2013 IEEE 1st International Conference on Condition Assessment Techniques in Electrical Systems

Operational Reliability Enhancement with PMUs in Indian Power Network

R. K. Pandey, *Senior Member IEEE*, P. Pentayya, A. Gartia, Rajkumar A. and Chandan Kumar

***Abstract*— This paper presents the operational improvements of power network with deployment of Phasor Measurement Units (PMUs). PMUs are newly emerged tools for monitoring the grid parameters and thus help system operator in quickly identifying the stressed areas and take remedial actions. This has been proved as suitable sensory device for immensely improving the situational awareness among system operators. In India, Synchrophasor technology is in its initial stages with lots of pilot/demo projects undergoing. Still at nascent stage of implementation also, this has shown immense potential benefits and is being used by the system operators for reliable operation of grid. The paper provides Indian utility experience of PMUs usage in evolving power systems. Also, the paradigm shift from the conventional SCADA system to Wide area measurement system in India has been adequately addressed.**

Keywords—Wide area measurement system (WAMS), Phaor measurement units (PMUs), Wide Area Measurement, Protection and Control (WAMPAC), SCADA,RTU,Disturbance Records (DR), Sequence of Events (SOE),N-E-W Grid, Indian grid

I. INTRODUCTION

The Indian electrical grid is among one of the largest power grids in the world with installed capacity of 225GW [1]. It comprises of five regional grids namely northern, eastern, north eastern, western and southern grid. Among these the first four are operating synchronously as N-E-W grid. On the other hand, southern grid is connected asynchronously with the N-E-W grid. It is envisaged that southern grid would be synchronized with N-E-W grid by 2014.

The Indian grid is operated by the hierarchy of control centres with the national load despatch center (NLDC) at the top of the hierarchy and five regional load dispatch centres (RLDCs) ,thirty three state load dispatch centres (SLDCs) in the middle and number of sub-load dispatch centres at the bottom of hierarchy.

The system operational strategy evaluation has been a matter of major concern in large power network. The Synchrophasors have been widely used and have shown very promising results with Grid stability and operational reliability [2-13]. The knowledge gained by PMUs has been of enormous help for situational awareness and visualization for operators' quick assistance in a large Grid structure. The experiences of the utilities in US and other countries [1-4] have shown the way of effective utilization of PMUs information for enhancing the operational efficiency.

The challenges and complexity in power system operation in India are increasing manifold day by day as a result of increasing system size, brisk pace of capacity addition, congestion in some transmission corridors, increasing competition in the electricity market, weather effects, large scale integration of renewable energy sources concentrated in certain areas and the gap between demand and supply causing unscheduled power flows. To operate such a massive power grid, WAMS have been taken up in the regional grids to gain experience and facilitate development of applications and as a precursor to the large scale WAMS Project with 1700 numbers of Phasor measurement units (PMUs) has been undertaken by Power Grid Corporation of India Ltd (PGCIL) covering the entire EHV network of Indian grid .The experience gained so far include early detection of faults in the system, situational awareness, security alerts based on angle deviation followed by huge gains in Post mortem analysis of the events, disturbances, identification of modes and computation of system inertia etc. thus leading to in depth understanding of the system behavior over a period [14]. The ability of the system operators to take decisions in real-time is dependent on their 'situational awareness' derived from the data/information available with them in real-time, now supplemented by data from PMUs.

Section II gives the complete background about conventional SCADA and PMUs existing at present. Section III presents the operational improvements in situational awareness. In Section IV the impact of Synchrophasor technology on system operation has been undertaken. Section V presents Challenges ahead in system operation and Section VI concludes the work reported.

