PMU Placement Considerations – A Roadmap for Optimal PMU Placement

V. Madani (*Fellow),* M. Parashar (*Member),* J. Giri (*Fellow),* S. Durbha *(Member),* F. Rahmatian *(S. Member),* D. Day (*Member),* M. Adamiak (*Fellow),* G. Sheble (*Fellow)*

Abstract--**Recent investments in the Synchrophasor technology have energized the industry and a significant number of Phasor Measurement Units (PMUs) are being deployed. By some estimates, just in North America, the number of PMU installations is expected to grow five-fold – from approximately 200 today to over a 1000.**

The first step in PMU deployment is a clear roadmap of the process for selecting the location of the additional PMU devices and establishing guidelines to assist with this decision-making process. Many of the existing optimal PMU placement approaches are mainly focused on a particular application (such as improving State Estimation). This paper proposes a more comprehensive, holistic set of criteria for optimizing PMU placement based on sound practical solutions by experienced industry practitioners. The methodology offers the flexibility for considering multiple, diverse factors that can influence the PMU siting decision-making process, including incorporating several practical implementation aspects (e.g. communications infrastructure, prohibitive deployment cost, etc). Application needs, reliability requirements, and infrastructure challenges that drive the overall solution for optimal PMU location selection are formulated and described.

***Index Terms*—PMU Placement, SynchroPhasors, Phasor Technology, Synchronized Measurements.**

I. Introduction

INVESTMENTS in the development of a Smart Grid require a clear vision of how to manage assets, comprehensive knowledge of existing infrastructure, and a well developed strategy and roadmap. The deployment of a large scale synchrophasor measurement system begins with a longer-term vision and the development of a comprehensive process including system studies, feasibility and gap analyses, economic evaluation, and implementation schedule planning.

A methodology for optimally determining the location of PMU devices is developed based on project and business requirements. PMU siting studies were conducted to identify optimal locations which would benefit the largest number of applications, such as Situational Awareness, Visualization and Alarming for Operators as well as Post-Disturbance Event Analysis for Engineers. The proposed methodology also considers several practical implementation aspects (e.g. infrastructure and communication considerations, prohibitive deployment cost, etc). The overall methodology, the various decision-making criteria, and the final optimal placement study results are summarized in this paper.

II. Methodology

The overall goal in PMU placement is to identify optimal locations that maximizes the benefit across multiple applications, as well as offers the least-cost solution by leveraging existing and planned infrastructure upgrades across the power company's footprint and its neighboring systems.

To achieve this objective, a methodology that is based on the 'Analytic Hierarchy Process (AHP)' [1] and the 'Weighted Average Criterion' for prioritizing PMU placement has been adopted. AHP is a systematic approach for priority setting and decision-making that decomposes any complex decision problem into more easily comprehensible sub-problems. The process involves:

- Structuring a decision problem into a hierarchy of goals, decision criteria (sub-criteria) and alternatives (Figure 1) for multi-criteria decision making (MCDM).
- For all choices under consideration for PMU placement, assume 'scores' to each location based on certain decision criteria such as applications needs, infrastructure considerations, etc.
- Allocating 'Weights' to each of the decision criteria.
- Prioritization is then based on the weighted sum of values across all criteria.

Placement studies are performed to assign scores based on the applicability of a particular PMU allocation site to each decision criteria. Once all decision categories have been filled-in, the net weighted score for each PMU site under consideration is computed, and this list of candidate sites was sorted in descending order. The optimal PMU allocation sites are those with the highest score; i.e. the ones towards the top of this sorted list. This proposed approach is generic enough

V. Madani is with Pacific Gas & Electric, CA 94017, USA (e-mail: vxm@pge.com).
M. Parashar is with ALSTOM Grid, WA 98052 USA (email: manu.parashar@areva-td.com).
J. Giri is with ALSTOM Grid, WA 98052, USA (email: jay.giri@areva-td.com).
S. Durbha is with Mississippi State University, MS 39762 USA (email: suryad@cavs.msstate.edu).
F. Rahmatian is with Quanta-Technology, NC 27607, USA (email: frahmatian@quanta-technology.com).
D. Day is with Pacific Gas & Electric, CA 93704, USA (e-mail: DCDb@pge.com).
M. Adamiak is with General Electric, PA 19087 USA (email: Mark.Adamiak@ge.com).
G. Sheble is with Quanta-Technology, OR 97219, USA (email: gsheble@quanta-technology.com).

