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Comparative Analysis of Power Quality Monitoring Systems

Syed Rizwan Hassan[1], Ateeq ur Rehman[2],Noman Shabbir[3], Arooj Unbreen[4]

[1]*Department of Electrical Engineering, NFC Institute of Engineering & Fertilizer Research Faisalabad (IEFR),Faisalabad, Pakistan*
[2]*Department of Electrical Engineering, GC University Lahore, Lahore, Pakistan*
[3]*Department of Electrical Power Engineering and Mechatronics, Tallinn University of Technology, Estonia*
[4]*Department of Electrical Engineering, University of Lahore, Lahore, Pakistan*

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***CorrespondingAuthor:**
syedrizwanhassan@gmail.com
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ABSTRACT

Electricity is the most important commodity used in our daily routine and power quality (PQ) is gaining interest from last few years. A review of the techniques used for power quality monitoring is presented in this paper. Major focus of this paper is on power quality monitoring (PQM) and management systems in the area of power industry. Techniques reviewed in this paper also include some power quality meter placement techniques. Efficiency and cost effectiveness of PQM system can be improved by applying the techniques that find the optimum number of monitors to be placed and the best locations where they have to be placed and these techniques are called power quality meter placement techniques. In this review initially methodology of each method is defined and then comparison between them is presented. Power quality monitoring and management strategies that are used internationally in industries are discussed and at the end some examples are presented that defines the efforts made in the area of power quality improvement.

I. Introduction

Complexity and size of electrical networks are growing due to increase in customer demand and size. Monitoring of parameters like frequency, voltage and current is mandatory to provide good quality electricity to the customer side from the power suppliers to avoid damages to the electronic devices. To ensure good PQ the monitors are used to analyze the system against certain power quality attributes. Flicker and harmonics are the major reason behind bad power quality.

Flicker occurs due to abrupt change in voltage and presence of non-linear loads produces harmonics in the system that generate heat causing the major reason of damage to electronic devices. IEC 1000-3-2, IEEE-519 and IEC 61000-4-30 Class A [1] are the important standards related to harmonics level which have to be maintained while monitoring the distribution system.

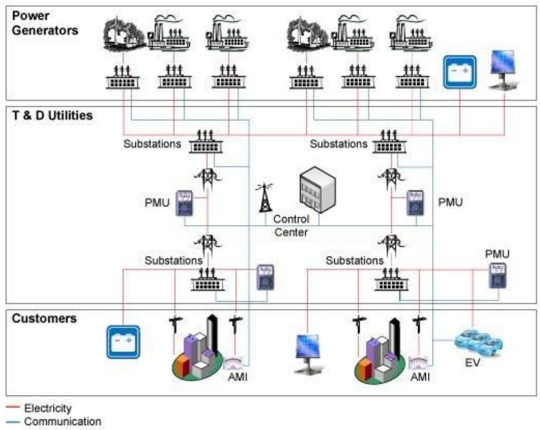

Figure 1: Power Monitoring Unit [2]

The monitoring is a process that continuously monitors the system for any kind of failure or interference. Latest monitors include modules that provide online monitoring facility and alarms are installed that alerts on any time of failure or interference detection. Monitoring is mostly a long term process that records data in databases that can be used to generate reports to improve the PQ and to take preventive action if required. Efficient monitor placement techniques are also discussed in the next sections that can be used to find out the optimal places in the network to place monitors to make the system cost effective and efficient. To ensure the PQ in an electrical network monitors are placed at various locations as shown in Figure 1 [2].

Goals of the power supplier is to ensure customer satisfaction which can be achieved by providing the power levels that are desired by them. So customer's complaints are

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the major factor that drives the suppliers to ensure good power levels. V. Becirovic et al. in his paper presented a method that divides the customers into three groups based on current waveform and the type power they use [3]. This classification based system make analysis of system more easy for the suppliers. The proposed model is voltage dependent with the major drawback that every time when there is some change in classification then we have to update the grouping system.

II. Discussion

A. *Power Quality Monitoring Systems & Techniques*

a) High-Resolution Technique for Flicker Measurement

Abrupt Variations in the voltage of power supply are called flickers which introduces interference in electrical networks and degrades the power quality [4]. This flicker is major source of interference and also causes damage to electronic equipment attached to such source. High resolution technique uses frequency spectrum analysis to observe and extract the flicker component from the signal. The purpose of extracting such flicker components is to make strategies and algorithms to remove such flicker problem to improve the power quality. This technique uses Pony's method and is more accurate. This method is more accurate and robust but mathematically it is more complex [5].

b) S-Transform Based Power Quality Analysis

In [6] a novel method of PQ analysis is presented that uses S-Transform based classification. The proposed method analyzes the frequency spectrum of signal by finding S-Transform of signal and was tested to detect some short term voltage disturbances and tracking their causes. Mathematical complexity of this method is high.

c) Data-Acquisition System for Power Quality Monitoring (SEMCE DAC)