II. COMPARATIVE ANALYSIS OF SCADA AND PMUS

Power system operation in India is primarily based on the conventional SCADA system which receives the data from Remote Terminal Units (RTUs) located across different substations and generating stations. The SCADA system normally updates the values of various quantities like real and reactive power, voltage, switch and circuit breaker position are either reported by exception or scanned periodically [2].The typical scan rates are every 1-4 seconds for circuit breakers and status indications; every 4-15 seconds for analog values. Limitations of SCADA includes lower scan rate, asynchronous data, steady state information, lack of wide area monitoring in real time and non-availability of phase angle. In India, there is hierarchical architecture through which the information is routed and updated (every 4-15seconds) at the respective Load Despatch Centre.

R. K. Pandey is with Electrical Engineering Dept. Indian Institute of Technology (Banaras Hindu University), Varanasi, India (e-mail: rpsneh@yahoo.co.in).

P. Pentayya, A. Gartia Rajkumar A. and Chandan Kumar are with Power Grid Corporation of India Limited (PGCIL). (e-mail: ppentayya@gmail.com, agartia@yahoo.com, anumasula@gmail.com, chandan8240000@gmail.com).

To change the scenario of load dispatching, PMUs have been introduced in Indian power system. At present the PMUs have been installed as pilot and demo project. Still they have given a lot of support to operators in real time as well as offline to analyze the Indian grid in a better way and take corrective decision as and when required. The Synchrophasor technology along with the high speed wideband communication infrastructure from substation to control centre has overcome the above limitation of SCADA. The scheme, in altogether, is known as Wide Area Measurement, Protection and Control (WAMPAC) or Wide Area Measurement System (WAMS). With the introduction of Synchrophasor technology it is now possible to monitor the phase angles difference at the control centre. Also, it enables visualization of voltage and current phasors, frequency, rate of change of frequency and angular separation at every few millisecond interval (in India at 40 milliseconds) in the Load Despatch Centre. Thus the dynamical behavior of power system can be observed in almost near real-time at the control centre which hitherto was possible only in offline mode in the form of substation Disturbance Records (DR) or through offline dynamic simulations performed on network model.

III. Situational Awareness and Effective Decision

Situational awareness is one of the important aspects of power system operation while assessing the operational strategy. Before the deployment of PMUs, SCADA was used in general to visualize the operational scenario of system. By using SCADA the change in system was observed after the refreshment of data in 4-15seconds. The tripping and sequence of events were transferred instantaneously, but still with time lag in event of communication failure. Most of the time operators were not able to visualize the disturbance going on in the system. The changes in the system were known to operators in following ways:

Sequence of event (SOE) Status received from SCADA and alarm generated based on that.

Change in frequency observed by the operator on screen by pop-up and alarms.

On automatic updating of line status and unit status in SCADA with delay of 4-15seconds due to limited communication bandwidth.

Telephonic conversation among the operators of load despatch enters and substation operators,

The delayed information to system operator acted as a lag in their decision making ability which, in general, leads to delay in restoration of system after any incidence. The phase angle information availability is very essential and effective signal to the system operator in real time to assess stress in the grid, as this helps in determining margin available in overloaded corridor and ensuring system islanding and separation. In real time, phase angle difference of back to back HVDC substations are available at operator console as it can be measured using the phase angle transducer with inputs from both bus, while for other transmission system, due to asynchronous data it was not desirable to calculate the phase angle difference. The asynchronous nature of data does not provide accurate angle difference information from two nodes on the network. Thus the phase angle differences obtained are most of the time erroneous and cannot be used for decision making. So, the other option available for measuring the phase angle difference is by real-time state estimation from the SCADA. Wide area angular differences are determined from the outputs of State Estimators, which in turn is a measure of simultaneous overloading of multiple transmission corridors. This somehow gave a very good result and helped operator in reducing the congestion of important transmission corridors of the system. The western region network diagram showing the value of important corridor angular difference calculated from real time state estimation from the SCADA is shown in Fig.1. In this figure SCADA dispaly shows the values of Korba-Kalwa and Vindhyachal–Asoj line obtained from State estimation with SCADA as well as angluar difference between the north and west bus of HVDC back to back Vindhyachal from the phase anagle transducer.

