Improving Monitoring, Control and Protection of Power Grid Using Wide Area Synchro-Phasor Measurements

HAMID BENTARZI

Signals and Systems Laboratory (SiSyLAB)
DGEE, FSI, Boumerdes University
e-mail: sisylab@yahoo.com
ALGERIA

Abstract: - When disturbances occur in power grid, monitoring, control and protection systems are required to stop the grid degradation, restore it to a normal state, and hence minimize their effects. However, in wide area power grid resulting from large extension and interconnection with neighbor grids, classical systems based on local independent measurements and decisions are not able to consider the overall power grid disturbances and then they are not able to avoid the blackout. The introduction of the advanced measurement and communication technologies in these systems may provide better ways to detect rapidly these disturbances and protect the overall grid from the propagation of the fast-cascading outages. Indeed, the observability of the wide area power system dynamics becomes feasible through the use of these recent developed technologies. Using wide area real-time synchro-phasor measurement system based on Phasor Measurement Units (PMUs), different types of wide area protection, emergency control and optimization systems can be designed and implemented.

Key-Words: - Power system, Phasor Measurement Units, emergency control and optimization systems, wide area protection system.

1 Introduction

Electric Power Systems are an essential infrastructure of modern society and have been characterized as the largest man-made systems. Catastrophic failures of power systems – popularly known as blackouts – occur infrequently, but when they occur they cause great trouble to the industrial companies. In recent years, it has become evident that precise measurements of power systems' state in real time is a very important tool for managing the operation of power systems, as well as mitigating some of the effects of catastrophic failures. So, stability of such system is of a great concern, since it is subjected to different disturbances that may cause a local or complete system collapse if no adequate actions are taken to prevent it. Therefore, many techniques have been developed to make the power system survives during disturbances and continue to operate. One recent developed technique that may be used is Synchronized Phasor Measurement. It's the most accurate wide area measurements (WAMS) technology for power systems, and points the path for the applications of these measurements to be realized in coming years. The synchronized phasor measurement concept was introduced about 25 years ago. It is now a mature technology with products being offered by leading manufacturers of electric power equipment. It has been well recognized by experts that synchronized phasor measurements offer the most direct and accurate tool for determining the state of the power system. In this paper, we discuss new technologies that allow wide area grid to be well monitored, controlled and protected against any disturbances. We have already designed and implemented PC based Phasor Measurement Unit through the use of the new technologies as well as we have tested its performance for showing its experimental evaluation. The design and implementation of such PMU as well as the test results are presented in first section. After that, we present the different steps which may be followed in order to develop PMU based Wide area measurement system taking into count quality of the power grid dynamics observability. In the next section, we have presented some applications where these advanced technologies have been used. Such applications have been developed for improving the monitoring, control and protection system for large scale power grid are discussed. We will end up this paper by presenting our research work results related to this subject.

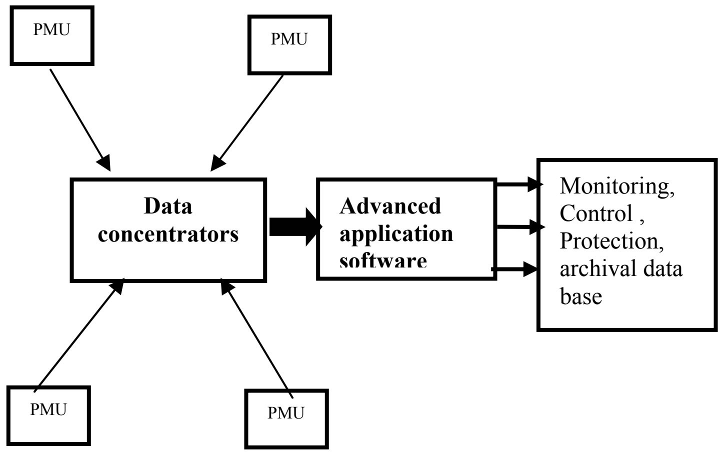

Figure 1. Applications of PMU in power system.

