Asian Journal of Science and Applied Technology
ISSN: 2249-0698 (P) Vol.3 No.1, 2014, pp.36-42

DOI: https://doi.org/10.51983/ajsat-2014.3.1.782

Wide Area Monitoring and State Estimation for a Given Phasor Network

A.H. Al-Shah
PG Student, Power System Engineering, SRCE, Alangulam - 627 808, Tamil Nadu, India
E-mail: shahktr@gmail.com
(Received on 25 March 2014 and accepted on 22 May 2014)

***Abstract* - In this paper, the modeling for a complete scenario of a proposed wide area measurement system (WAMS) based on phasor measurement units (PMUs) technology is presented. The purpose is to increase the overall system efficiency and reliability for all power stages with improved monitoring, protection, and control capabilities of power networks. The developed system is simulated using the Matlab/Simulink program. The power system layer consists of a 500 kW generation station, two transformers, four circuit breakers, two short transmission lines, and two one MW loads. The communication layer consists of four PMUs, located at generation and load buses. The proposed system is tested under two possible cases; normal operation and fault state. It was found that power system status can be easily monitored and controlled in real time by using the measured values online which improves the overall system reliability and avoids cascaded blackout during fault occurrence. The simulation results confirm the validity of the proposed WAMS technology for smart grid applications.**

***Keywords:* Wide Area Monitoring Protection and Control (WAMPAC), Phasor Measurement Unit (PMU), Wide Area Monitoring AM),Global Positioning System (GPS), Wide Area Controller (WAC), Local Area Controller (LAC), Phase Angle Monitoring (PAM), Automatic Generation Control (AGC), Circuit Breaker (CB), Current Transformers (CTs), Potential Transformers (PTs)**

I. Introduction

The power system network is a complex man-made system so it has many problems, it should reliable and supply electrical energy continuously without any interruption. The occurance of blackout and outage must be avoided. The black- out is a combination of series of interrelated events occurring on a power system network. These series of events are hard to control even with modern powerful systems and can no longer be contained to the small portion of the system. Sometimes these small events or disturbances can be affected adversely to a system wide effect. Therefore for controlling this, many techniques have been developed to survive he power system during disturbances and to continue its operation. One of the recent technique which is used is WAMPAC with time synchronized measurement. It is a technique which transports the local information of selected areas to the remote location to check the state estimation. Presently, the main technology used for state estimation is PMUs and is the most precise and advanced technology. It gives information about the current phasor, voltage phasor, value of frequency and rate of change of frequency, this all informations are synchronized. In an environment where the protected area of power system is large, it would be very hard to design a protective or emergency control scheme based on fixed parameter settings. As technology advances day by day, the time frame of synchronized information has been steadily reduced from minutes, to seconds, milliseconds, and now in microseconds. If only Phasor Measurement Unit measurements are used, there are also no complications from the use of both polar and rectangular values in the state estimation process, as would be done when including PMU measurements in traditional state estimators. For example, one of the main applications of PMUs is their use on monitoring and control operations.

This technology can be made possible by advancements in computer and processing technologies and availability of GPS signals. We are very rapidly approaching an era where all metering devices will be time synchronized with high precision and accurate time tags as part of any measurement. To achieve the benefits, advancements in time synchronization must be matched by advancements in other areas. One example is data communications, where communication channels have become fast and more reliable in streaming PMU data from remote sites to a central facility.Improvements in instrument transformers (such as optical transducers) are important for the quality of the signals supplied to the PMU.

Phasor Measurement Unit

One of the most important measurement devices in Phasor network is PMU. The PMU is capable for measuring the synchronized voltage and current phasor in a power systems. The commercialization of the GPS with accuracy of timing pulses in the order of 1 microsecond made possible for the commercial production of phasor measurement units. PMU is considered to be one of the most important measuring devices for the future of phasor network systems. The distinction comes from its unique ability to provide synchronized values of voltages and currents from widely dispersed locations in an electric power grid. Simulations and field experiences from the phasor network suggest that PMUs can revolutionize the ways that power systems are monitored and controlled.

