is calculated to detect the transient event. For harmonic analysis, the magnitudes and phase angles of each individual harmonic component are measured using 128-point radix 2 FFT. Then total harmonic distortion (THD), total even harmonic distortion (TEHD), total odd harmonic distortion (TOHD), and distortion factor (DF) are calculated. Especially for current, total demand distortion (TDD) and K-factor are calculated. Frequency must be measured accurately because it indicates the balance between supply and demand in the power system. In this paper, over-frequency and under-frequency events are defined. Table 4 summarizes the data stored when each event happens.

Table 4 Stored data according to PQ events

Kinds	Stored data
Sag Swell Interruption	Duration, Magnitude (Min or Max), Kind, Starting time, Clearing time, Mean value
Undervoltage Overvoltage	Duration, Magnitude (Min or Max), Starting time, Clearing time, Mean value
Unbalance	Duration, Unbalance factor, Starting time, Clearing time, Mean value
Flicker	Duration, IFL, P_{st}, P_{lt}, Starting time, Clearing time, Mean value
Transient	MAVSA, Happen time
Harmonics	Duration, THD, TDD, Starting time, Clearing time, Mean value
Over & under frequency	Duration, Frequency (Min or Max), Starting time, Clearing time, Mean value

These data will be saved in the database and will be used later for statistical analysis. Statistical analysis is divided into two parts. One is the analysis performed at one measurement point with one monitor to evaluate the power quality of that point. The other is the analysis performed in the entire measurement area with multiple monitors to evaluate the power quality in that area. For the PQ diagnosis, the statistical analysis on multiple customers is essential and helpful.

5. Prototype development

The prototype of proposed PQMS is constructed. The PQ meter consists of analog input module, signal conditioning module, data acquisition module and data communication module. In the prototype PQ meter, a low performance PC board using Intel Celeron^{TM} CPU is used for the control of data communication and data acquisition. The PQ meter does not require high-performance processors because it only performs the data acquisition and transmission. In the signal conditioning module, analog signals are conditioned to suitable levels so that the data acquisition module can convert the analog input signals to the digital raw data. The data acquisition module has a 7.68 kHz sampling rate, 16 bit resolution and 1 Mbytes FIFO buffer for reliable data measurement. Acquired raw data are transmitted to the PQ analyzer through the high-speed communication channel. Fig. 5 shows the appearance of the developed prototype PQ meter.

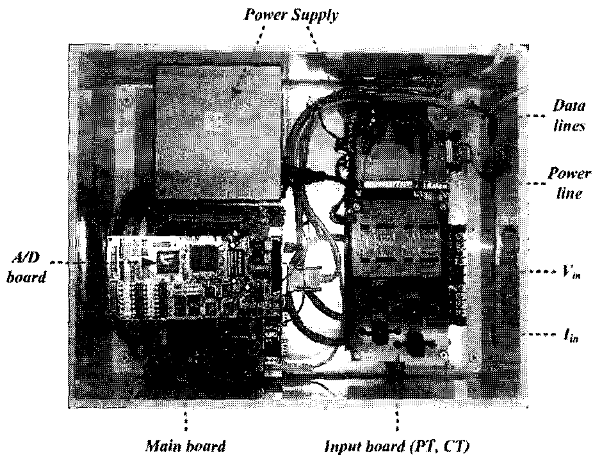

Fig. 5 Prototype of PQ meter

The raw data from several meters are processed in the PQ analyzer and the power quality analysis is conducted. The PQ analyzer consists of a power quality analysis module and data communication module. The prototype PQ analyzer is developed using the industrial PC board with Intel Pentium IIITM 850MHz CPU and it can sufficiently handle up to 10 PQ meters simultaneously. Fig.

6 indicates the appearance of the developed prototype PQ analyzer.

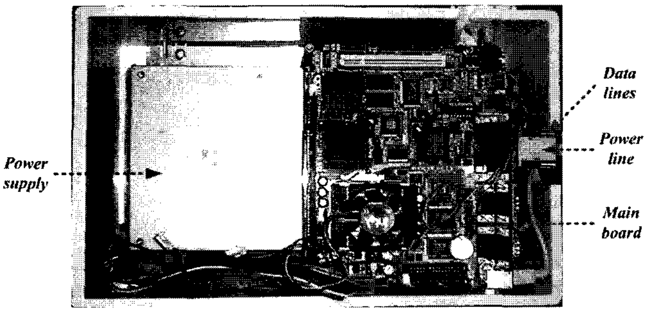

Fig. 6 Prototype of PQ analyzer

With this type of PQ meter and PQ analyzer, the prototype test system is constructed. The test system consists of a PQ meter, PQ analyzer, GUI, 3-phase voltage source simulator and loads. The 3-phase voltage source simulator can produce voltage with arbitrary magnitude and frequency. Therefore, it can be used as a PQ event source. The distribution network is relatively simple because the voltage source can sufficiently produce the necessary signal to check the ability of the proposed system. Using this test system, a real-time test is performed. The 3-phase voltage source simulator generates voltage sag, voltage swell, interruption and transient. The corresponding results in the GUI program are displayed in Fig. 7.