2 PMU based Wide Area Measurements System

In a wide area measurements system (WAMS), the Phasor Measurement Unit (PMU) is considered to be one of the most important measuring devices that can provide synchronized phasor measurements of voltages and currents from different locations in an electric power system. These PMUs should be associated with a reliable high-speed communication system for transferring all measurements and indicators to a central position, e.g. a control center, for evaluation and decision. From this central position, action orders are then sent to different parts of the power system shown in Figure 1. Such-WAMS with digital processing and communications, making data flow and information management central, may be implemented in the smart grid.

2.2 PC based Phasor Measurement Unit

The purpose of phasor measurement is to produce a simplified representation of power system parameters that accurately represents the actual power system status. The measurement rate, measurement accuracy, conversion technique, and final data rate all have to be integrated for optimal performance.

The phasors may be calculated over any number of waveform samples, but most algorithms use a block of samples that span an integer number of cycles. This span of time over which the phasors are calculated is called the “window.” The 50-Hz waveform is constantly changing, so the phasors calculation will represent an average value over the calculation window. Information bandwidth and phasor sample rate are basic considerations that are characterized by data-handling capability.

There are four main considerations for choosing an appropriate phasor computation algorithm: the phasor sample rate, accuracy of the representation of included information (the pass-band), the ability to reject undesirable information (rejection outside the pass-band), and measurement time delay.

The recently published IEEE Standard C37.118[1] will assure that compliant phasor measurement units will report phasors using the same convention for measuring phase angle, particularly when the underlying power system frequency is off-nominal.

The phasor measurement unit has the ability to track the phasor values of voltage and current synchronously on power system in real time. Its system hardware shown in Fig.2 mainly consists of synchronized sampling board where the measured values of the power system parameters fed from PT and CT in analog forms are passed through an anti-aliasing filter amplifier (low pass filter). Besides, sample and hold circuits and analog multiplexed are used to sample the six different signals supplied by instrument transformers at the same time. The sampled signals are fed to the PC data acquisition board that converts these samples into digital form where it will be processed [2].

In our proposed scheme, PMUcan correctly extract the

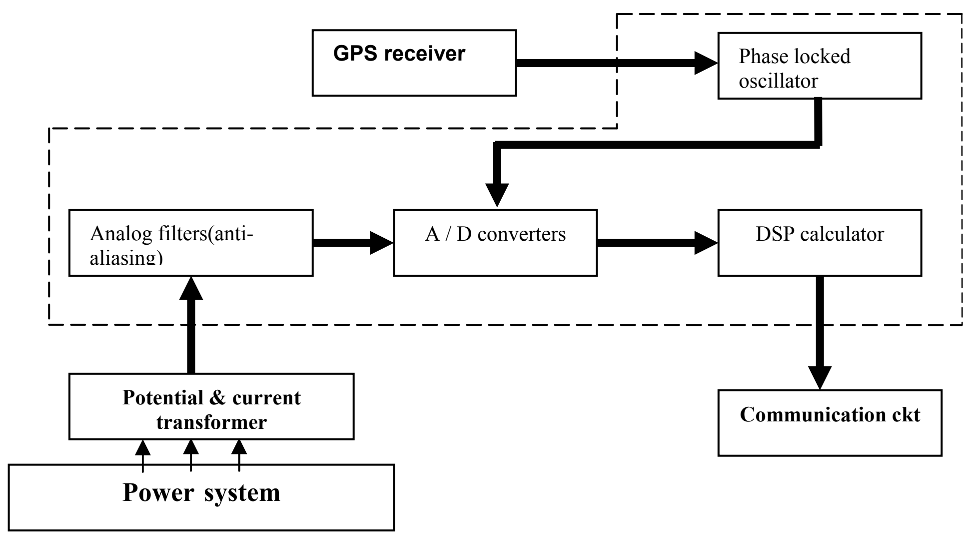

Figure 2. Functional Block Diagram of the PMU.