The SEMCE DAQ is a data acquisition system designed to measure PQ metrics at smart grids. This system provides real time monitoring for future improvements. The important parameters such as voltage, current, frequency, power and harmonics are measured by this system. Computational accuracy and performance of this system is very good. Due to its low cost and data transmission capability it is suggested to implement this system in current smart grids for PQM [7].

d) Power Quality Monitoring System Over the Internet

This system merges the PQM systems with the internet using computers, web servers and communication systems to transmit the high quality and large size data over the communication line. M. Zhang and Kaicheng Li investigated this system for PQM and research have shown that this system is efficient, low cost and is compatible to implement with the existing Supervisory Control and data acquisition (SCADA). This system also uses global positioning system (GPS) for synchronization [8].

e) Integrated Power Quality Monitoring System

This monitoring system integrates data from all intelligent devices but it was suggested to collect the data only related to disturbance created in the system to identify the cause that produce such disturbance. The standard followed by the devices that are used for power monitoring is IEC610000-4-30. Also Suggestion to allocate high data throughput for PQM systems is presented in [9].

f) FPGA Based Power Quality Monitoring

For sensitive and high cost user equipment the PQ has to be maintained and for this purpose we have to implement PQM continuously. S. Folea et al. has designed a FPGA based system has two analog channels for measuring current and voltage for PQ analysis and is connected with the computer using WiFi module for transmission of acquired data for further processing. This FPGA board include LCD for displaying data. This system is not much power efficient, so need further improvements [10].

g) Power Quality Monitoring Using OPNET

OPNET simulator for the analysis of PQM is presented in [11] by Y. Bi et al. This research explores the importance of online and real time monitoring of PQ. These type of systems need communication systems also so study of several type of systems was done and OPNET simulator is used for their analysis. It is also found in this paper that 10M Ethernet cable is better for fulfilling the demand of the online PQM systems.

h) Spectrum Analysis Based Power Quality Monitoring System

Normally the data collected from the PQ monitoring system is in time domain. Spectrum Analysis is a technique in which the time domain data obtained is analyzed after frequency domain transform. This spectrum analysis based system is developed by L. Penghui et al. [12]. LabView analyzer is used for analysis in this system. For PQ monitoring voltage and current of electrical network is considered for distortion created by harmonics. A transformer substation is tested to analyze the proposed system and analysis has shown that the proposed system has detected the harmonics and THD in the network.

i) Power Quality Monitoring Using Pseudo-Measurments

To identify the power quality issues in a large scale distribution networks the pseudo-measurements method is used. S. R. K. Kanaesalingam et al. applied an intelligent application based on pseudo-measurement to find the power quality in 33KV distribution network.

j) Co-Operative Sensor Network for Power Quality Monitoring

In this PQM system the wireless sensor nodes are used for quality monitoring. This is a distributed system and main features of this system includes scalability and self-organization. Advantage of this system includes the access to any node at any time to acquire data.

Voltage is very important PQ factor. To have a better PQ we have to make sure the monitoring of voltage levels. A system is presented in [13] which monitors voltage quality using sensor motes.

k) Web-Services Framework for Power Quality Monitoring

F. Gomez et al. presented an idea to use web services platform for online power quality monitoring and processing the data that is collected by monitors. This system determines whether any disturbance in power quality is produced or not after analyzing the signal collected form the smart meters and after that location is identified on which any fault is detected. This web based forum can be used for data collection, fault detection, diagnosis and real time monitoring. The proposed system is tested and results have shown that the proposed system can be implemented for PQ measurements in real environments. Further improvements that are required in this system is to make this system more secure [14].

B. Meter Placement Techniques

a) Optimal Power Quality Meter Placement

To reduce the cost of PQM systems this method chooses meter placement points using adaptive quantum-inspired binary gravitational search algorithm(QBGSA) which is more accurate and fast as compared to previously developed algorithms. This system also reduces the redundant data measurements [15].

b) Binary Firefly Algorithm

This algorithm uses numbers of monitors needed, monitor coverage area and sag propagation index as objective functions for optimum monitor placement selection [16]. This approach is applied on IEEE 118 bus system and results have shown that this function can be used for optimum monitor placement selection in PQM systems.

c) Intelligent Meter Placement Method

For PQ measurements in smart grids an intelligent meter placement method was proposed by S. Ali et al. [17] which is based on data driven network system resulting in reduction of uncertainty in PQ values on power links that are not monitored properly. Best monitor placement links are identified using algorithm based on Bayesian network models and entropy based measurements. The results have shown that the prediction error based algorithm developed achieved better results. Improvements are required to make it applicable for large scale networks, running time of the algorithm also has to be reduced and addition of some evaluation method to find optimum number of monitors to be used for PQM is to be there.

C. Comparison Between Different Power Quality Monitoring Techniques

Power quality monitoring techniques and power quality monitor placement methods are discussed respectively in section B and section C. PQM techniques vary in their working algorithms, PQ parameters they measure, size of networks on which they operate and their complexity. After going through several PQM techniques it is possible to understand the basic operation of these technique and a comparative analysis is possible after reviewing these techniques. Table 1 below show a comparison between different PQM and PQ meter placement techniques.