978-1-61284-788-7/11/$26.00 ©2011 IEEE

that it is applicable to any power company that is considering PMU installations.

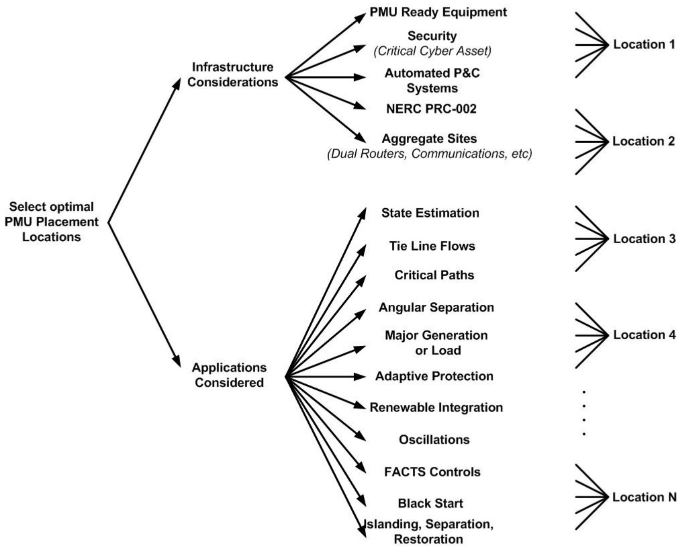


Fig. 1. The Analytic Hierarchy Structure for PMU placement decision criteria.

III. PMU Placement Decision Criteria

The set of decision-making criteria utilized in the PMU allocation process were chosen based on the priorities set by the engineering staff and business requirements. These criteria can broadly be categorized into '*Application Requirements*' and '*Infrastructure Considerations*'.

A. Application Requirements

This includes a list of functions or applications that shall be served by the synchrophasor system. The usefulness of a PMU at a particular location in serving an application's needs is very much application dependent, as suggested by the various studies and analysis that were conducted; the results of which are described below.

1) State Estimation (SE)

The objective of this study was to identify locations where additional observability via the PMU system would improve the SE solution both in terms of accuracy and robustness. The analysis was conducted on a state estimator snapshot obtained from the most current version of the power company's model, with the following attributes:

- Comprised of 3477 buses and 2465 stations.
- Included 6545 SCADA injection measurements and 7239 flow measurements.
- Also included external companies.

'SE Metrics' were used to quantify and prioritize locations where PMU measurements would improve the SE performance and accuracy. One meaningful indication of the SE function accuracy is the "variance of the SE system state errors", where the system state (voltages and angles) errors are defined as:

$$e = x_{true} - x_{estimated} \qquad (1)$$

The smaller the magnitude of the variances; the better the SE solution. The goal was to identify all stations 115kV and above where these variances were high, and consequently PMU allocation at these locations would help reduce the variance and improve SE.

Additionally, areas with observability problems (i.e. locations with a high level of pseudo-measurements) and critical measurements (i.e. non-redundant measurements) were also selected. The "residual sensitivity matrix" was utilized here to identify critical measurements; allocation of PMUs at these locations would then increase the local redundancy and reduce the number of critical measurements.

The expected benefits from PMU placement at the suggested locations from this study were:

- An increase in the number of valid SE solutions.
- A reduction in the number of critical measurements.
- An improvement in the SE accuracy (i.e. reduction in the "variance of state").
- Improved SE convergence speed (i.e. reduction in the SE factorization solution times).