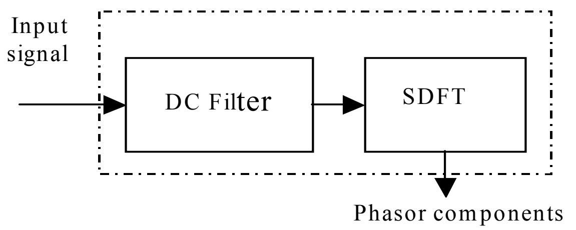

Fig.3 PMU enhancement computing algorithm

phasors of the fundamental components and symmetrical components of voltage or current waveforms and then accurately estimates their instantaneous amplitude, phase angle, and frequency, even when disturbances occur in a large scale and complex power systems. It uses the sample by sample basis instead a frame or cycle basis (data window) to obtain the accurate fundamental phasors. This is to fulfill the high speed measurement and detection feature required by the PMU and protective system. The approach consists first of removing unwanted dc components of the input measured signal using a fast digital filter algorithm, which is suitable for such a real-time application, and then provide the filtered signal to the Smart DFT[3] algorithm to accurately generate the phasor measurement components as shown in Fig.3.

The synchro-phasor is estimated from data samples using a standard time signal generated by-GPSas the reference for the sampling processor for the whole system.

Labview software tool has been used for developing the graphical user interface (GUI) in order to visualize the real-time signals as well as to communicate with other systems.

The PMU is tested by applying to it a fault current signal generated by computer simulation. The obtained results show that the used method is capable of completely eliminating the dc offset and thus greatly improving the performance of the full-cycle DFT algorithm.

Moreover, the performance of the proposed PMU algorithm has been tested under transient and dynamic power system conditions, which is important for the protective relaying applications. These tests have been performed for signals as function of time by varying magnitudes and/or frequencies. It can be noticed that the PMU tests results as shown in Fig.4 are very encouraging[4].

2.2 Power Grid Dynamics Observability

Engineers and mathematicians have developed a variety of algorithms to determine the best PMU locations for observability of the whole power system. To be practical, a PMU strategy should aim for full observability, work well on the heterogeneous nature of power system topology, and allow for a system planner