For state estimation, the SCADA systems obtain the snap of the real time network and then check for the network configuration to validate the system. One complete scan of the large number of devices could last from 2 to 10 seconds. During normal steady-state conditions, the result from the state estimation is reliable and can be used for making decision. However, when the system state changes in between, the data retrieved no longer represent the system state accurately and the result obtained from state estimator may not be of use anymore.

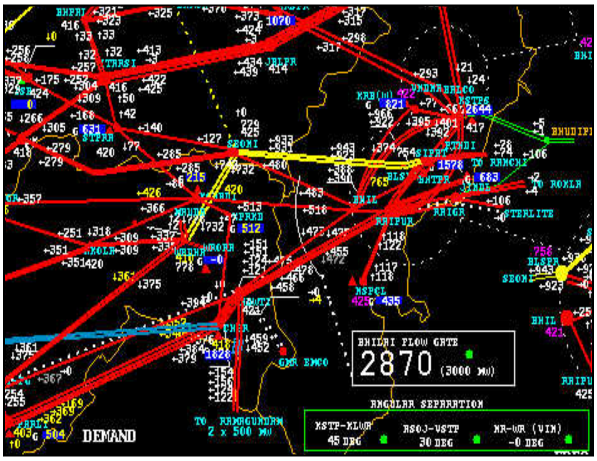

Fig. 1. SCADA dispaly of Korba-Kalwa and Vindhyachal–Asoj obtained from State estimation with SCADA along with angluar difference between the north and west bus of HVDC back to back Vindhyachal from the phase anagle transducer.

During restoration of the system, there are lots of problem an operator has to face due to delay in receiving the current status on the SCADA interface. As the restoration of disturbed part of the system has to be done in a sequence to avoid any further tripping in the system, the status of the system is very important for operator. The sequence of steps is followed after the visualization and demonstrates that the previous step has successfully been completed which led to delay in the recovery.

Low frequency oscillation [12] which is one important aspect of power system stability was not available to the operator as SCADA system is not meant to detect such fast oscillation in the system. With many inter-regional interconnections, inter- area modes have been observed in the grid. But the grid operator had no such visualization available at their console. The limitation lies in the fact that conventional SCADA provide data in 2- 10 seconds range which will not detect oscillations as these oscillations lies in the range of (0.1-3 Hz).

The SCADA system supports multiple communication protocols which should have aided the system operator to its potential. The data from RTU is received through optical fiber, microwave, PLCC etc. Thus due to non availability of redundant communication system and inherent bandwidth limitation of different communication channels added to the delayed information transfer, the SCADA may not be a good information processing device which may be the most effective in real time scenario.

IV. Impact of Synchrophasor Technology on System Operation

With the deployment of Synchrophasor technology from year 2010 in India, a lot of change has come in the system operation. PMUs have given a new direction to the grid operation as they provide the GPS time stamped data which has overcome the limitations with respect to state measurement and its telemetry at the control centre. Synchrophasors are precise in measurements of system states available from Phasor Measurement Units (PMUs), as these are time-stamped with a common time reference. Precise time stamping has enabled operators to have a signature of the grid for that particular instant. Deployment of the Synchrophasor technology for real time and off-line applications is still under development worldwide and lots of applications are coming up. The conventional SCADA is now having a transition from “state estimation” to “state determination”.

Synchrophasor measurement and high speed communication facility have now aided system operator with many new tools to operate the system more securely and efficiently. The applications of Synchrophasor technology are enormous as it also gives the frequency, rate of change of frequency, voltage and current phasors, digital values like status of circuit breaker and derived values such as real and reactive power, sequence currents and voltages. The PMUs have given following insight into the health of grid and its operation:

Low frequency oscillation and its analysis

Accurate frequency measurement from different location and the detection of out of phase sub-system.