SEMCE DAC, the PQM method proposed by S. D. Grigorescu et al. [7] is considered to the best one as it is a low cost and flexible system that monitors multiple PQ attributes and provide both real-time and long-term monitoring.

TABLE 1. Comparison between PQM systems

No.	PQM Method	Advantages	Disadvantages	Monitored PQ Attributes
1	High resolution technique for flicker measurement	Accuracy Robustness	Mathematical Complexity	Flicker
2	S-transform techniques for PQ signals detection and analysis	Accuracy	Mathematical Complexity	Voltage sag, swell and interruption THD
3	Ata- acquisition system for PQ monitoring (SEMCE - DAC)	Reduced Cost Data Transmission Capabilities System flexibility	Data Transmission	Voltage, current, frequency & harmonics, THD
4	PQ monitoring system over the internet	Low cost Could be implemented over SCADA	Security	Current voltage
5	Integrated PQ monitoring system	Efficiency	Cost of smart meters	Voltage harmonics
6	PQ measurement system using FPGA	Easy to implement Cheap	Difficult system to handle (power consumption and Storage issues)	Voltage Current
7	PQ monitoring using OPNET	Online Monitoring	Absence of long – term monitoring	Transmission time of some PQ attributes was measured
8	PQ monitoring System using spectrum Analysis	Efficiency	Mathematical Complexity	Harmonics THD
9	PQ monitoring using Pseudo-measurements	Ability to analyze large areas	Mathematical Complexity	Voltage current
10	Co-operative sensor network for PQ monitoring	Scalable and Self organizing method	Expensive tools	Voltage
11	Web-services framework for PQ Monitoring	Good Operation time	Complexity	Voltage sag
12	Optimal PQ meter placement	Speed Accuracy	Mathematical Complexity	-
13	Binary firefly algorithm	Solving the multi objective optimization problem for OPQM	Mathematical complexity	-
14	Intelligent meter placement method	Reduce uncertainty over non- monitored links	Running time not very good	-

D. Power Quality Monitoring Policies and Practices

Worldwide efforts have been made to ensure the good quality of power from supplier to receiving end. J. V. Milanovic conducted a survey regarding industry practice about PQM in 43 countries using a questionnaire. Response from 114 power companies is recorded and it is observed that most of them have control centers to continuously monitor the status of power quality monitors to ensure better power quality. Survey shows that around the world these power quality schemes are almost same with minor changings. Important finding of this survey are listed below:

- Mostly fixed monitors are used by transmission system operators (TSOs) and portable monitors are mostly used by distribution system operators (DSOs) and 82% of system operators are using fixed monitors for continuously PQ check.

- Customer complaints are the primary motivation for PQ monitoring.
- Location of Permanent monitor installation is majorly dependent upon customer PQ requirements.
- Purchasing of Monitors is majorly dependent on its performance, number of input channels, data output c compatibility and cost.
- Each individual utility uses only few different models of PQ monitors
- While carrying out measurements, overall system current is considered rather than a specific customer current and all three phases are monitored.
- The results of data processing are used for internal or external reporting on specific events

- Two thirds of voltage measurements are line-to- natural voltages rather than line to line voltages.

European energy regulators through their branch organizations CEER and ECRB [18] published the guidelines that contains some general recommendations about monitor placement, parameters selection and result reporting.

E. *Struggles Regarding Power Quality Improvement*

Power quality improvement strategies are applied continuously to improve the PQ. In many countries new technologies of power quality monitoring like smart meters are implemented and continuous online power quality monitoring techniques are implemented. P. Santarious presented a long term power quality monitoring method [19], in which continuous power quality in monitored for a period of 12 years(1997-2005) by considering important power quality parameters like harmonics, unbalance and flicker. After analysis it was found that the major factor in power quality disturbance is flicker.

L. Campus found that flicker occurred many times due to construction work and industrial load and some voltage dips are occurred as a result of lightening in his research done at Portuguese electricity and transmission grid from 2010 to 2011 by continuously measuring voltage at delivery points [20].

S. Sultan et al. analyzed electrical distribution networks of Libya in terms of PQ. The research also describes the major sources causing PQ disturbances and their solutions. It was found in this research that lack of awareness is also a major cause of PQ issues in less developed countries.

III. Conclusions

This paper presents an overview of several modern power quality monitoring techniques and power quality monitor placement techniques. Also research done before to develop the efficient ways to improve PQM and PQ monitor placement methods is also helpful in improving the PQM systems. Important power quality attributes include flickers, harmonics, voltage sags and …etc.

Both real-time monitoring and long-term monitoring systems or both are studied in this research. A comparison is presented in tabular form between different power quality monitoring systems on the basis of advantages, disadvantages, attributes they count for PQ measurements and mathematical complexity. Beside that comparison a comparison between monitor placement techniques is also presented.

Among all the PQM systems that are compared in this paper, SEMCE DAC is found to be the most effective, cost efficient and flexible method. By incorporating wireless communication technology in PQM systems make it possible to access the monitoring systems from far away.

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