2) Critical Paths (Regional Corridors, Tie-lines, & Angular Separation)

This criterion includes the allocation of PMUs to ensure adequate monitoring capabilities of angular separation as well as the power flows on each of the transmission lines that constitute the major transmission paths.

- *Path 66:* Also known as the California-Oregon Intertie (COI), these are the imports into Northern California.
- *Path 15*: This is the North-South California transmission in central California.
- *Path 26:* This is a set of three 500 kV transmission lines in Southern California.

Other tie-lines linking the power companies within the US Western Interconnection have also been included under this criterion. Some of the envisioned benefits from PMU installations at these locations include the ability to monitor both static and dynamic stresses observable in the MW/MVAR flows and the angular-separation across these corridors, and early detection of weakening grid conditions (such to line trips and associated impedance changes) and potential instabilities such as those encountered during the August 10, 1996 US Western Interconnection separation [2].

Angular separation can be detected as groups of coherent generation are found, as these groups separate, and as these groups divide indicating disintegration. Identification of such separations is the first step to remediation by islanding into micro-grids with subsequent micro-grid balancing by demand shedding [3-5]. Such techniques are promising to help enhance blackout prevention.

3) Local and Inter-Area Oscillations

Low-frequency electromechanical oscillations in the Western interconnected grid have been known to exist for several years. While these oscillations are typically well damped and therefore harmless, there is always the danger of the oscillations gradually becoming unstable with increased loading (i.e. small-signal instability phenomenon), or the possibility whereby severe faults can create steadily growing oscillations that lead to partial or total power system breakdown (e.g. August 10, 1996 US Western Interconnection break-up). Similarly, local oscillations at individual generators, if not properly identified and controlled, can lead to permanent damage of expensive power system equipment (such as rotor shafts). The high resolution PMU measurements enable observation of power system dynamics and characterization of the stability of such low-frequency oscillations in real time. In fact, within the US Western Interconnection, comprehensive calibration tests for validating the dynamic system performance have been conducted since 2000 by intentionally injecting known test signals into the grid (e.g. dynamic brake insertion, low/mid-level HVDC modulation); and the system's dynamic response has been captured through the PMU-based Wide-Area Measurement System (WAMS) [6]. These tests have become a common practice in the US Western Interconnection.

The goal of this study was to utilize the more traditional model-based approach of performing an eigen-analysis on the dynamic model to extract the local and inter-area modal characteristics (i.e. modal oscillatory frequency, damping levels, and mode shape information). The immediate advantage of this model-based approach is that it provides both modal observability and controllability information, even at locations where measurements may not be available, and therefore can recommend new PMU locations so that grid oscillation modes can be better detected and controlled.

In this study, a Western Interconnection Planning Case was analyzed using PowerTech's 'Small-Signal Stability Analysis Tool (SSAT). The model included:

- 16,791 AC buses with 3,346 generators and 8,284 loads.
- 14,524 transmission lines.
- 21 areas.

Both inter-area and local oscillatory modes were identified (see Table 1), and for each of the modes, the following information was obtained:

- *Mode Frequency (Hz):* The natural frequency of the electromechanical oscillation (Note: Modes within the 0.1Hz and 1Hz range are typically 'inter-area' modes, while modes within the 1Hz and 3Hz range are 'local' modes).
- *Mode Damping (%):* It characterizes the **rate-of-decay** of the oscillations – the lower the damping levels, the closer the power system is to dynamic instability; negative damping means the system is definitely becoming unstable
- *Mode Shape:* This provides the relative **observability** of a mode at each generation station (Note: The locations with high observability are places where PMUs should be allocated to detect this mode).
- *Mode Participation Factor:* This characterizes the **controllability** of a particular mode's behavior at each generation location (Note: The locations with high controllability are places where PMUs should be allocated for implementing control schemes to dampen out the mode).

TABLE I
DOMINANT INTER-AREA MODES WITHIN WESTERN INTERCONNECTION.

