View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Online Research Database In Technology

Technical University of Denmark

PMU Applications - From Situation Awareness to Blackout Prevention

Yang, Guangya; Gordon, Mark; Nielsen, Arne Hejde; Østergaard, Jacob

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Yang, G., Gordon, M., Nielsen, A. H., & Østergaard, J. (2009). PMU Applications - From Situation Awareness to Blackout Prevention. Paper presented at Siemens - Future Energy Systems Workshop, Lyngby, Denmark.

DTU Library
Technical Information Center of Denmark

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

PMU Applications – From Situation Awareness to Blackout Prevention

Guangya Yang, Mark Gordon, Arne Hejde Nielsen, Jacob Østergaard

I. State of the art of PMU Application Techniques

The technique of phasor measurement has been made available from the application of global positioning system (GPS). With the satellite-triggered time stamp, phasor measurement unit (PMU) can provide synchronised and high speed measurement of positive sequence voltage and current of electric power systems [1]. From the birth of this technology, the potential of PMUs to improve the system operation has been attracting attention from power engineering communities worldwide.

The earliest research involving the application of synchronized measurement signals was made in 1980s [2], [3]. With the propagation of PMU, the study on its application has become an attractive area since the middle of 1990s [4], [5], [6]. So far, the open literature regarding PMU applications covers various topics, such as model validation, stability assessment, corridor supervision and state estimation. In [7], based on PMU measurement, a variable impedance method combing trajectory sensitivity method is developed to find out the problematic parameters of the system. The method is presented to multiple-area dynamic simulation and can be used to reduce the searching area for the problematic component in big power systems. An online overhead line parameter identification method is proposed in [8]. The parameter variation caused by conductor sag is addressed based on PMU measurement. The accuracy of the method is verified with different data windows.

The application of PMU signals to system stability analysis is of most concern. In [9] PMU signals selected from strategic locations have been processed in the time and frequency domains and then the result is presented to fuzzy rule-based classifiers initialized by large accurate decision trees. Rapid stability assessment can be achieved from 1 to 2 seconds post-disturbance records by wide area PMU measurement after fault clearing. Decision trees are also used in another work [10] for online security assessment. The real-time security indicators are obtained from PMU signals and presented to decision trees which are periodically updated by offline studies. Online estimation of electromechanical mode is addressed in [11]. A regularized robust recursive least squares method is proposed utilising an autoregressive moving average exogenous (ARMAX) model which is for the typical measurement data and a robust objective function for handling the nontypical measurement data.

Voltage stability is addressed in several documents. In [12], a voltage instability risk indicator is developed based on fast local phasor measurements. The method is established for real-time adaptive identification of

Thevenin equivalent circuit parameters. To detect the voltage instability triggered by outages of transmission or generation equipment, the authors in [13] have proposed a sensitivity index of the reactive power generation to load. The model uses PMU measurements and can observe the voltage instability of the whole region for online use. Another work [14] exploits PMU data to estimate simple equivalent models of interconnected systems for PV curve calculation and stability prediction.

Transmission corridor supervision is also an important PMU application. In [15], a measurement–based reactance and inertia extrapolating algorithm is developed to build up an equivalent model of a radial power system. The method can be used to represent the inter-area dynamics on the transmission path which is dominated by single inter-area mode. Energy function is employed in [16] to identify the transmission line transient and small-signal stability status associated with active power flow. The transmission path is modeled as a two-machine system and based on PMU data, the transmission corridor parameters and equivalent inertias can be estimated. The authors in [17] have proposed a new equivalent model for which the parameters can be estimated by the least square method using continuous samples of PMU measurement. Along with the model, the load margin of the transmission corridor can be available which can be used as voltage stability index. Reference [18] studies the online measurement of transmission line impedance with PMU input to adjust the distance relay settings for real-time use.

Efforts have also been made in improving traditional state estimation with PMU data. In [19], a distributed state estimation algorithm has been proposed for large-scale power systems. Based on Diakoptic method, the system can be divided into several subsystems and the input from PMUs is used to solve each subsystem's estimation. By this method, computational time can be saved without losing accuracy. The authors in [20] present the beneficial impacts and the challenges of utilising PMU data for state estimation.