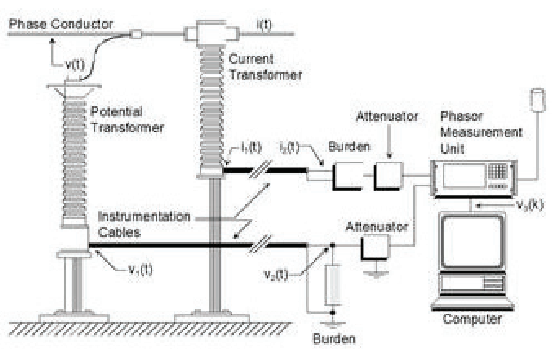

Fig. 1 Phasor Measurement From CT and PT

In this paper we introduce the PMU's simulation in MATLAB and we integrated PMU in a simple phasor network. We did simulation in MATLAB/SIMULINK.

System Description

The principle of a WAMS network based on synchrophasors dataisdescribed in this section. The system consists mainly of two layers. First, the electrical power system layer which consists of generation station with 500 kW output rated power, 2-power transformers (T1and T2) linking different parts of the electrical system, 2- short transmission lines (T.L1, and T.L2), 4- circuit breakers (CB1, CB2, CB3, and CB4) and 2-loads each of one MW. Second, the WAMS layer which consists of 4-PMUs that will collect the data received from remote locations for analysis and control actions.

System Modeling

A small size WAMS platform testbednetwork was modeled as shown in Fig. 3. This proposedcommunication network can be implemented in the lab bylocating one PMU at each generation or load bus where allPMUs will measure voltage and currentmeasurements in order to monitor the systemstatus and taking the proper control action if required.

The PMU simulation was done with usingSampling clock pulses to achieve synchronization betweensynchrophasors which are phase locked to the signal providedby the Global positioning system (GPS) receiver built insideor outside the PMU. The GPS module is simulated as a clockenabling pulses sent to all PMUs at the same time so that allof them will have the same time tags and in accordance thesame reference wave can be used at all different PMU locations through the WAMS.

II. Wide Area Monitoring

PMUs create a picture showing the stability status of the nodes in the monitored area in real time. PMUs compare this picture at the same reference time. Using real-time information from PMUs and automated controls to predict, identify, and respond to the power system problems; a smart grid can automatically avoid or diminish power outages, power quality problems and supply disruptions in the network.

A Phasor network consisting of PMUs spread throughout the power system network and GPS time stamping can provide a theoretical accuracy of synchronization better than 1 microsecond. "Clocks need to be more accurate to ±500 nanoseconds to provide the one microsecond time standard needed by each device performing Synchrophasor measurement." For 60 Hz systems, PMUs must deliver between 10 to 30 value based synchronous reports per second depending on the application.

III. Wide Area Control

Normal control measures are linked with permanent control activities, that can be either discrete control methods, e.g., tap changer and shunt devices, or continuous control methods, such as frequency control. Normal control is defensive, *i.e*., measures which are taken to adjust the power system operational conditions to the present and near future probable situation. Normal control methods are usually repeated, e.g., tap-changer, reactive shunt devices, frequency control and AGC. The difference between normal and emergency control is the penalty for the phasor network if the control achievement is not performed. If a normal, protective, control deed is not performed, then there is an increased risk for the failure of power system stability that the system stability will be lost if a severe disturbance occurs. If an emergency, corrective, control action is not performed in the phasor network, the system will go unsound. The response requirement (time and reliability) are normally higher for emergency control measures then for normalcontrol actions in the power system. Emergency control functions are almost always habitual in the network, while normal control measures can be either automatic or manual control, e.g., in combination with alarms. The actions taken in the power system network are however fairly similar for both normal control and emergency control. Protection, overall system protection, and emergency control contain remedial measures, *i.e*., actions are really needed to save the component or the system. Protection can very well be regarded as binary (on/off) emergency control, but by custom, protection is quite precise. Angle control is more exact if based on PMUs value based protection. Without PMUs, the power flow is an indirect method of measuring and controlling the angle. The measures to be taken are similar as for power flow control. PMU is a device for synchronized measurement of ac voltages and currents,then frequency and rate of change of frequency with a common time (angle) reference. The most commonly used time reference is the GPS signal, which has a precision better than 1 microsecond. In this way, the ac quantities can be calculated, converted to Phasor (complex numbers by their magnitude and phase angle), and time which is imprinted.By using PMU wide area measurements, we take voltage, current, frequency and phase angle from both ends of a transmission line and then send it to remote location by means of communication and there we compare these values with their respective GPS time. Actually our aim is to control the power flow. In the control room there are some predefined values, those measurements (send by the PMU) are then compared with those values, if there is a difference in the values of voltage, current and phase angle then the power that will flow is changed, so to overcome that a signal is generated send it to the local area control room.