Mode Frequency (Mode Name)	***Mode Damping***	***Mode Shape Count***
0.34 Hz (Alberta Mode)	11.62 %	792
0.22 Hz (North South Mode)	14.80 %	432
0.61 Hz	13.37 %	538
0.63 Hz (BC Mode)	12.52 %	123
0.53 Hz (Desert Southwest)	14.63 %	118
0.81 Hz	12.18 %	85
0.99 Hz	10.32 %	60

An example of the mode shape information that was obtained from the SSAT tool is shown in Figure 2. This particular mode shape is associated with the commonly observed 'North-South' inter-area mode, where the northern portion of the Western Interconnection (Alberta, B.C. Hydro, Pacific Northeast) is known to oscillate against the southern portion of the Western Interconnection (Southern California, Mexico-CFE, Arizona) at approximately 0.22Hz. Here, the most dominant mode shape elements were found to be in Alberta and Arizona (i.e. the two geographic extremes of the Western Interconnection).

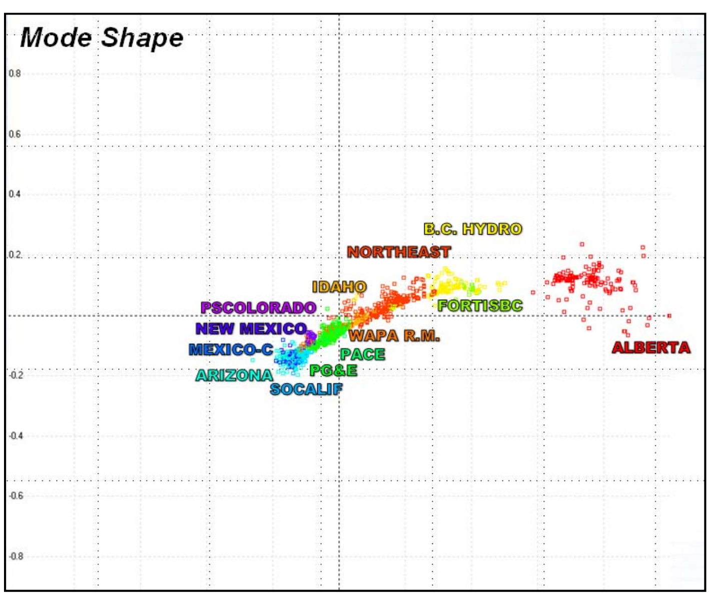


Fig. 2. The Example mode shape information for the North-South mode (0.22Hz @ 12.40% damping).

4) Major Generation and Load

Generation stations with a combined capacity of 1000MW or above, or single generating units with capacity greater than 500MW have been selected as the sites for PMU placement under this criterion. Similarly, stations feeding major load centers were also chosen as candidates for PMU installation.

The expected benefits from these new PMU allocations include the ability to monitor the performance of Power System Stabilizers (PSS) and other controls at the major generation stations, as well as assessing the load response characteristics such as Fault Induced Delayed Voltage Recovery (FIDVR) which is typically associated with highly concentrated induction-motor loads (e.g. air-conditioning load without compressor under-voltage protection), which results in depressed voltages for several seconds following a fault in the system [7]. It is important that such characteristics be represented properly in simulation programs. The ability to capture high-resolution data from these sites during power system tests and other disturbances will therefore be very valuable in calibrating the generator and load model parameters and keeping planning models up-to-date. The steady state model update based on state estimation is now supplemented with tools to update the dynamic equipment models. Additional future data to be considered includes dynamic data within the plants, such as oscillating torques on the generation shaft.

5) Other Critical Substation Locations

This criterion covers all stations that are of special importance for one or more of the following reasons:

- *Renewable Integration:* This includes stations that are interconnection points for a group of variable generation (e.g. feeders to large wind farms). PMU placements at these locations are expected to be useful in tracking the dynamic output of these intermittent resources and determining their response characteristics (low voltage ride through capability, local oscillations, frequency response characteristics, etc). More specifically, due to the fast response of the synchrophasor measurements, incipient loss of power can better be tracked and, as control systems evolve, better track the ramp rates of renewables.
- *FACTS Controls*: These are stations with controllable devices such as HVDC and SVC controls. PMUs at these locations in the short-term shall provide valuable measurements to evaluate the controller performance, and in the future could be utilized in feedback control schemes that dampen inter-area oscillations or regulate voltage.
- *Adaptive Protection:* The PMU locations for adaptive protection are based on system studies which identify impedance based relays applied to long transmission lines where potential encroachment due to power swings or increasing powerflow is of concern. Under this concept, PMU information can provide supervisory to the line protection to prevent unnecessary action outside of the zone of protection. Benefits include improved grid reliability during major disturbances.
- *Islanding, Separation & Restoration:* These include interfaces at known separation points as well as locations with black-start generation capabilities. The expected benefits from PMU installations at these locations include early detection of islanding conditions and remedial action either by an adaptive protection system or an extended remedial action system. Key placements can assistance with the restoration process, and resynchronization back into the main grid. Black-start investigations of alternative system configurations, including operation of transmission lines at reduced voltages with bypassing of transformers are enabled with detailed phasor measurements of potential overvoltage locations.

B. Infrastructure Considerations

In addition to the application needs, it is equally important that several infrastructure considerations (e.g. communications availability, redundancy, etc) are also considered during the PMU placement decision-making process. For example, while a particular location may be highly desirable from application's perspective, the lack of established infrastructure to communicate these measurements to the control center make it cost prohibitive to have a PMU at that location. The infrastructure factors that were considered in the PMU allocation process are summarized below.

1) PMU Ready Equipment (Devices & Infrastructure)

Many electric power utilities have IED (Intelligent Electronic Devices) such as relays and other monitoring equipment throughout its system. A number of these devices are PMU-ready devices, and acquiring synchrophasor measurements at these locations would only entail firmware upgrades or replacing the device. Significant installation cost and time, including wiring and connection to instrument transformers, can be avoided by using IED's at these locations.

A very significant cost element in a large scale PMU deployment project is the cost of communication infrastructure required for effective operation of the system. Accordingly, it is desirable to leverage the existing communication infrastructure to the extent possible. Stations that are already part of power company's WAN Operation Data Network (ODN), having adequate bandwidth and/or the desired redundancy to stream the PMU measurements reliably in real-time to the control center, are preferred locations for PMU placement.

Independent of existing devices, the availability of the "type" of synchrophasor also needs to be evaluated. Today's PMUs are capable of reporting a fast rise-time synchrophasor known as "P" or Protection class synchrophasors as well as "M" or Measurement class synchrophasors. The application needs of the synchrophasors from a given location must be evaluated ("P" or "M" class or both) as well as the capability of the PMU to deliver both and the communication bandwidth to carry both – if needed.

2) Aggregate Sites

The IP network for synchrophasor traffic should be designed in a hierarchical fashion such that data streams from multiple PMUs may flow through strategically positioned "aggregation sites" where substation PDCs are deployed before it is forwarded to the control center PDCs. This aggregation of traffic into larger easier to manage links will not only improve network performance and allow for a more controlled deployment of advanced network features such as Multicast, MPLS, Prioritization and Queuing, enabling enhanced performance without overly complicating the network design, but is also expected to control costs. These aggregation sites are also ideal candidates for PMU placement from an infrastructural point-of-view.

3) *NERC PRC 002 Sites*

PRC 002-2 is NERC's 'Disturbance Monitoring and Reporting Requirements' to ensure that Transmission Owners collect adequate data needed to facilitate analysis of disturbances. The requirements are applicable to all stations that:

- Contain any combination of three or more transmission lines operated at 200kV or above and transformers having primary and secondary voltage ratings of 200kV or above.
- Are connected at 200 kV or above through generating unit step up transformer(s) (GSU(s)) to a generating plant having either a single generating unit of 500 MVA or higher nameplate rating, or through a GSU(s) to a generating plant with an aggregate plant total nameplate capacity of 1500 MVA or higher.