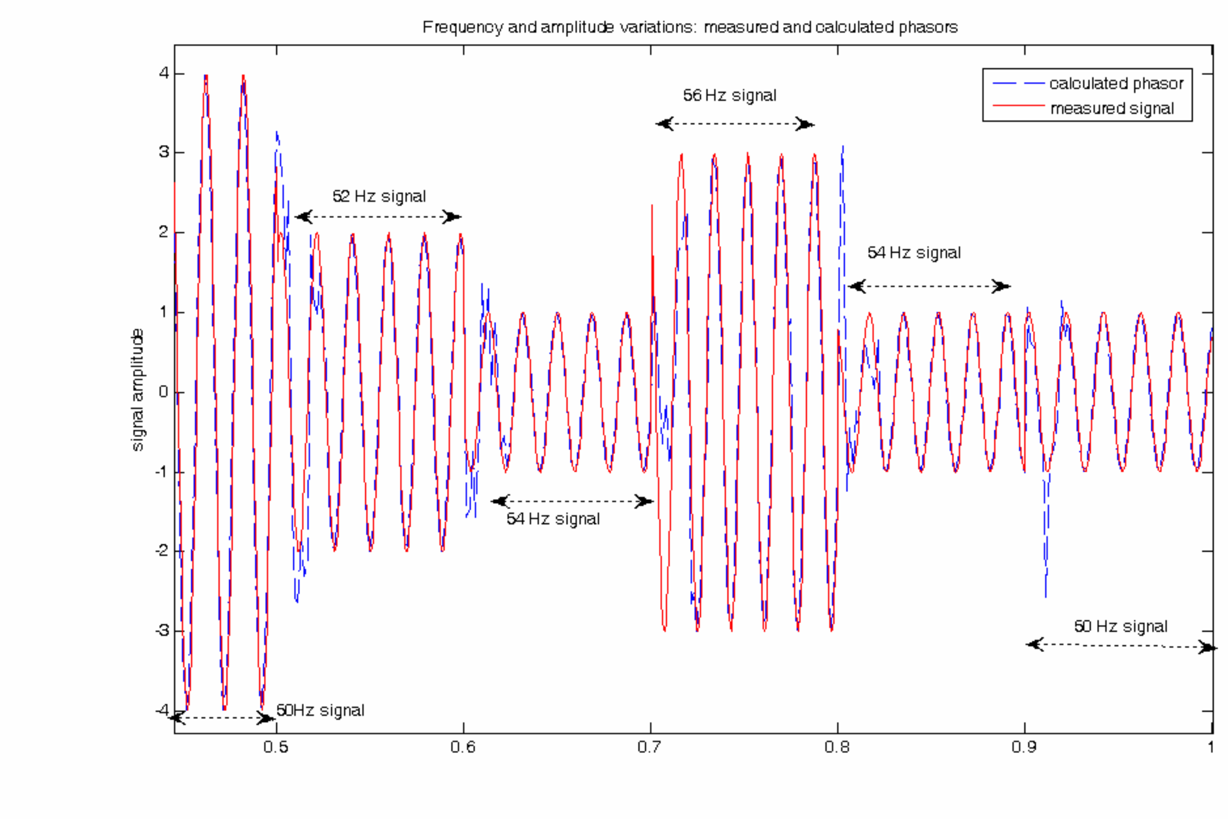

Fig.4 Signal magnitude step changes from nominal level

to adapt the strategy to meet their unique needs and system configuration. Power system Observability refers to the f'act that measurement sets and their distribution are sufficient for solving the current state of power systems. Placing a PMU at every substation would certainly provide all the necessary real-time Voltage magnitudes and angles for system observability. However, this is redundant due to an important attribute of PMUs. Provided that you know a bus's voltage magnitude and angle, all current phasors, and the connecting line parameters, then all connecting bus voltages and angles can be calculated. This significantly reduces the number of PMUs (and therefore cost) needed for complete observability. Due to this, Baldwin*, et al*[5] estimated that for a real system, PMUs are required to be on a minimum of 1/5th-1/4th *(20-30%)* buses to achieve full system observability. Because of the ability of the PMU to observe neighboring busses.

Installing PMUs for full system observability is a large investment. The strategy used needs to be practical, adaptable, and cover the entire process from preparation to installation schedule. Three steps such as placement model, placement algorithm, and phased installation cover entire process.

-The placement algorithms such Spanning Tree based on graph theory developed by[6]. Reynaldo Nuqui and Integer Programming developed Ali-Abur [7]require a list of busses, a list of branches or incidence matrix, and a list of which busses have injection. The placement algorithms do not take into account physical locations, component states, or the number of transformers in a substation. Thus the person running the placement algorithm must interpret the real system into a very simplified format, determining what exactly qualifies as a bus and how to modify existing models for certain situations.

The integer programming method can work very well and fast. The amount of result variance and run time will depend on the specific algorithm used by the optimization toolbox.

-Installation Schedule: In reality however, fully observable placement sets may not be immediately attainable or even necessary at all. By preparing an implementation schedule that takes observability into account, the PMU planner can make the most of the available PMUs long before full observability is reached. Even when the goal is to attain full observability, it is unlikely that a system owner will purchase and install all the PMUs at once. This large investment will likely be spread out over several years by installing a subset of the PMUs each year in steps or phases. How to choose which PMU locations selected in each step should depend on the operator's most urgent need and gradually increasing the overall observability with each phase.