The Wide Area structural design consists of various area loads in the power system network *i.e*. Residential, Commercial, Farm, Agriculture, and Industrial loads. The residential and commercial load consists of resistive and inductive loads only, but the farm load, Agriculture load and Industrial load consisting of resistive, inductive and three-phase motor loads. The loads are controlled by WAC and additional customers of each load in the system are controlled by a LAC. Control area Manager of each client in the system receives signals from fault sensing system which send control signals to WAC through TCP/IP sender/receiver and manage each area all the way through bidirectional communication.

IV. Wide Area Protection

There exist always some disturbances in a power system network but the time scale in which the dynamics of the disturbances affects the power network may be from several minutes to milliseconds. Time also depends upon the nature of the disturbances occured. So in all such cases there is a need of protection of the system which consists of the following factors:

a.classification of the disturbance in the system;

b.location of the disturbancein the system;

c.identification and prediction of disturbance in the system.

In order to protect the phasor network, we must have a full knowledge about states of the system. The knowledge of the complete state of the phasor network, represented by several network parameters, requires real- time state measurements as an input. Adaptive approach is preferred in such circumstances, possessing ability to adjust to changing system conditions. Relays which are participate in wide-area disturbance protection and control should preferably be adaptive. Relay system design should satisfy minimum requirements of having the ability to communicate with the outside world within a short period of time. The communication links in the system must be secure, and the possibility of their failure must be allowed for the design of the adaptive relays. The system measurements which are used in the relays must be related to the parameters that help observe the disturbance propagation. Such measurements must provide complete information about changing system conditions so that they will be useful in the management of the disturbance. PMU can explicitly fulfill all this requirement of power system.

The power system states like voltage magnitude, volt- age phase angle, current magnitude, current phase angle, frequency and rate of change of frequency; all data are provided by PMU. All given states are real time, time synchronized, accurate and error free data because these states are directly measured from instrument transformers. That is why our protection system will not go for maloperation and the phasor system will remain stable. PMU which is situated at the both ends (sending and receiving ends) of the transmission lines and continuously give time synchronized system states to a remote location. These are all very important here.

V. Phase angle Monitoring

Through PMU we can monitor real time Phase angle of different nodes accurately because it is time synchronized and accurate PAM is too much important for a phasor network. PAM enables access in real time to the accurate phase angle difference between any pair of buses located at any distance. PAM allows prediction of potential problems in the system both locally and regionally. Basic PAM functionality has already been implemented in the network with commercial and pilot software tools, and deployed in practice. Though very basic, system operators and area coordinators can be assisted by PAM in a variety of real time operational situations, such as monitoring angle separation or rate of change of angle separation between two buses or two parts of a grid to determine stress on the system very accurately. Another critical application of PAM in the system is during restoration. The phase angle value across an opened tie line in the network or an opened circuit breaker would guide an operator in circuit breaker closing.The function of closing would take place only if the phase angle was below a preset threshold. The information obtained from PMUs in the phasor network can also be included in the CB interlocking logic. In a novel method for predicting the rotor angle stability condition of a large phasor system based on the use of the PMU and artificial intelligence is presented.

Frequency and Rate of Change of Frequency Monitoring

We can measure frequency and rate of change of frequency through PMU very accurately. Change in frequency can reflect the change in impedance value of power system component. We can observe the stability of the system through rate of change of frequency.

VI. Events Recording

It is very hard to find out the cause of occurance of blackout and determine the root cause of large scale disturbance. When recorded data are not real time synchronized, so PMU is the only solution to this problem. PMU provides means for accurate, long term and wide area system dynamic recordings. The high data rate and precision that the technology provides also allow for capturing fast changing system dynamics of the phasor network. The measurements taken by a wide area system dynamics recording technology are also helpful in determining the phasor system characteristics such as line parameters, thermal limits, load models, machine performance, and parameters of its associated control system models. All real time synchronized data from PMU can be record in hard as well as in soft form.

VII. Simulation Results

A Matlab Simulink model of a phasor network has been constructed in order toinvestigate the performance of the proposed WAMS forsmart grid applications. In order toestimate the PMUs characteristics in the network, two types of tests arecarried out. The first is normal operation test without anyfault in the system or unbalance in the network. The second is faultoperation test which used as an extreme condition to showthe behavior of the phasor network under this condition.