In this real-time test, transient, interruption, voltage swell and voltage sag occurs and all related information is stored. In Fig. 7, the left window lists all the events that happened in the past. The right window shows the waveform of the selected event. In Fig. 7, interruption has been chosen and its waveform has been displayed. The last window in the bottom of Fig. 7 lists the 3 latest events for alarm purposes. As shown in Fig. 7, the proposed PQMS accurately captures PQ events and stores the event data. It also effectively indicates the waveform and detailed information concerning the PQ event in one window.

6. Conclusion

This paper has proposed the improved PQMS with an innovative distributed monitoring structure. In this system, the conventional PQ monitor is divided into PQ meter and PQ analyzer for cost reduction and efficient data processing.

The PQ meter only performs raw data acquisition and the PQ analyzer performs power quality analysis. This structure is particularly suitable and competitive for large-scale PQMS. In addition, this system has more advantages than the conventional PQMS in regards to flexibility, modularity, upgrade, speed and efficiency. The PQ monitoring algorithm that detects 11 events and captures steady-state trends has also been implemented and adapted for the new structure. The prototype of the proposed PQMS has been constructed and real-time tests have been performed using this prototype system. The GUI program

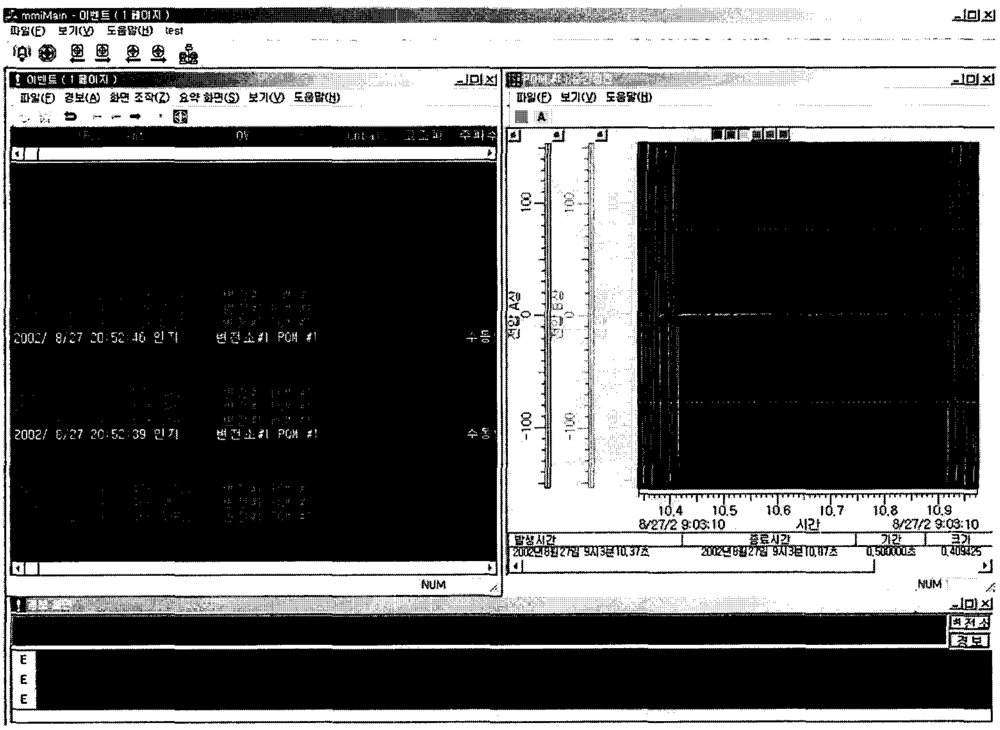

Fig. 7 Test results shown in GUI program

has effectively displayed all the information about the PQ events that happened in the distribution system.

Acknowledgements

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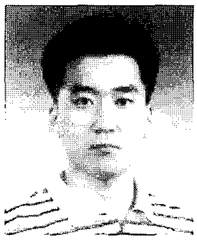

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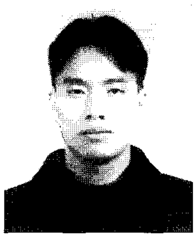

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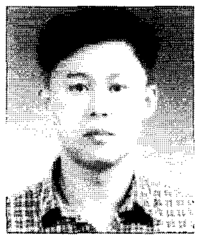

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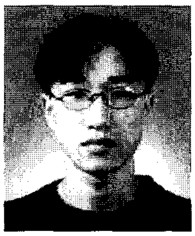

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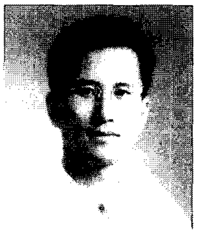

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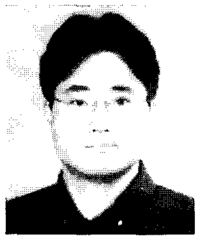

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