Phasor angle difference over a wide area to detect the separation of two systems.

Rate of change of frequency and loss of generation estimation

Post disturbance analysis with the help of PMUs data.

Low frequency oscillations (LFO) are observed in the Indian grid with the interconnection of regional grids with each other via synchronous links. The availability of time synchronized 25 samples per second from the PMUs with time synchronized values has provided the operator to visualize the LFO (Fig.2) in the magnitude (0.1-3 Hz). In Fig.2, the low frequency oscillation of 0.35 Hz, having negative damping of 8.6 % and high amplitude during the occurrence of Sipat and Bilaspur generation loss on 14th Sept, 2012 have been demonstrated.

This has given a signal to the Grid operator for identifying the recurrent nature of appearance of modes for various operating scenarios. Analysis of different events with the help of matrix pencil and modified prony method was carried out by Western regional load despatch centre (WRLDC) who is responsible for the secure and reliable operation of the Western regional grid in India. It was observed that the inter-area mode of 0.35 Hz is observed with negative damping during most of the ringdown condition in the grid. Also the modes 0.7, 1, 1.4 and 2 Hz are observed in the grid with negative damping. Whenever the operators observe such negative damping, they try to relieve the stress in the grid and control measure to increase the damping. This also helped in tuning of the TCSCs at Raipur.

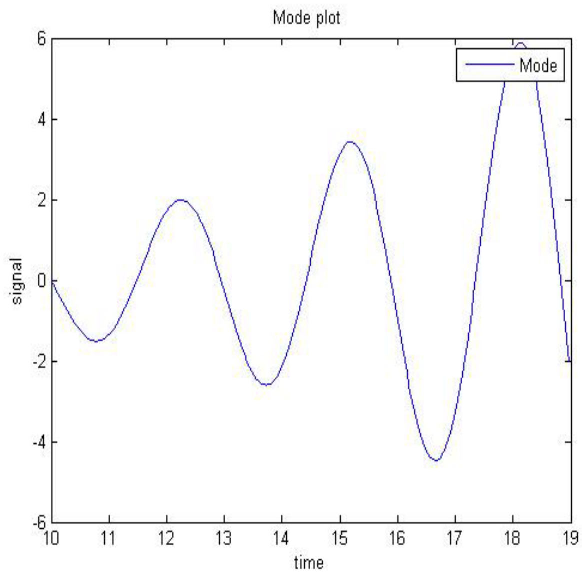

Fig. 2. 0.35 Hz having negative damping of 8.6 % and high amplitude during the occurrence of Sipat and Bilaspur generation loss on 14th sept,12.

An accurate frequency measurement and coherent group formation during occurrence of any event can easily be detected from the PMUs. During a bus fault, as shown in Fig. 3, at 400 kV Parle substation in Western Region, the generators in western part of the Western grid were in anti-phase with Northern generators. This anti-phase swinging was observed in system for 3 seconds and they again reached the set equilibrium point. This suggests that there is a need to strengthen the links between western and northern grid on India. Such minute details have been observed using PMUs which helped in the offline study and disturbance analyses of the event.

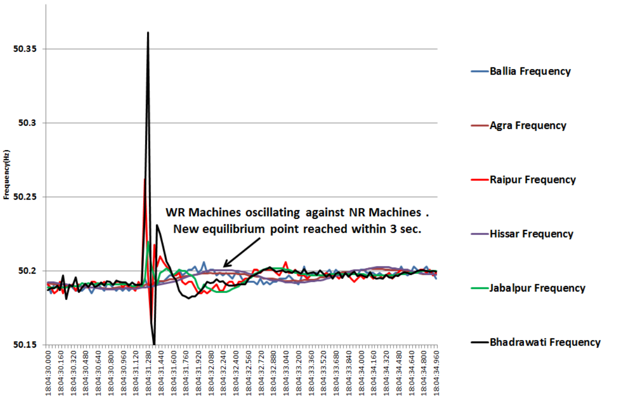

Fig. 3. Frequency plots during bus fault at 400 kV Parli Substaion illustarting the antiphase swinging of Western region machines with Northern Region.