Normal Operation Test

Fig. 2 represents the phasor network during normal operating condition. The generation station with500 kW supplies power to two 1 MW load. There is no disturbance in the system, so all PMUsshowsstable readings within the references. Figs. 3-5 show the readings ofPMU at the generator side. Figs. 6-8 show the readings ofPMU at the load side.

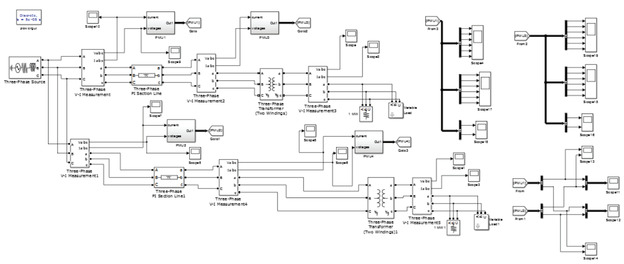

Fig. 2 Phasor Network without Fault

The PMUs read voltage magnitude, voltage phase angle, current magnitude, current phase angle, frequency and rate of change of frequency. The data measured by thesimulated PMUs shows that thedeveloped WAMSsucceeded to measureaccurately thesystemstatus in real time (online). However, for completeverification of its performance another test with applying afault at the given phasor network and observing their responses.

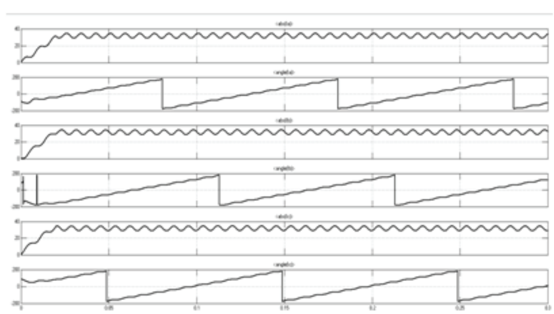

Fig. 3 PMU Current Measurement Generator Side

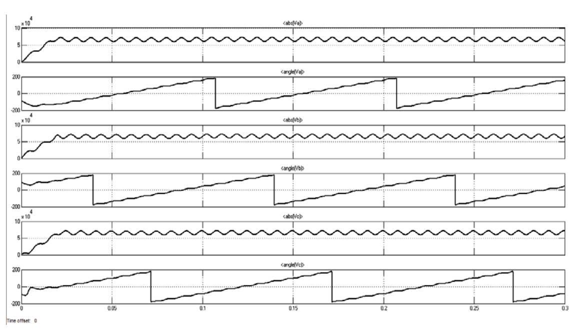

Fig. 4 PMU Voltage Measurement Generator Side

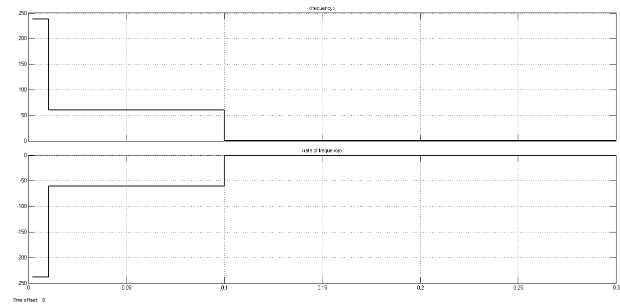

Fig. 5 PMU Frequency and Rate Of Change Of Frequency Measurement Generator Side

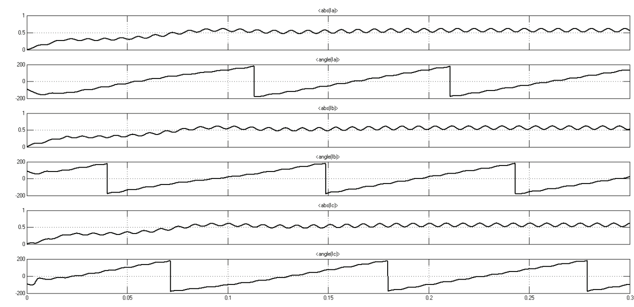

Fig. 6 PMU Current Measurement Load Side (Before Fault

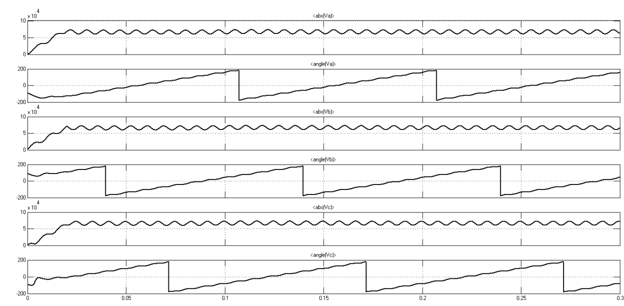

Fig. 7 PMU Voltage Measurement Load Side (Before Fault)