The NERC PRC 002 requirements call for synchronized sequence of event, fault recording and dynamic disturbance recording data at high sampling rates. Many multi-functional devices that fulfill the PRC 002 data requirements are also equipped with PMU functionality. Hence, installing such devices at those locations where the PRC-002-02 requirements are applicable, would provide synchrophasor data at no additional cost. This is a major improvement over the traditional post disturbance analysis functions of energy management systems.

4) *On Critical Cyber Asset (CCA) List*

PMUs and their associated communications infrastructure's cyber security compliance is a significant issue. Accordingly, those locations that have already been identified as containing critical cyber assets, and thus have (or shall have) the required security practices in place to meet the NERC CIP 003-009 standards, would also be preferred PMU allocation sites from an infrastructure planning point-of-view.

IV. Optimal PMU Placement Results

The 'Weighted Average Criterion' was applied to the PMU placement problem utilizing the various application and infrastructure criteria discussed in the previous sections (Figure 3). All stations at the 115kV level and above within the power company's footprint and in neighboring systems were considered. For all potential PMU allocation sites, the net weighted score was computed. Those locations with the highest scores were selected as the sites for PMU placement.

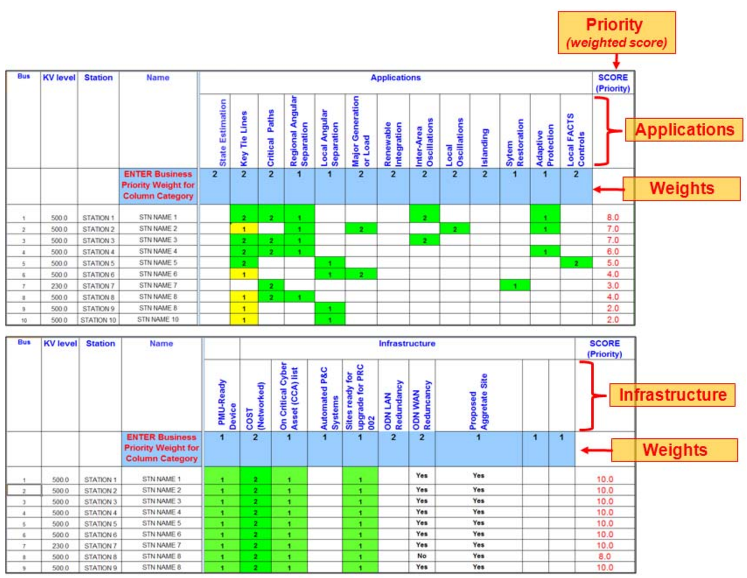


Fig. 3. The 'Weighted Average Criterion' methodology overview.

V. Conclusion

The advent of a wide-area synchronized phasor measurement network is the next major evolution of control center capabilities; remarkably beyond today's traditional energy management system analysis. This energy management system evolution is a paradigm shift and moves the analysis from static analysis to dynamic analysis. The benefits to operation and to planning, resulting from verified model parameters within a static time frame and a dynamic time frame, has the potential to provide a significant increase in the productive use of equipment, increased performance (despite operational and equipment margins being more reduced, than in the past), and increased efficiency to conserve the cost of production and optimize delivery to the consumer. PMU placement is a fundamental optimization process that seeks the best overall operational and planning benefits, subject to the overall total cost of operational, maintenance, and capital costs.

In this paper, an Analytic Hierarchy Process and a

Weighted Average Criterion for prioritizing PMU placement has been demonstrated. The criteria for evaluation were decided by the engineering and operations teams. Results of the analyses were as expected for the 500kV system; however, a number of unexpected monitoring sites rated highly due to their importance for a number of the other identified criteria.

VI. References

[1] T. L. Saaty, "The Analytic Hierarchy Process",Mc-Graw-Hill, New York, NY.,1980.

[2] I. Dobson, M. Parashar, C. Carter, "Combining Phasor Measurements to Monitor Cutset Angles, *43rd Hawaii International Conference on System Sciences*, Jan. 2010, Kauai, HI.