With the demand increase and power system liberalisation, the utility worldwide is exposing to increasing operation uncertainties and blackout risks. PMUs will be of help in providing strategic information for control room decision support. References [21], [22], [23] discuss the architecture of wide area monitoring and control system and some PMU application concepts in practice. The work in [24] presents the recorded real system events data to the designed system obtaining favorable results.

So far many countries have installed PMUs and gained valuable practices [25]. The potential of PMU in improving power system operation and control has been recognised. In USA, wide area monitoring system (WAMS) is adopted to validate system performance and model by probing tests [26]. In China, WAMS is being used for system model validation and stability monitoring [27]. Canada Hydro-Québec currently employs wide-area monitoring and control system for frequency regulation and prevention of geomagnetic storm-induced contingencies [28]. These practices enrich the understanding of the ability of PMU in real time system supervision. Table I lists the current PMU application practice in some parts of the world [29].

Table 1 Practices of PMU applications in different parts of the world**

PMU applications	North America	Europe	China	India	Brazil	Russia
Post-disturbance analysis	√	√	√	P	T	√
Stability monitoring	√	√	√	P	P	√
Thermal overload monitoring	√	√	√	P	P	√
Power system restoration	√	√	√	P	P	P
Model validation	√	√	√	P	T	√
State estimation	T	P	P	P	P	P
Real-time control	T	T	T	P	P	P
Adaptive protection	P	P	P	P	P	P
Wide area stabiliser	T	T	T	P	P	P

** T: Under testing; P: Under planning.

II. Potential PMU Applications in Network Situation Awareness

PMU installations worldwide bear witness to a general belief in the value of the additional phase information in the voltage and current measurements and high speed synchronised measurement including solutions of secure and reliable operation. PMU is seen as the fundamental device enabling the real–time system measurement and security assessment for control room application. Many new topics have been derived from this change.

Topics suggested to be addressed in PMU applications are listed below.

A. Visualisation of PMU information

The large size of data obtained from PMU measurements is bringing out a problem for online visualisation. The numerical representation of system states need to be visualised for being read and understood by operators. The information shall include the variance of voltage, angle, frequency, topological changes, thermal conditions, harmonics, etc. Available techniques for visualisation also include worst case alarm or graphic interface [30]. Beside this, possible solution includes proposing static system performance indices which can be instantly calculated based on strategic PMU input to generally reflect the operating state of the system.

B. Dynamic security assessment (DSA)

Online DSA depends on the quality of system model and the measured data. Reliable methods are required for online model validation and state estimation using PMU signals. DSA has to fulfill the functions of identifying and predicting stability or instability, distance to security margin and power oscillations. Sensitivity indicators for interconnected power systems need to be developed to properly interpolate different operating regions of power systems containing different generating topologies. These indicators can be used and applied in coordinated control framework as well as preventive and emergency control. Of particular interest are indicators for proximity to voltage collapse, frequency instability and transient (angle) instability. Therefore DSA is classified into the following categories [31]:

1) Voltage security

Voltage stability can be categorised into different time spans. For the short-term issue, (real-time or quasi-real-time, 1~2 seconds), static local bus or line voltage stability indices together with system reactive power margin may be a feasible way for real-time use. For mid-term or long-term voltage stability detection (above 10 seconds to minutes), possible solutions may include using system equivalent circuits, such as Thevenin or Telegen, or power flow Jacobian eigenvalue analysis, or trajectory sensitivity based analysis etc, to identify and predict system voltage instability during or after events.

2) Small signal stability

There are basically two kinds of methods for small signal stability study. The first type of methods is traditional eigenvalue analysis which presents the dominant frequency and damping to the operator. It is heavily dependant on the accuracy of system model and computationally expensive especially for large-scale systems. Another kind of way is measurement-based method. This method uses measured data to estimate a defined model which represents current system. It avoids solving nonlinear differential equations. PMU data can be used as the input signal to adaptively tune the model and hence the oscillation and damping of the power system can be estimated. In addition, signal processing methods, such as Fourier transform, wavelet transform and Prony analysis, are also candidate solutions for oscillation detection.

3) Transient security assessment

Methods for transient security need to provide automated real time computation for stability prediction after the fault inception and clearance. So far analysis tools include extended equal area criterion or energy function. This assessment can also be done with off-line analysis in order to build up data warehouse for online stability identification based on real-time measurement. Available data mining methods include decision trees, artificial neural network, support vector machine, etc.