3 Improve monitoring system

Using real-time information from PMU and automated controls to anticipate, detect, and respond to system problems, a smart grid can automatically avoid or mitigate power outages, power quality problems, and service disruptions.

A phasor network consists of phasor measurement units (PMUs) dispersed throughout the power system, Phasor Data Concentrators (PDC) to collect the information and a Supervisory Control And Data Acquisition (SCADA) system at the central control facility. Such a network is used in Wide Area Measurement Systems (WAMS), the first of which was begun in 2000 by the Bonneville Power Administration [8]. The complete network requires rapid data transfer within the frequency of sampling of the phasor data. GPS time stamping can provide a theoretical accuracy of synchronization better than 1 microsecond. "Clocks need to be accurate to ± 500 nanoseconds to provide the one microsecond time standard needed by each device performing synchrophasor measurement." For 50Hz systems, PMUs must deliver between 10 and 30 synchronous reports per second depending on the application. The PDC correlates the data, and controls and monitors the PMUs (from a dozen up to 60). At the central control facility, the SCADA system presents system wide data on all generators and substations in the system every 2 to 10 seconds. PMUs often use phone lines to connect to PDC, which then send data to the SCADA and/or Wide Area Measurement System (WAMS) server. Thus this network of PMUs-can provide real-time monitoring on a regional and national scale. Many in the power systems engineering community believe that the Northeast blackout of 2003 would have been contained to a much smaller area if a wide area phasor measurement network was in place[8].

Similar to this, PMUs can improve system models when the data is analyzed offline. Time synchronized recording of how a generator or other systems react after a series of actions can be used to verify/improve existing models or create new ones. Measuring the current phasors from both ends of a transmission line is also useful in deriving the line's π model.

4 Improve control and protection integrated system

Under frequency load shedding scheme is the most commonly used control system to balance the generation and load (power demand) and it is the last control step for preventing electric power system from blackouts. It deals with shedding the appropriate amount of load for removing the overload situation. This may be performed in many steps with each step having its own setting frequency and percent of load to be shed.