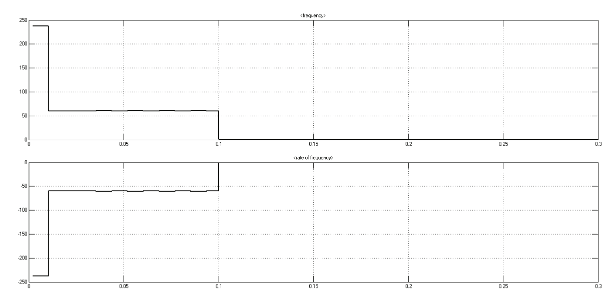

Fig. 8 PMU Frequency and Rate Of Change Of Frequency Measurement Load Side (Before Fault)

Fault Operation Test

In this case, a three line to ground fault (3-LGF) is applied at the network. Fig. 9 represents the phasor network with three phase fault. Figs. 10-12 show the readings of PMU at the load side. According to Fig. 9, the whole systems hows normal operation for 0.066 sec, the fault is occurred after 0.066 sec and it is cleared after 0.166 sec.

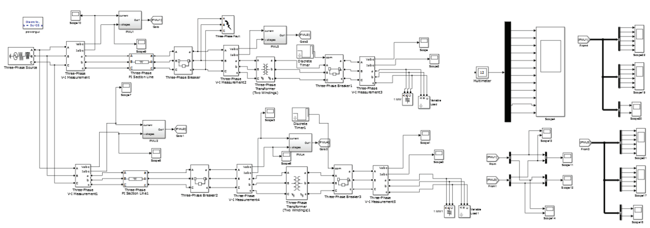

Fig. 9 Phasor Network With Fault

By measuring these data inreal time from PMUs to protect the other generation stationswhichare the most valuable part in the power network fromdamage, preventing cascaded turnoff stations which mayresult in major blackouts and maintaining a healthy powersystem. Furthermore, it helps analyststo determine the type of fault that has been occurred using thedata transmitted from PMUs.

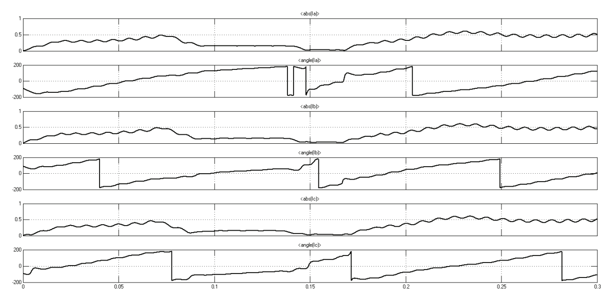

Fig. 10 PMU Current Measurement Load Side (After Fault1

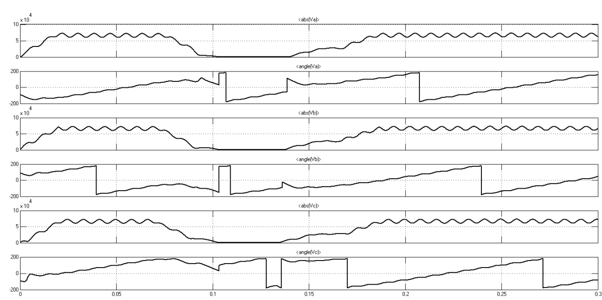

Fig. 11 PMU Voltage Measurement Load Side (After Fault

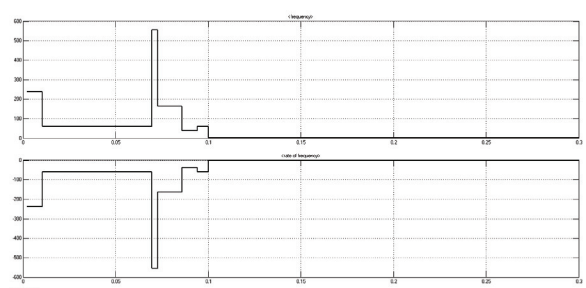

Fig. 12 PMU Frequency and Rate Of Change Of Frequency Measurement Load Side (After Fault)

Conclusions

This paper has reviewed three typical applications of PMUin distribution system including wide area monitoring, protection and control. PMUs possess significantadvantages in improving the data accuracy in all of the aboveapplications. Phase angles, which can be directly obtained byPMUs, also provide important information forprotection.The power system states like voltage magnitude, voltage phase angle, current magnitude, current phase angle, frequency and rate of change of frequency; all data are provided by PMU. All given states are real time, time synchronized, accurate and error free data. A performance analysis for the PMU based WAMS phasornetworkwas presented. The developed system was tested under twodifferent possible conditions i.e, under normal and fault conditions. The developed simulated WAMS phasornetwork verified its effectiveness for smart grid applications.