[3] Ahmed, S.S., Sarker, N.C., Khairuddin, A.B., Ghani, M.R.B.A., Ahmad, H.; "*A* Scheme for Controlled Islanding to Prevent Subsequent Blackout*," IEEE Trans. Power Syst*., vol. 18, no. 1, pp. 136-143,. February 2003.

[4] Qianchuan Zhao, Kai Sun, Da-Zhong Zheng, Jin Ma, Qiang Lu, "A study of system splitting strategies for island operation of power system: a two-phase method based on OBDDs," *IEEE Trans. Power Syst.*, vol. 18, no. 4, pp. 1556-1565. Nov. 2003.

[5] Haibo You, V. Vittal, Zhong Yang, "Self-healing in power systems: an approach using islanding and rate of frequency decline-based load shedding", *Power Systems, IEEE Transactions on*, Vol. 18, No. 1. (2003), pp. 174-181.

[6] N. Zhou, J.W. Pierre, and J.F. Hauer, "Initial Results in Power Systems Identification from Injected Probing Signals Using a Subspace Method," *Power Systems, IEEE Transactions on*, Vol. 21, No. 3. (2006), pp. 1296-1302.

[7] L.Y. Taylor, R.A. Jones, S. M Halpin, "Development of Load Models for Fault Induced Delayed Voltage Recovery Dynamic Studies", *IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy in the 21st Century*, 20-24 July 2008, Pittsburgh, PA.

[8] V. Madani, G. Duru, B. Tatera, M. Jones, B. Pace, "A Paradigm Shift to Meet the Protection and Control Challenges of the 21st Century", *Georgia Tech Protective Relaying Conference*, May 2007, Atlanta, GA.

VII. Biographies

Vahid Madani (F' 2008) is the technology lead for advanced wide-area warning systems and remedial action schemes (RAS), and is a principle engineer responsible for Protection and Control Standards and modernization at Pacific Gas and Electric co., USA. He is a Tau Beta Pi member, a registered Electrical Engineer with nearly 30 years of academic and utility experience and is the recipient of many distinguished citations for leadership, innovations and contributions to the power system industry and education.

His latest assignment is deployment of the large scale interconnected advanced warning systems, integration of synchrophasor technology into the PG&E's Energy Management System (EMS), and development of a synchrophasor based interconnected RAS.

Mr. Madani has various technical, advisory, and leadership roles in North America and internationally, has numerous publications, and has contributed to the development of many applications in system protection and intelligent restoration.

Manu Parashar (M' 2003) is a Principal Power System Engineer at ALSTOM Grid T&D Inc in Redmond, WA, where he is involved in developing synchrophasor applications for smart grid projects. Prior to that, he was with Electric Power Group where he was responsible for all synchrophasor related research & development initiatives, including leading the development of the Real-Time Dynamics Monitoring System™ (RTDMS) for synchrophasor applications.

Dr Parashar received his BS, MS, and PhD degrees in Electrical Engineering from Cornell University, Ithaca, NY, in 1997, 1999, and 2003, respectively.

Jay Giri (F' 2002) is presently director of Power Systems Technology and Strategic Initiatives at ALSTOM Grid, in Redmond, Washington. He also manages a group of power system engineers developing control center software for smart grid project deliveries.

In 1978 he and 11 others co-founded Energy System Computer Applications (ESCA). In 2010, after numerous mergers and acquisitions, ESCA became part of ALSTOM Grid.

Dr. Giri designed and implemented the original software for the ESCA automatic generation control (AGC) and dispatcher training simulator (DTS) power system simulation functions. Today the ALSTOM AGC controls over 50% of North American generation as well as generation in many other countries, and the ALSTOM DTS is a predominant simulator used by utilities worldwide.

An affiliate professor at the University of Washington, Dr. Giri is a co-author of the "Energy Management Systems" chapter of the Electrical Engineering handbook and co-author of numerous other technical publications and presentations. He has a PhD from Clarkson University in New York and a B.Tech from IIT, Madras. In 2002, he was elected IEEE Fellow with the citation: "For contributions to the design and implementation of power system control centers."