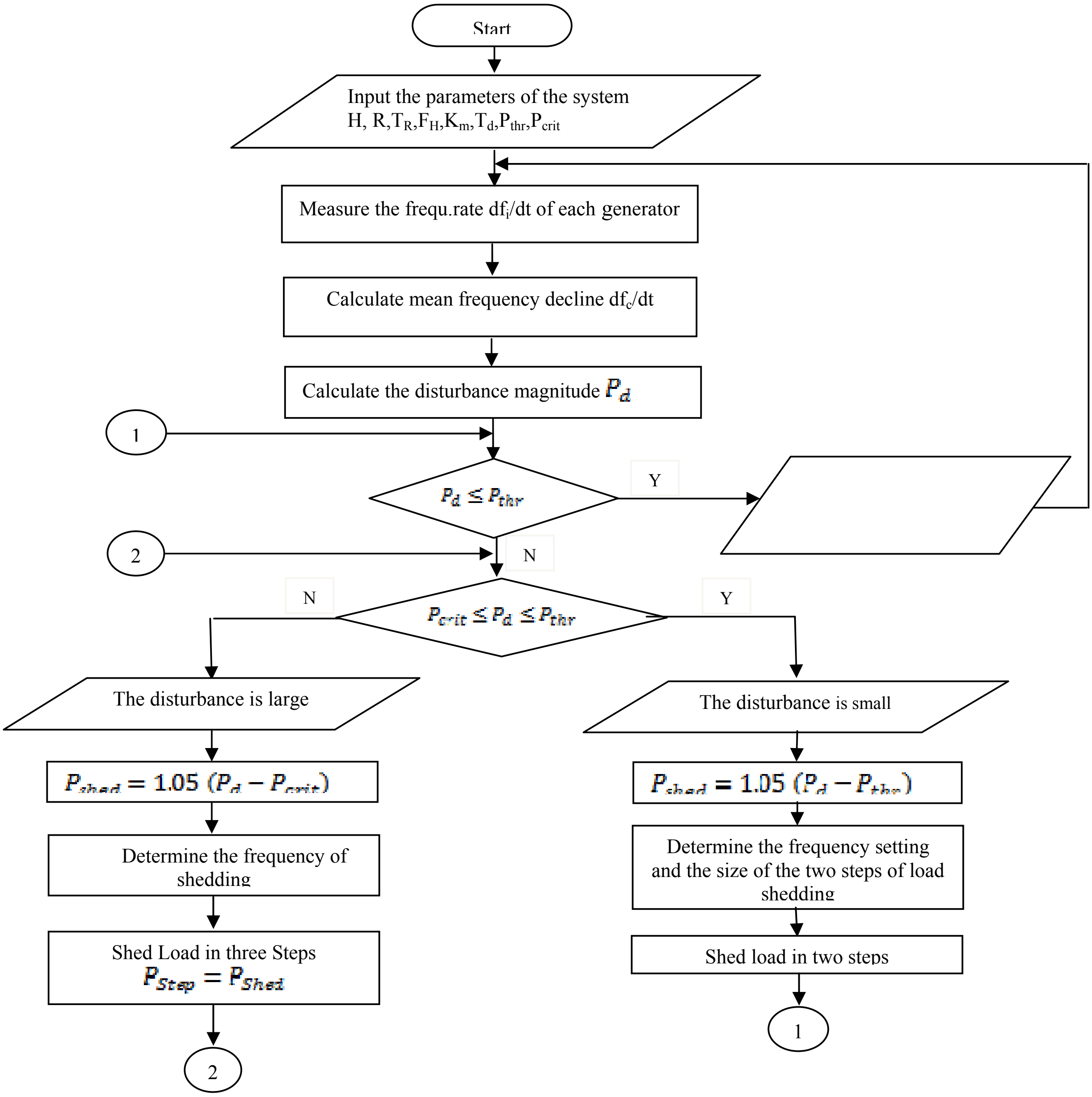

Figure 5. The flowchart of the proposed algorithm

One application of PMU in power system has been developed which is the implementation of an adaptive load shedding scheme. Because, in this type of load shedding the amount of load to be shed is determined adaptively according to the size of the disturbance.
After measuring the frequency by PMU at each generator in the power system, the rate of frequency decline of each generator is determined in the center, and then the system mean frequency decline of the system is calculated according to the following formula :

$$\frac{df_c}{dt} = \frac{\sum_{i=1}^{n} H_i \frac{df_i}{dt}}{\sum_{i=1}^{n} H_i} \quad \frac{df_c}{dt} = \frac{\sum_{i=1}^{n} H_i \frac{df_i}{dt}}{\sum_{i=1}^{n} H_i} , \qquad \text{(Hz/s)} \qquad (1)$$

Where: df_c/dt $\frac{df_c}{dt}$ is the rate of mean frequency decline,
and df_i/dt $\frac{df_i}{dt}$ is the rate of generator (i) frequency decline,
and Hi is the inertia constant of generator (i).

Then, the size of the disturbance in the system may be determined using the following formula:

$$P_d = 2\frac{H_{sys}}{f_n}\frac{df_c}{dt}, \quad \text{(pu)} \qquad (2)$$

Where f_n fn is the nominal frequency of the system in hertz (50Hz), and Hsys is the equivalent inertia constant (in second) of the system.

After the disturbance is estimated using (2), its condition is determined by comparing it to two specific values which are threshold power (Pth) and critical power (Pcr) as shown inFig.5.

The first frequency setting of the proposed adaptive centralized load shedding scheme is set to 49.5 Hz in order to allow the frequency decline to be arrested far before reaching the critical frequency. The other frequency settings are determined automatically according to the last value of shedding frequency.

The test and evaluation of our proposed algorithm under different disturbance sizes and conditions using the model of IEEE-9 bus power system gives good result.

