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Remote Power Quality Monitoring and Analysis System Using LabVIEW Software

Phang Yoke Yin and M. V. Chilukuri, *Senior Member, IEEE*

Abstract— **This paper presents the development of a computer based data acquisition system that provides real-time monitoring of voltage and current at the customer's point of common coupling (PCC). Any power quality disturbances sustained by the user throughout the monitoring period were detected and recorded on remote PC. Post acquisition analysis was performed on the data collected. The power quality system was put to several tests and experiments during the development stage of the system. Actual continuous real-time monitoring was carried out for one-week duration using the developed system and results were analyzed and reported.**

***Index Terms*—Power Quality, Voltage Sag, Real-Time Monitoring, Harmonics.**

I. Introduction

WITH the electric industry undergoing changes in quality, increased attention is being focused on reliability and power quality. Many high-tech electricity-dependent devices and equipment used in commercial and industrial facilities are sensitive to many types of power quality disturbances. On the other hand, the increasing use of power electronics devices contributes further to the arising power quality problems.

There are numerous types of power quality problems which might have varying and diverse causes. Moreover, it is all too common that different power quality problems can occur simultaneously, interchangeably or randomly. In order to understand the power quality problems better, comprehensive monitoring and data collection of power quality events are important. Monitoring system can serve as a vital diagnostic tool and help to identify the cause of power quality disturbances and even possible to identify problem conditions before they cause interruptions or disturbances.

The primary international organizations or study committees working on power quality issues include the Institute of Electrical and Electronic Engineers (IEEE), International Electrotechnical Commission (IEC) and International Council on Large Electric Systems (CIGRE). The
recommended guidelines for power quality monitoring were discussed in [1]. Algorithms as well as methods for disturbance detection, classification and analysis, have been proposed in literature [2] – [4]. Also, similar projects on the development of power quality problems monitoring system had been implemented in [5] – [6]. This paper proposes the development of a computer-based data acquisition (DAQ) system that provides real-time monitoring of voltage and current, with remote monitoring feature. The DAQ system runs on a desktop computer with National Instruments (NI) 6034-E DAQ card. The DAQ system was implemented as a virtual instrument (VI), whereby programming and user interface was developed using the NI LabVIEW software. The main objectives of the project were to capture power quality disturbance events and perform post-monitoring analysis on the disturbance data.

II. Experimental Hardware Setup

The power quality monitoring system uses six channels for the measurement of three-phase voltage and current. The measured analog signals undergo signal conditioning, before being digitized in the DAQ card (A/D converter) and finally fed to the computer for processing. The software consists of two main programs, which are for data acquisition and data analysis. Data acquisition program is used to perform real-time power quality monitoring, detection and data recording whereas data analysis program is for post-acquisition data analysis. The DAQ system can be connected to internet, through which it can be monitored and controlled remotely in web-based format. For automatic e-mail notification and data sharing online, the DAQ system incorporates with other software such as MS Outlook and FTP server.

A. *Monitoring and Analysis Features*

Basically, the data acquisition program can detect certain power quality disturbances such as transient, voltage sag and swell based on the user-defined thresholds. Once a power quality disturbance is detected, the waveform data for all channels are recorded, including pre-trigger and post-trigger data. Automatic e-mail notification is triggered whenever a disturbance is detected or error has occurred. The summary of the power quality disturbances detected is displayed in the disturbance table. Basic parameter calculations are also available in the DAQ system, including RMS values, $V_{peak-peak}$, fundamental frequency, power factor, active power and harmonic analysis such as total harmonic distortion (THD), power spectrum plot as well as harmonic amplitude versus frequency chart. Moreover, the data acquisition program can

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M. V. Chilukuri is with Faculty of Engineering, Multimedia University, Cyberjaya 63100, Malaysia (e-mail: chilukuri@ieee.org).
Phang Yoke Yin is with ABB, Malaysia (yoke-yin.phang@my.abb.com)

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perform periodic RMS logging according to user-specified interval and duration.