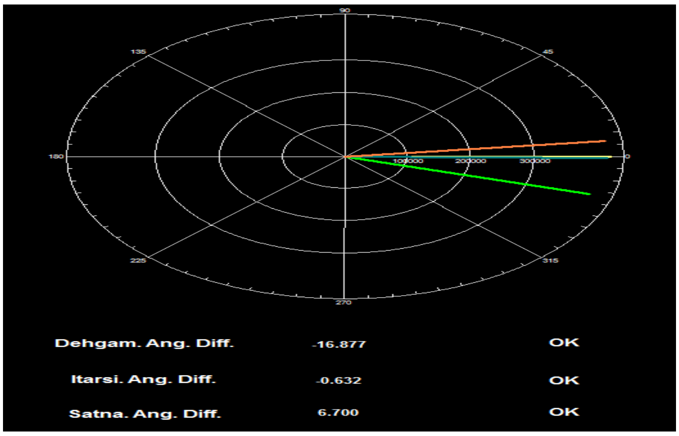

Fig. 4. Angular Difference Monitoring at control centre

Phase angle measurement is the essence of PMUs as it enables the operator to visualize the phase angle difference between the two nodes in the system in real time. The phase angles help the operators in finding out the stressed portion in the grid and on basis of that real time action can be taken to relieve the congestion and overloading for increasing the reliability. Fig.4 represents the phase angle measurement view in western region from the PMU. This has enhanced the visibility of the grid. Thus it may be noted that PMUs can improve the visibility of entire grid followed by effective operator decision with analytics in real time, if adequately planned.

The additional feature of PMUs is the rate of change of frequency (ROCOF) measurement. The ROCOF value acts as a signature during the sudden loss of generation/load in a grid. This may help in case of multiple tripping (not occurring simultaneously) to find out the amount of generation/load loss during the occurrence. Fig.5 shows the tripping of Anpara and Rihand thermal power station (TPS) in Northern grid [13]. The tripping of Rihand TPS was confirmed from sequence of event (SOE) obtained from SCADA while tripping of Anpara unit was not observed. From the SOE, it is clear that one unit of Rihand tripped corresponding to event 1 observed and another unit tripped at event 2 as shown in Fig.5. The df/dt obtained shows that the generation loss was more during event 1 as df/dt value is approximately twice that of the event 2. Apart from that no other spikes in df/dt was observed in the system which implies that the Anpara TPS units also tripped during the event 1 leading to high value of df/dt.

One paradigm shift that has been observed is in the off-line analysis of the disturbance with the introduction of PMUs. Synchrophasor data has given the operator to look into the detail of any disturbance with sub second information and analyze the same. This further helped in devising the change required to improve the security of the grid. One similar case study was done to analyze the Talcher-Kolar HVDC pole 2 blocking on 19th May, 2012. The nearest PMUs data from Raipur was analyzed and the various stages of the event have been described in detail along with verifying the operation of special protection scheme (SPS) for Talcher-Kolar Bipole. The Fig.6 shows how with tripping of pole, frequency increased in N-E-W grid and after operation of SPS at Talcher generating station tripping/ramping down of generation which again led to frequency drop. This has validated the SPS operation at Talcher end.