Therefore security assessment of power systems needs to consider:

- System Monitoring
- Security Analysis
- Security Margin Determination

With the increased power system complexity over many different spatial horizons security assessment needs to consider both steady state as well as dynamic system properties.

Steady State Assessment: Online methods are needed complimentary to the existing SCADA and EMS system which would verify bus voltages and line power flow limits especially considering topological transitions between pre-contingency and post-contingency operating states. One such example is system separation event, or system islanding.

Dynamic Assessment: Real time and automated tools are needed for continuously evaluating system stability margins as well as margins following up on contingency occurrence by examining system damping and quality of service.

The basic functions of an online DSA need to consider the following actions:

1. Evaluation of system snapshot
2. Combination of dynamic and contingency data in performing real time DSA
3. Report on results via online ‘Visualization’ tools to system operators
4. Invoke alarm state responses for both automated and HMI interfaces depending on short term, mid-term or long term predictability
5. Identify security issues and make recommendations to system operators for responsive procurement of actions (optimization)

Table II lists some online DSA installations.

Table II. DSA Installations

Country	Company	TSA	VSA	SSSA	FSA	IS / OS
Australia	NEMMCO	√		√	√	I/S
Bosnia	NOS	√	√			I/S
Brazil	ONS	√	√	√	√	I/S
Canada	BCTC	√	√			U/D
Canada	Hydro-Quebec	√	√			I/S
China	Beijing Electric Power Corp	√				I/S
China	CEPRI	√				I/S
China	Guangxi Electric Power Co.	√		√	√	I/S
Finland	Fingrid		√	√		I/S
Greece	Hellenic Power System		√			I/S
Ireland	ESB	√	√			I/S
Italy and Greece	Omases Project	√	√			O/S
Japan	TEPCO	√	√			I/S
Malaysia	Tenaga Nasional Berhad	√	√			I/S
New Zealand	Transpower	√	√		√	I/S
Panama	ETESA	√	√			I/S
Romania	Transelectrica	√	√			I/S
Russia	Unified Electric Power System	√	√			I/S
Saudi Arabia	SEC	√	√			U/D
South Africa	ESKOM	√	√			U/D
USA	PJM	√	√	√		I/S
USA	Southern Company	√				I/S
USA	Northern States Power	√				I/S
USA	MidWest ISO		√			I/S
USA	Entergy		√			I/S
USA	ERCOT	√	√			I/S
USA	FirstEnergy		√			U/D
USA	BPA		√			I/S
USA	PG&E		√			U/D
USA	Southern Cal Edison		√			U/D

TSA: Transient Stability Assessment; VSA: Voltage SA
SSSA: Small Signal SA; FSA: Frequency SA
IS: In Service; OS: Tested but out of Service
UD: Under Development

C. State estimation

Another potential of PMU is to improve the performance of state estimators from which further system studies and anlyses can benefit. PMU data gathered by the Phasor Data Concentrator Basic Software may be transferred directly to SCADA system for further processing. One significant reason is the expected improvements in state estimation in regards to reliability and accuracy. PMUs measure the voltage and current phasors at bus systems and feeders with very high accuracy in regards to magnitude and phase angle, offering a time synchronization capability better than 1 microsecond. In addition, PMUs are capable to send measured data with validity stamp, which can indicate if the "quality" of the sent data is inside defined limits or not. Research work results have shown significant improvement of the state estimators, if in some case more then 10% of all busses in a power system are equipped with PMUs [32] [33].

The new approach must manage classical transducer measurements (rms voltage, active and reactive power, topological information without time stamp), which are transferred to the control centre computer via Remote Terminal Units (RTUs), Additionally Phasor quantities and topology information, which are transferred with precise time stamp, have to be processed as well.

A rather new proposal for the improvement of the power system state estimator is made by Prof. Sakis Meliopoulos of the University of Georgia, Atlanta, USA. According to his research work, all data measured by numerical intelligent electronic devices (IEDs) in a substation can be used for topology identification (status of breakers and isolators) and precise estimation of voltage & current phasors [34]. With this principle, and with the measurement of the same quantities (voltage & current) with various primary VTs and CTs - for example in a high voltage substation - and the connected IEDs, it was found out that the final evaluation in a substation computer could bring higher accuracy than selected single measurements. Thus, the substation computer may be used as a first stage of a distributed state estimator. Therefore, a distributed state estimator may be built up with this strategy, sending compressed and exact data to the control center computer for further processing [35].