The main priority for the data analysis program is voltage sag analysis. The sag characteristics calculated include characteristic magnitude, P-N factor, phase jump, sag depth, retained voltage, sag area, and event severity index. Other than that, the sag type (type A, C and D) is determined based on the symmetrical component method. The disturbance events stored in the log file can be plotted against various sag standards, i.e. SEMI F47, CBEMA, ITIC and IEC, on the disturbance chart. Also, the voltage dip table is provided for the log file based on the IEC 61000 standard. Besides the similar basic parameter and calculations as the data acquisition program, the data analysis program has other additional features such as graph display of active power, reactive power, apparent power, THD and phasor diagram. Due to the possibility of large data files, the data analysis program has a search function with search criteria based on sag magnitude or duration.

B. *Computation for Power Quality Parameters*

The computation for some of the power quality parameters are explained as follows:

1) *Voltage sag and swell detection:*
Sag detection method used in this project was based on IEEE standard 1159 [1], where RMS voltage below 0.9 p.u. of the system voltage is considered as voltage sag. The sag duration was calculated from the time either one of the phases dropped below the minimum voltage limit until all of the three phases recovered within voltage limit.

2) *Transient detection:*
The transient detection method used in this monitoring system was based on a simple voltage threshold trigger. If the peak or valley of the voltages exceeded the voltage threshold, transient was detected and the data was logged.

3) *Voltage Unbalance:*
For this project, the IEEE standard is followed whereby voltage unbalance is defined as maximum deviation from the average phase voltage divided by average phase voltage.

4) *Sag Characteristics:*
The procedures in calculating sag characteristics were based on [7], where discrete Fourier transform (DFT) was used when finding complex voltage.

III. IMPLEMENTATION AND EXPERIMENTAL RESULTS

The DAQ system was put to several tests during the development stage of the system for data verification. The disturbance detection feature was tested by creating voltage sag with Industrial Power Corrupter (IPC) while transient was generated by load switching. The three phase voltages and currents were continuously sampled at a sampling rate of 12,800 samples/s, which correspond to 256 samples/cycle with 50 Hz fundamental frequency. Among the experiments conducted include:

A. *Comparisons of Data with IPC*

The objective of this experiment was to compare the data logged using the DAQ system developed in this project and Industrial Power Corruptor (IPC) DAQ system. In this experiment, the IPC was used to generate voltage sags and swells of several voltage standards using Industrial Power Corrupter (IPC) settings. The disturbance duration and magnitude was recorded and compared with the actual disturbance logged by IPC. Table 1 shows the data comparison between IPC and developed DAQ system.

TABLE 1: DATA COMPARISON

Steps	IPC		LabVIEW		Magnitude difference (%)	Duration difference (Cycles)
	Magnitude (%)	Duration (cycles)	Magnitude (%)	Duration recorded (s)		
SEMI F47						
#1	50	10	50.31	0.22	0.62	+1
#2	70	25	70.25	0.5	0.35	0
#3	80	50	80.31	1	0.39	0
#4	0	1	-	-	-	-
#5	80	10 sec	80.16	10	0.20	0
#6	90	15 sec	89.88	14.98	-0.13	-1
ITIC						
#1	120	25	119.94	0.48	-0.05	-1
#2	0	1	-	-	-	-
#3	70	25	70.16	0.5	0.24	0
#4	80	10	80.02	10	0.02	0
#5	110	10	109.89	9.98	-0.10	-1
CBEMA						
#1	115	1	112.52	0.02	-2.16	0
#2	30	1	39.94	0.02	33.15	0
#3	70	10	70.12	0.2	0.17	0
#4	87.5	2 sec	87.78	2	0.32	0
#5	107.5	2 sec	-	-	-	-
IEC 4-11						
#1	0	1	-	-	-	-
#2	40	10	Incomplete data	0.22	-	+1
#3	70	25	70.18	0.5	0.26	0

Overall, the percentage magnitude error was about three percent for this experiment, except for certain conditions where the sag duration was one cycle. The detected disturbance duration had at most one-cycle error due to the sag detection method used.