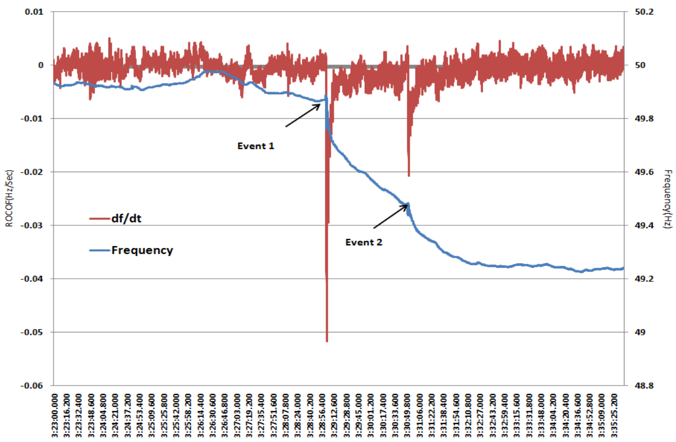

Fig. 5. The tripping of Anapara and Rihand units signature with the help of frequency and df/dt plot obatined from PMUs located at Raipur.

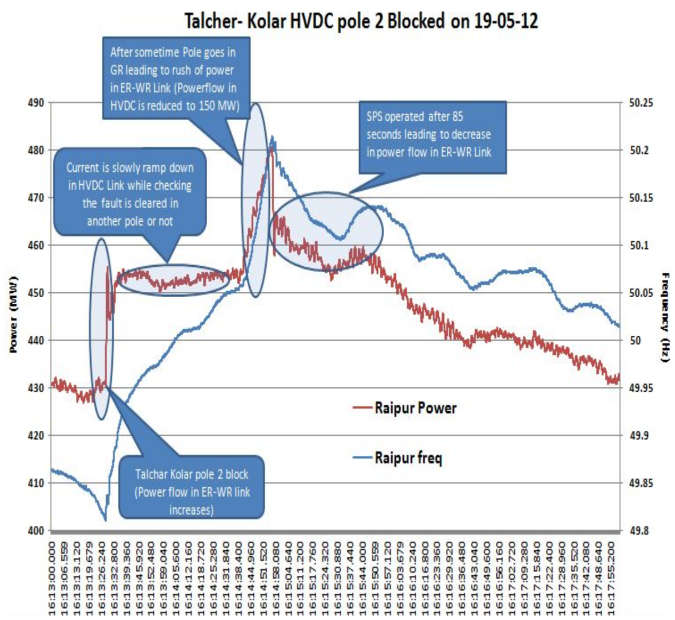

Fig. 6. N-E-W Grid frequency variation and associated effects.

The various challenges faced by system operator using conventional SCADA are getting resolved with the help of PMUs. With the new technology a lot of data is now available to the operator for forensic analysis of the grid. Lots of development and innovation is still undergoing in the field and many more pilot projects are under implementation stage. This will give a boost to development of the wide area situational awareness with a combination of PMUs, SCADA, weather forecast data, market information, GIS mapping and other real time and historical data for a better visualization of grid. All information may form the essential component for on-line analysis and follow up decisions for grid security and smooth system operation.

V. PMUS IMPLEMENTATION AND CHALLENGES

The major challenges in the implementation of PMUs are related with the communication infrastructure and its redundancy. The PMUs are sending data via Phasor Data Concentrator (PDC) located at control centres at high rate .The only communication medium that support such kind of data transfer is optical fiber based communication (others are there for the purpose but due to limitation in bandwidth they introduce latency). But the challenge lies in the fact that the optical fiber communication from all the substations/ generating stations is not available and the redundant communication paths will take its time to come into the reality. The high speed data obtained from PMUs at control centres need to be processed and pass on to the analytics application which is a challenge in the form of handling the BIG Data. To implement control actions derived from WAMS, the PMUs should also be compliant with IEC-61850-90-5 to carry out local actions at substations level. Even the standard has been developed, yet no utility adopted the same. The other challenge faced with the PMUs has been the dynamic performance standards for PMUs during off-nominal frequency. As there is no dynamic standard yet by any agency so it's a challenge to verify of the dynamic performance of the PMUs.