The advantage of this method is that the amount of load to be shed is not large for all the disturbances unlike the conventional one. Therefore, unnecessary shedding is avoided which allows both a better service to different consumers and the system collapse prevention [9].

Adaptive protection is a concept that has been around for decades but has yet to be widely implemented in transmission systems. Presently, protective relays operate based off fixed settings. Theses settings could have been set many years ago and have no way to shift depending on whether the system operator would like the system to operate on one side or the other of the security/dependability (reliability). With appropriate communications, PMUs would allow for detecting system conditions and either change protection settings itself, or wait for operator to remotely change settings based off real-time data from PMUs. This could be particularly effective in reducing the harm caused by cascading blackouts. When the system conditions are particularly stressed, the protection settings should be set to be more secure so that one event doesn't trip a line, which then overloads and trips another line, and so on. Line fault location can also be performed if PMUs are located on each end of the line to measure both current phasors [10].

5 Conclusion

This paper presents PC based phasor measurement prototype which has been developed in our laboratory using data acquisition card. The PMU is tested by applying to it a fault current signal generated by computer simulation. This test has also been performed for signals as function of time by varying magnitudes and/or frequencies. The obtained results show that the used method is capable of completely eliminating the dc offset and thus greatly improving the performance of the full-cycle DFT algorithm.

In this work, some applications of PMU in power system have been described such as the adaptive load shedding scheme. The advantage of this method is that the amount of load to be shed is not large for all the disturbances unlike the conventional one. Therefore, unnecessary shedding is avoided which allows both a better service to different consumers and the system collapse prevention.

Moreover, one other class of PMU application in protection field has been presented. Where the supplied information by PMU can be used for improving protection system reliability (security/dependability).

It can be noticed that the developed as well as applications tests results are very encouraging.

References

[1] IEEE Std. C37.118, IEEE Standard for Synchrophasors forPower Systems, 2005.

[2] A. R. Ouadi, H. Bentarzi and J. C. Maun, A new computer based phasor measurement unit framework, *the 6th Int. Conf. SSD'09*, Djerba, Tunisia, 2009.

[2] T. Lin and A. Domijan, Recursive algorithm for real-time measurement of electrical variables in power systems, *IEEE Tran.Power Del., vol. 21*, 2006, pp.15-22.

[3] P.M. Anderson and A.A. Fouad, *Power System Control and Stability*, New York, IEEE Press, 2002.

[4] A.Ouadi, H.Bentarzi, S.Botoura and J.C.Maun, Dynamic Performance Enhancement of Phasor Measurement Unit, *MEPCON'09*, Assut, Egypt, 20-22thDec.2009.

[5] T. L. Baldwin, L. Mili, M. B. Boisen Jr., R. Adapa, Power System Observability with minimal phasor measurement placement, *IEEE Transactions on Power Systems*, Vo. 8, No. 2, May 1993.

[6] R. F. Nuqui, A. G. Phadke, Phasor Measurement Unit Placement Techniques for Complete and Incomplete Observability, *IEEE Transactions on Power Delivery*, Vol. 20, No. 4, October 2005.

[7] A.Abur, B. Xu, Optimal Placement of Phasor Measurement Units, *PSERC Publication,* October 2005, pp05-58.

[8] K. Vu, V. Centeno, S. Skok, M. Begovic, Benefits of synchronized-measurement technology for power-grid applications, *Proceedings of the 40th Hawaii International Conference on System Sciences*. 2007.

[9] H. Bentarzi, A.Ouadi, N. Ghout, F. Maamri and N.E.Mastorakis,A New Approach Applied to Adaptive Centralized Load Shedding Scheme, *8th WSEAS Int. Conf. on CSECS*, Tenerife, Spain, Dec.14-16, 2009.

[10] E.Price, Practical considerations for implementing wide area monitoring, protection and control, *IEEE Conference for Protective Relay Engineers*. 2006