B. *Monitoring of Voltage Sag during Motor Start Up*

The objective of this experiment was to monitor and record the voltage sag effect created due to induction motor starting. Two case studies of motor starting were shown here, where a full load motor was started in normal condition and the other during voltage sag. The drop in voltage during starting depends on the system parameters, such as short-circuit power and motor power rating.

For voltage sag due to induction motor starting, the general RMS voltage pattern is as shown in Figure 1, whereby voltage would decrease and then increase slowly. From the RMS voltage graph, the sag depth recorded was about 0.01 p.u., which was very small because the motor power was 3 kW only. Hence, the usual 0.9 p.u. threshold could not trigger the sag detection, and a larger threshold was used instead.

Similarly, the starting of motor during voltage sag also showed the motor sag was very small and could not simulate the multistage sag. For motor starting during voltage sag,, there was additional drop in voltage because the voltage drop during sag slowed down the affected motor and caused an additional increase in load current, as shown in Figure 2. In actual cases, the motors used are larger and the sag created will be bigger.

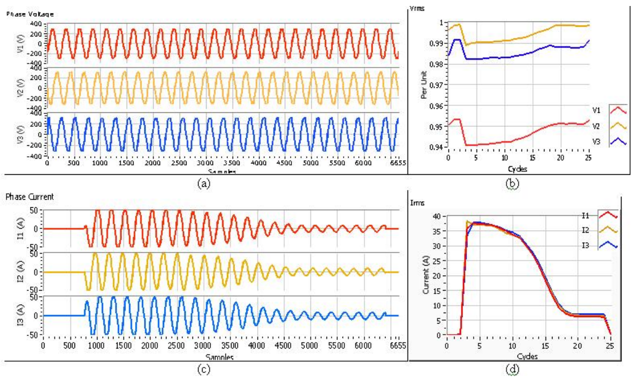


Figure 1: Motor waveforms during starting in normal starting condition (a) Instantaneous phase voltages (b) RMS phase voltages (c) Instantaneous phase currents (d) RMS phase currents

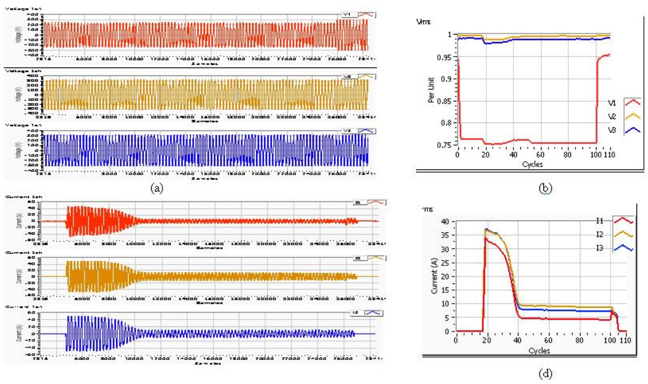


Figure 2: Motor waveforms during starting in voltage sag condition (a) Instantaneous phase voltages (b) RMS phase voltages (c) Instantaneous phase currents (d) RMS phase currents

C. Simulation of Line-Line Fault

The aim of this experiment was to test the acquisition system by simulating short circuit faults on the motor. Two types of faults were created, which were the double line to ground fault and the double line fault on phase one and two. The primary protection would operate and trip the circuit when the relay detects the fault current. Otherwise, the fault would be automatically cleared by the fault module itself after five seconds, acting just like secondary protection. The study was conducted with operating conditions in full load, half load and no load. Figure 3 shows the waveforms logged during starting in full load condition. When fault occurred, fault current rose higher than normal current while voltage on faulty phase dropped in proportional to the fault current. The fault current and voltage sag magnitude depend on many parameters such as load conditions and types of faults. Due to inadequate equipment, only two phase currents were monitored throughout the experiment, which were I_1 and I_2. Since there was no input to the phase three current channel, the I_3 experienced maximum drift of 50 A and thus can be ignored.