VI. CONCLUSIONS

The Synchrophasor technology has given operator a new tool to look into the finer detail of the dynamic behavior of the large power system. It has led to paradigm shift from state estimation to state determination. Synchrophasor experience in India is very promising and enriching and has led to very good understanding of the grid events. Though the applications are still at initial stage in India, it has led to significant change in the operators' outlook towards the grid operation and system understanding under variety of disturbances. Now with the initiative taken as pilot and demo projects in India, much information available is utilized while taking the adequate decisions to increase security and reliability of the grid. Further, there is need to install PMUs to all the critical EHV substations, LV side of generators to get the necessary data for observability and improving the decision making capability of system operators. This may also help in planning the installation of new FACTS devices in order to improve the grid performance under dynamic conditions. The installation of PMUs at distribution level would also help in analyzing the impact on the grid with the renewable integration. Further, PMUs may form an important component in upcoming Smart Grid in India; therefore proper employment of PMUs at this stage may be beneficial manifold.

ACKNOWLEDGEMENTS

The authors acknowledge with thanks the guidance and support given by managements of POSOCO as well as PGCIL and for permitting the publication of this paper. The authors are also thankful to WRLDC and NRLDC personnel for their support. The views expressed in this paper are of authors and not necessarily that of the organizations they represent.

REFERENCES

[1] Central Electricity Authority, *All India Installed Capacity,* [online]. Available : http : / / cea.nic.in / reports / monthly / executive_rep / installedcap_allindia.pdf

[2] "New Technology can Improve Electric Power System Efficiency and Reliability", Today in Energy, U.S Energy Information Administration (eia), March 30, 2012.

[3] Terzija Vladimir, V alverde Gustavo, Cai Deyu, Regulski Pawel, Madani Vahid , Fitch John, SkokSrdjan, Miroslav M.Begovic & Phadke A, "Wide-Are Monitoring, Protection, and Control of Future Electric Power Networks", Presented At Proceedings of the IEEE, Vol. 99, NO. 1, Jan 2011, PP. 80-93.

[4] G. Liu, V. Venkatasubramanian and J. R. Carroll, "Oscillation Monitoring System using Synchrophasors". In Proc. of IEEE PES General Meeting, Calgary, Canada. July 2009.

[5] M.Sherwood, D. Hu and V.Venkatasubramanian, "Real-Time Detection of Angle Instability using Synchrophasors and Action Principle", Bulk Power System Dynamics and Control-VII, August 2007, Charleston SC.

[6] G. Liu, J. Quintero, and V. Venkatasubramanian, "Oscillation Monitoring System based on wide area synchrophasors in power systems," Proc. IREP symposium 2007. Bulk Power System Dynamics and Control - VII, August 19-24, 2007, Charleston, South Carolina, USA.

[7] Kathleen Wolf Davis, "On the NE Blackout's Tenth Anniversary: PMU Data Analytics in Future Grid Reliability", Intelligent Utility, Aug 13, 2013.

[8] PMU Enhanced Power System Operations, Interactive Energy Roadmap to Achieve Energy Delivery Systems Cybersecurity, Sept 2011.

[9] Chakrabarti S, Kyriakides E, "Optimal Placement of Phasor Measurement Units for Power System Observability", IEEE Transactions on Power Systems, Vol.23, No. 3, pp1433-1440.

[10] Hongxian Wu, Bellevue WA and Giri J, "PMU Impact on State Estimation Reliability for Improved Grid Security", Transmission and Distribution Conference and Exhibition, pp 1349-1351, 2005/2006, IEEE PES.

[11] Real-Time Stability Assessment in Modern Power System Control Centres, IEEE Press Series on Power Engineering.

[12] K. Prasertwong, N. Mithulananthan and D. Thakur, "Understanding Low Frequency Oscillation in Power Systems," IJEEE, UK, June 2009.

[13] Report on the Grid Disturbances on 30th July and 31st July 2012, POSOCO,Aug,2012.

[14] "Synchorphasors Initiative in India" POSOCO, India, June 2012.