D. Penetration from distributed generation

Large share of distributed generation in different kinds of renewable energy technologies, such as wind energy, combined heating plant or photovoltaics, will interact the transmission network from planning, operation and control levels. Interesting topics also include the effect of increasing use of electric vehicles on the grid. These energy sources provide variant outputs to the grid which bring uncertainties to the network performance, such as security, reliability, harmonics, etc. For control room applications, energy forecasting and real-time PMU measurement need to be combined for the entire network situation awareness, where possible services could include online visualisation, real-time stability margin evaluation, early alerting, etc.

III. PMUs-Based Countermeasure Selection for Blackout Prevention

Major North American and European 2003 power system blackouts have drawn concerning attention to the risk and exposure of modern power systems to catastrophic failures. Several IEEE and Cigré task forces have been established since, to understand and determine the cause and countermeasures of catastrophic power network failures [36]. Generally, large blackouts are caused by a sequence of dependent failures on individual components. These failures are usually caused by different kinds of instability, such as voltage stability or transient stability. Also, protection malfunction is a non-neglectable reason. The prevention scheme of cascading failures have to consider system and device loadings, improved instability detection and predefined or automated countermeasure selections.

For blackout prevention, countermeasures should be coordinated in a global manner to optimise the total risk. The corrective and emergency control actions of a system may include but not limited to:

- Out-of-step protection
- Under-frequency load shedding
- Generator rescheduling and voltage control
- Interchange scheduling
- Capacitor and reactor switching
- Transformer Tapping
- FACTS control
- HVDC power modulation
- Unstable device tripping
- System islanding

The implementation of control actions has to be based on different instability detection and participation of each action to the instability mode. The quantities of actions need to be optimised to minimise the control risk. Large scale offline studies are required to investigate the effect of each control action or combination of control actions in different operating conditions. Verification needs to be done either by hardware or software based experiments. Data mining techniques may be necessary to distinguish the situation and help to find out the efficient action. With PMU data, observability of the system can be improved. Several derivatives of system states can be available based on fast measurements where the system condition in the future time interval can be predicted with a relatively good accuracy. The result can be useful for stability detection and countermeasure selection.

A. WAMS and Control Systems

From wide area perspective, the following applications are expected:

1. Voltage Control
2. WAMS for Oscillations, Voltage Stability or thermal limitations
3. Wide area protection

Most functions of these systems are separate from those of the existing SCADA systems. The implementation of such systems in addition to SCADA systems with the focus on the supervision of network interconnections would offer much more accurate network information across interchange borders. The higher transparency for corridors and interconnections is a first step towards an optimal utilization of available transfer capabilities in the transmission system. By means of measurement and recording of the frequency or phase-angle oscillations the current stability condition of the power system can also be evaluated and monitored. The second step is to actively influence the system to use available transmission reserves. In order to use network Var, Generator Active Power rescheduling capabilities in a most beneficial way it is necessary to have automated control schemes for normal and emergency situations. These control schemes have to take system aspects into account, which means the usage of dynamic wide area information. All automatic interactions have to be well defined and transparent for the operator to avoid unpredictable interactions. Beside these new technologies the more traditional ways of discontinuous mechanical control should be considered as well, like generator/load tripping, shunt capacitors or reactor bank switching, etc.

IV. Conclusion

PMUs are considered a fundamental measurement device for real-time power system monitoring. The penetration of this technique has a deep impact on the methodologies or even principles of system analysis and control. So far there is still a general lack of available methods for integrating PMU information for system security assessment and blackout prevention. However, the potential and benefits of PMU's have been recognised and significant application studies and implementation projects are in development stages.

REFERENCES

[1] A. G. Phadke and J. S. Thorp, Synchronized Phasor Measurements and Their Applications, 2nd ed. Berlin: Springer US, 2008.

[2] J. S. Thorp, A. G. Phadke, and K. J. Karimi, "Real time voltage-phasor measurement for static state estimation," IEEE Transactions on Power Apparatus and Systems, vol. PAS–104, no. 11, pp. 3098–3106, Nov. 1985.

[3] J. S. Thorp, A. G. Phadke, S. H. Horowitz, and M. M. Begovic, "Some applications of phasor measurements to adaptive protection," IEEE Transactions on Power Systems, vol. 3, no. 2, pp. 791–798, May 1988.