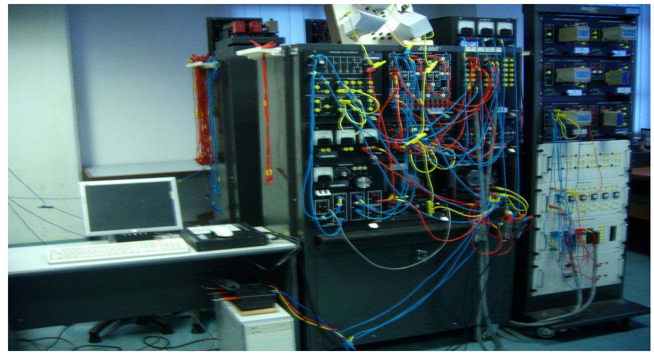


Figure 3: Experiment setup for line-line fault:

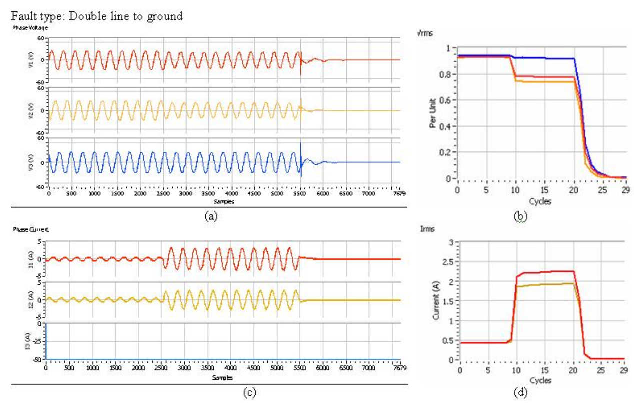


Figure 4: Motor waveforms for full load (a) Instantaneous phase voltages (b) RMS phase voltages (c) Instantaneous phase currents (d) RMS phase currents

D. Real-Time Monitoring at Supply Panel

Continuous monitoring was carried out at the Machine and Drive lab in Multimedia University, Cyberjaya for one-week duration. Periodic RMS values saving for one-minute duration were executed automatically in every ten-minute interval. The measured voltages were higher than actual values due to high measurement error of twelve percent. Hence, normal operating condition was often mistakenly detected as voltage disturbance and caused unnecessary logging if the rms threshold were unsuitable. On the contrary, actual voltage disturbance could not be detected accurately after threshold adjustment. Throughout the monitoring period, only one voltage distortion was recorded, as shown in Fig 4.

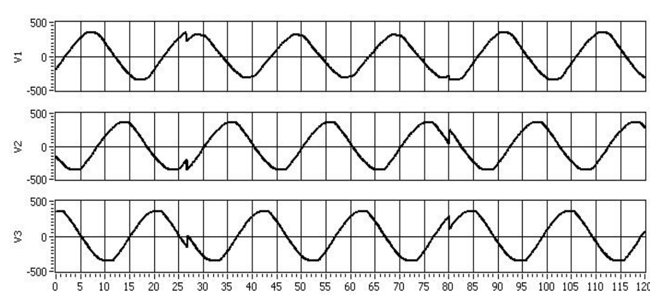


Figure 5: Captured voltage distortion

IV. Conclusion

In this project, a data acquisition (DAQ) system for remote monitoring of power quality disturbances was successfully developed and tested using laboratory experimental setup. The real-time power quality monitoring system developed offers some of the basic power quality monitoring features that are available in power quality monitoring equipment. Several tests and experiments were carried out to test run the system for local and remote power quality monitoring. Based on the measurements results obtained, it was observed that the accuracy of the developed DAQ system was a major problem during continuous real-time monitoring for long duration. Further improvements on the DAQ system include: accuracy, implementation of simpler and efficient algorithms. The developed laboratory prototype is found to be cost effective and useful for developing wide-area power quality and energy monitoring system suitable for commercial and industrial customers.