References

[1] Y. Hu, R. M. Moraes, V. Madani and D. Novosel, "Requirements of Large-Scale Wide Area Monitoring, Protection and Control Systems," Proc. 10th Annu. Fault Disturbance Anal. Conf., Atlanta, April 2007, pp. 1-9.

[2] C. Martinez, M. Parashar, J. Dyer and J. Coroas, "Phasor Data Requirements for Real Time Wide-Area Monitoring, Control and Protection Application," EIPP White Paper, 2005, p. 8.

[3] J. Z. Zhu, D. Hwang and A. Sadjadpour, "Real Time Congestion Monitoring and Management of Power Sys-tems," IEEE/PES Transmission and Distribution Confer-ence and Exhibition: Asia and Pacific, Dalian, 15-18 August 2005, pp. 1-5.

[4] J. Bertsch, M. Zima, A. Suranyi, C. Carnal and C. Re- htanz, "Experiences with and Perspectives of the System for Wide Area Monitoring of Power Systems," CI-GRE/IEEE PES International Symposium of Quality and Security of Electric Power Delivery Systems, Montreal, 7-10 October 2003, pp. 5-9.

[5] A. Guzman and D. Tziouvaras, "Local- and Wide-Area Network Protection Systems Improve Power System Re-liability," Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources, Clemson, 14-17 March 2006, pp. 174-181.

[6] A. G. Phadke, J. S. Thorp and K. J. Karimi, "Real Time Voltage Phasor Measurements for Static State Estima- tion," *IEEE Transactions on PAS,* Vol. 104, No. 11, 1985, pp. 3098-3107.

[7] M. Zima, T. Krause and G. Andersson, "Evaluation of System Protection Schemes, Wide Area Monitoring and Control Systems," 2002.

[8] "IEEE Standard for Synchro Phasor for Power Systems," IEEE C37.118, 2005.

[9] J. S. Thorp, A. G. Phadke, S. W. Horowitz and M. M. Begovic, "Some Applications of Phasor Measurements to Adaptive Protection," *IEEE Transactions on Power Sys- tems,* Vol. 3, No. 2, 1988, pp. 791-798.

[10] C. Martinez, M. Parashar, J. Dyer and J. Coroas, "Phasor Data Requirements for Real Time Wide-Area Monitoring, Control and Protection Application," EIPP White Paper, 2005, p. 8.

[11] D. Kosterev, A. Meklin, J. Undrill, B. Lesieutre, W. Price, D. Chassin, R. Bravo and S. Yang, "Load Modeling in Power System Studies: WECC Progress Update," IEEE Power & Energy Society General Meeting, Pittsburg, 20- 24 July 2008, pp. 1-8. doi:10.1109/PES.2008.4596557

[12] A. G. Phadke, J. S. Thorp, R. F. Nuqui and M. Zhou, "Recent Developments in State Estimation with Phasor Measurements," IEEE Power Systems Conference and Exposition, Seattle, 15-18 March 2009, pp. 1-7. doi:10.1109/PSCE.2009.4839954

[13] M. Zhou, V. A. Centeno, J. S. Thorp and A. G. Phadke, "An Alternative for including Phasor Measurements in State Estimators," *IEEE Transactions on Power Systems,* Vol. 21, No. 4, 2006, pp. 1930-1937. doi:10.1109/TPWRS.2006.881112

[14] G. Valverde, C. Deyu, J. Fitch and V. Terzija, "Enhanced State Estimation with Real-Time Updated Network Pa- rameters Using SMT," IEEE Power & Energy Society General Meeting, Calgary, 26-30 July 2009, pp. 1-7.

[15] R. F. Nuqui and A. G. Phadke, "Phasor Measurement Unit Placement Techniques for Complete and Incomplete Observability," *IEEE Transactions on Power Delivery,* Vol. 20, No. 4, 2005, pp. 2381-2388.