[4] A. G. Phadke, B. Pickett, M. Adamiak, M. Begovic, G. Benmouyal, J. Burnett, R. O., T. Cease, J. Goossens, D. Hansen, M. Kezunovic, L. Mankoff, P. McLaren, G. Michel, R. Murphy, J. Nordstrom, M. S. Sachdev, H. S. Smith, J. S. Thorp, M. Trotignon, T. C. Wang, and M. A. Xavier, "Synchronized sampling and phasor measurements for relaying and control," IEEE Transactions on Power Delivery, vol. 9, no. 1, pp. 442–452, Jan. 1994.

[5] J. Burnett, R. O., M. M. Butts, T. W. Cease, V. Centeno, G. Michel, R. J. Murphy, and A. G. Phadke, "Synchronized phasor measurements of a power system event," IEEE Transactions on Power Systems, vol. 9, no. 3, pp. 1643–1650, Aug. 1994.

[6] C.-W. Liu and J. Thorp, "Application of synchronised phasor measurements to real-time transient stability prediction," IEE Proceedings–Generation, Transmission and Distribution, vol. 142, no. 4, pp. 355–360, Jul. 1995.

[7] J. Ma, D. Han, W.-J. Sheng, R.-M. He, C.-Y. Yue, and J. Zhang, "Wide area measurements-based model validation and its application," IET-Generation, Transmission and Distribution, vol. 2, no. 6, pp. 906–916, 2008.

[8] T. Bi, J. Chen, J. Wu, and Q. Yang, "Synchronized phasor based on-line parameter identification of overhead transmission line," 2008 Third IEEE International Conference on Electric Unity Deregulation, pp. 1657–1662, 2008.

[9] I. Kamwa, S. R. Samantaray, and G. Joos, "Development of rule-based classifiers for rapid stability assessment of wide-area post-disturbance records," IEEE Transactions on Power Systems, vol. 24, no. 1, pp. 258–270, 2009.

[10] K. Sun, S. Likhate, V. Vittal, V. Kolluri, and S. Mandal, "An online dynamic security assessment scheme using phasor measurements and decision trees," IEEE Transactions on Power Systems, vol. 22, no. 4, pp. 1935–1943, 2007.