V. Appendix

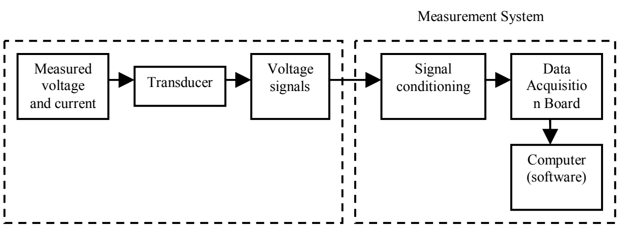


Figure 6: Data acquisition block diagram

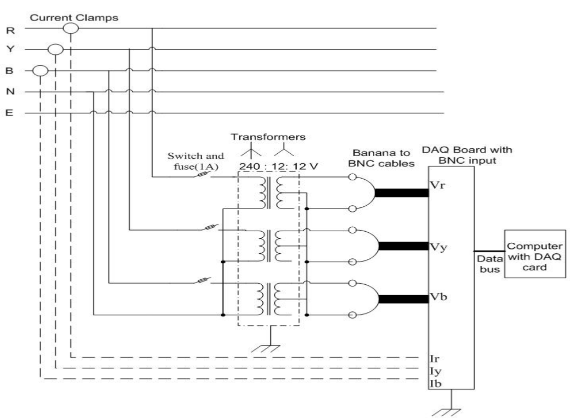


Figure 7 Circuit diagram of actual hardware setup

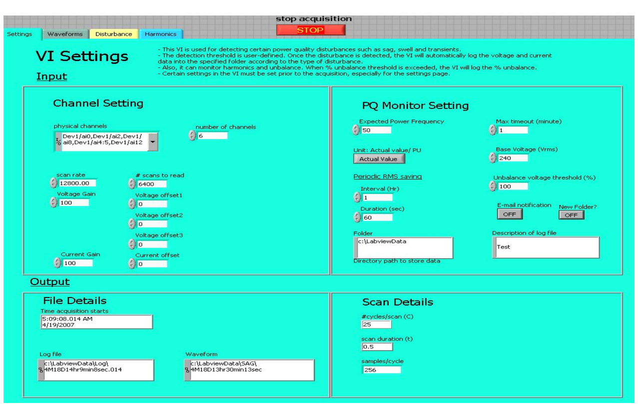


Figure 8: Software settings for PQ monitoring and detection

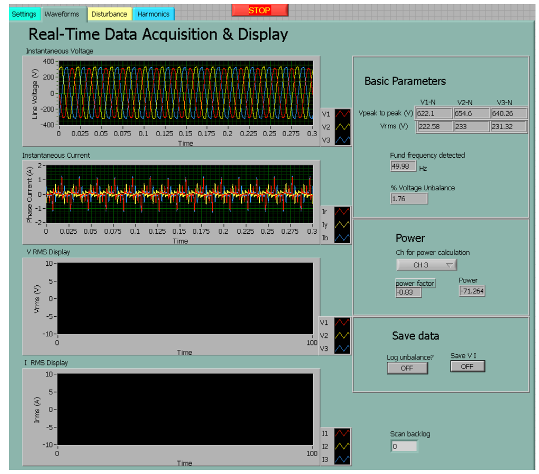


Figure 9: Real-Time PQ monitoring Software Display Menu

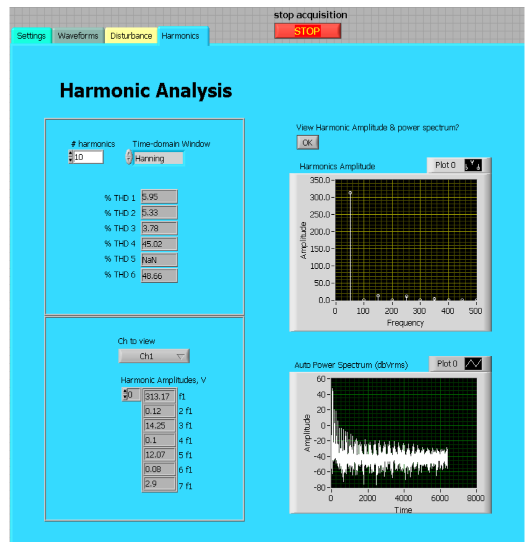


Figure 10: Real-Time Harmonic Monitoring and Display

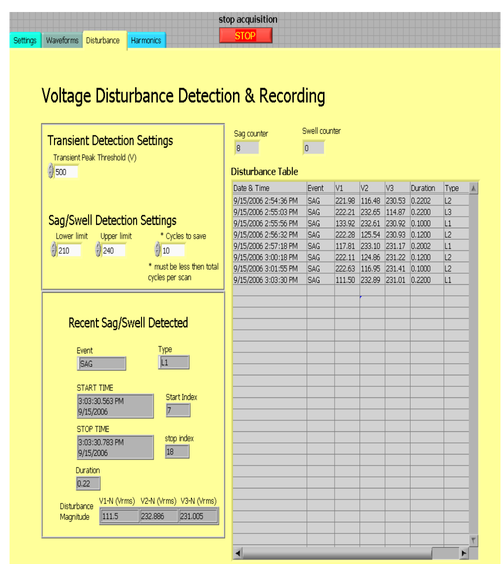
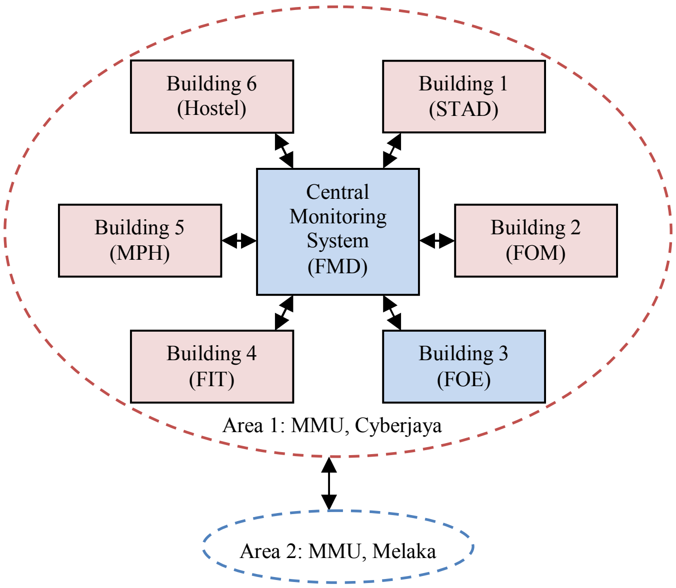


Figure 11: Real-Time Power Quality Remote Monitoring and Detection



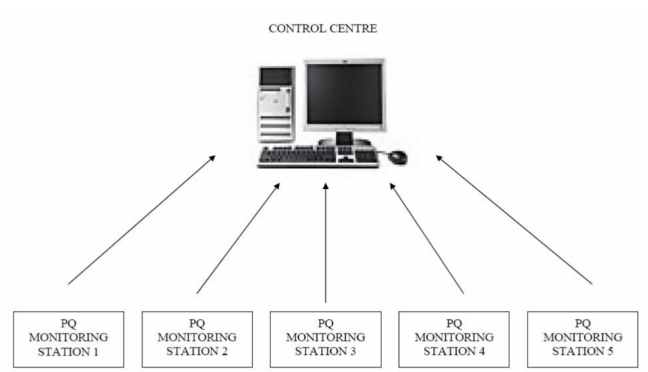


Figure 12: Remote Power Quality Monitoring and Analysis System (a) Developed prototype (highlighted in blue) (b) Wide-Area Power Quality and Energy Monitoring System for possible extension (highlighted in pink)

VI. References

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VII. Biographies

M V Chilukuri (SM’2004) is Lecturer at Faculty of Engineering, Multimedia University, Cyberjaya, Malaysia. His fields of interest are Power Quality, Time-frequency Analysis, Soft Computing, Condition Monitoring, Distributed Generation and Partial Discharges. He is Member of IET, and member of IEEE-Power Engineering Society, Industrial Application Society, Instrumentation and Measurement Society and Signal Processing Society.

Phang Yoke Yin received B.E degree in Electrical Engineering from Faculty of Engineering, Multimedia University, Cyberjaya. Currently she is Engineer at ABB Malaysia. Her research interests are power quality and harmonics.