[11] N. Zhou, D. J. Trudnowski, J. W. Pierre, and W. A. Mittelstadt, "Electromechanical mode online estimation using regularized robust RLS methods," IEEE Transactions on Power Systems, vol. 23, no. 4, pp. 1670–1680, 2008.
[12] S. Corsi and G. N. Taranto, "A real-time voltage instability identification algorithm based on local phasor measurements," IEEE Transactions on Power Systems, vol. 23, no. 3, pp. 1271–1279, 2008.
[13] M. Glavic and T. Van Cutsem, "Detecting with PMUs the onset of voltage instability caused by a large disturbance," 2008 IEEE Power and Energy Society General Meeting, pp. 1–8, 2008.
[14] M. Parniani, J. Chow, L. Vanfretti, B. Bhargava, and A. Salazar, "Voltage stability analysis of a multiple-infeed load center using phasor measurement data," 2006 IEEE PES Power Systems Conference and Exposition, pp. 1299–1305, 2006.
[15] J. H. Chow, A. Chakrabortty, L. Vanfretti, and M. Arcak, "Estimation of radial power system transfer path dynamic parameters using synchronized phasor data," IEEE Transactions on Power Systems, vol. 23, no. 2, pp. 564–571, 2008.
[16] J. H. Chow, A. Chakrabortty, M. Arcak, B. Bhargava, and A. Salazar, "Synchronized phasor data based energy function analysis of dominant power transfer paths in large power systems," IEEE Transactions on Power Systems, vol. 22, no. 2, pp. 727–734, 2007.
[17] M. Liu, B. Zhang, L. Yao, M. Han, H. Sun, and W. Wu, "PMU based voltage stability analysis for transmission corridors," 2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, pp. 1815–1820, 2008.
[18] I.-D. Kim and R. K. Aggarwal, "A study on the on-line measurement of transmission line impedances for improved relaying protection," International Journal of Electrical Power and Energy Systems, vol. 28, no. 6, pp. 359–366, 2006.
[19] W. Jiang, V. Vittal, and G. T. Heydt, "Diakoptic state estimation using phasor measurement units," IEEE Transactions on Power Systems, vol. 23, no. 4, pp. 1580–1589, 2008.
[20] H. Wu and J. Giri, "PMU impact on state estimation reliability for improved grid security," 2005/2006 IEEE/PES Transmission and Distribution Conference and Exhibition, pp. 1349–1351, 2006.
[21] J. Bertsch, C. Carnal, D. Karlson, J. McDaniel, and K. Vu, "Wide-area protection and power system utilization," Proceedings of the IEEE, vol. 93, no. 5, pp. 997–1003, 2005.
[22] M. Zima, M. Larsson, P. Korba, C. Rehtanz, and G. Andersson, "Design aspects for wide-area monitoring and control systems," Proceedings of the IEEE, vol. 93, no. 5, pp. 980–996, 2005.
[23] M. Begovic, D. Novosel, D. Karlsson, C. Henville, and G. Michel, "Wide-area protection and emergency control," Proceedings of the IEEE, vol. 93, no. 5, pp. 876–891, 2005.
[24] C. Taylor, D. Erickson, K. Martin, R. Wilson, and V. Venkatasubramanian, "WACS−Wide-area stability and voltage control system: R&D and online demonstration," Proceedings of the IEEE, vol. 93, no. 5, pp. 892–906, 2005.
[25] Cigre Work Group C4.601 (P. Pourbeik Convener), "Wide area monitoring and control for transmission capability enhancement," CIGRE Technical Brochure, Final Report, Jan. 2007.
[26] J. F. Hauer, W. A. Mittelstadt, K. E. Martin, J. W. Burns, H. Lee, J. W. Pierre, and D. J. Trudnowski, "Use of the WECC WAMS in wide-area probing tests for validation of system performance and modeling," IEEE Transactions on Power Systems, vol. 24, no. 1, pp. 250–257, 2009.
[27] Y. S. Xue, "Some viewpoints and experiences on wide area measurement systems and wide area control systems," 2008 IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy in the 21st Century, pp. 1–6, 2008.
[28] I. Kamwa, J. Beland, G. Trudel, R. Grondin, C. Lafond, and D. McNabb, "Wide-area monitoring and control at Hydro-Québec: past, present and future," 2006 IEEE Power Engineering Society General Meeting, pp. 1–12, 2006.
[29] S. Chakrabarti, E. Kyriakides, T. shu Bi, D. yu Cai, and V. Terzija, "Measurements get together," IEEE Power & Energy Magazine, vol. 7, no. 1, pp. 41–49, 2009.
[30] P. M. Mahadev and R. D. Christie, "Envisioning power system data: vulnerability and severity representations for static security assessment," IEEE Transaction on Power Systems, vol. 9, no. 4, pp. 1915–1920, Nov. 1994.
[31] Cigre Work Group C4.601 (P. Pourbeik Convener), "Review of online dynamic security assessment tools and techniques," CIGRE Technical Brochure, Final Report, Jan. 2007.
[32] J. Chen and A. Abur, "Placement of PMUs to enable bad data detection in state estimation," IEEE Transactions on Power Systems, vol. 21, no. 4, pp. 1608–1615, 2006.
[33] J. Chen and A. Abur, "Enhanced topology error processing via optimal measurement design," IEEE Transactions on Power Systems, vol. 23, no. 3, pp. 845–852, 2008.
[34] A. P. S. Meliopoulos, G. Cokkinides, F. Galvan, and B. Fardanesh, "Distributed state estimator – advances and demonstration," Proceedings of the 41st Annual Hawaii International Conference on System Sciences, pp. 1–11, 2008.
[35] Siemens - EPRI presentation, "Phase Angle Measurements in State Estimator," 16th, Jun. 2004.
[36] R. Baldick, B. Chowdhury, I. Dobson, Z. Dong, B. Gou, D. Hawkins, H. Huang, M. Joung, D. Kirschen, F. Li, J. Li, Z. Li, C.-C. Liu, L. Mili, S. Miller, R. Podmore, K. Schneider, K. Sun, D. Wang, Z. Wu, P. Zhang, W. Zhang, and X. Zhang, "Initial review of methods for cascading failure analysis in electric power transmission systems - ieee pes cams task force on understanding, prediction, mitigation and restoration of cascading failures," 2008 IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, pp. 1–8, 2008.