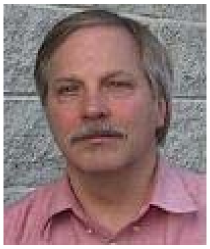
Surya S. Durbha (M' 2006) received the B.S. degree in civil-environmental engineering and the M.S. degree in remote sensing from Andhra University, Visakhapatnam, India, in 1994 and 1997 respectively and Ph.D degree in computer engineering from Mississippi State University (MSU) in 2006. He was an application scientist at the Indian Institute of Remote Sensing, Department of Space, India from 1998 to 2001. He is currently an Assistant Research Professor at the Center For Advanced Vehicular Systems (CAVS)and the Department of Electrical and Computer Engineering at MSU. He is currently working in the areas of information services, geospatial interoperability, data mining, and standards for the smart gird, sensor web enablement frameworks, and image information mining tools.. He served on the program committees of several international conferences including SSKI, SSTDM, and IGARSS, and co-chaired sessions at various conferences.

Farnoosh Rahmatian (S'89, M'91) received B.A.Sc. (Hon.), M.A.Sc., and Ph.D. degrees from the University of British Columbia, Vancouver, BC, Canada, in 1991, 1993, and 1997, respectively, all in electrical engineering. From 1997 to 2004, he was a Director of Research & Development at NxtPhase Corporation, working on precision high-voltage optical instrument transformers for use in high-voltage electric power transmission systems. From 2004 to January 2009, he was the Director of Optical Systems and Advanced Systems Applications at NxtPhase T&D Corporation, focusing on application and commercial use of optical voltage and current sensors. Since May 2009, he has been a Sr. Director at Quanta Technology, working on synchrophasor measurement systems, high-voltage testing, smart grid sensors and standards, and instrumentation calibration.

Dr. Rahmatian has also been an adjunct professor at the Department of Electrical and Computer Engineering at the University of British Columbia, and a member of: IEC TC38 working groups on instrument transformers, Standards Council of Canada, Canadian Standards Association, CIGRE, IEEE Power & Energy Society, and IEEE Photonics Society. He is the vice-chair of IEEE/PES Power System Instrumentation and Measurements committee. Dr. Rahmatian has received an R&D 100 award for the development of the optical fiber current and voltage sensor in 2002, has authored or co-authored over 50 scientific and technical publications, and holds 10 US patents.

Dewey Day is a Senior IT Architect at Pacific Gas & Electric. He has been involved with microwave and fiber projects to meet PG&Es internal communicaitons requirements for 16 years. For the last 10 years Dewey planned all microwave and fiber installations throughout PG&Es service territory.

Mr. Day holds a BSEE from CSU Fresno, with specialization in Power Systems and Communications. He is also PG&Es representative to the WECC Telecom Work Group.



Mark Adamiak (F 2005) is the Director of Advanced Technologies for GE Smart Substations and is responsible for identifying and developing new technology for GE's substation protection, control, and automation business. Mark received his BS and ME degrees from Cornell University in Electrical Engineering and an MS-EE degree from the Polytechnic Institute of New York. Mark started his career in NYC with American Electric Power (AEP) and then transitioned to GE in 1990 where his activities have ranged from advanced development, product planning, application engineering, and system integration. Mr. Adamiak was the Principle Investigator on the EPRI IntelliGrid project that defined an architecture for the Smart Grid. Mark is a Fellow of the IEEE, a member of the IEC Working Group on Utility Communication, a US Regular Member of CIGRE, and a GE Edison award winner for 2008.

Gerald B. Sheblé (IEEE: M 71, SM 85, F 98) attended Purdue University (BSEE 1971 and MSEE 1974). He received Ph.D. in 1985 from Virginia Tech. Dr. Sheblé received MBA from the University of Iowa in 2001, specializing in Economics and Finance.

His industrial experience includes over fifteen years with a public utility, a research and development firm, a computer vendor and a consulting firm. Dr. Sheblé has participated in functional definition, analysis and design of applications for over fifty Energy Management Systems. His consulting experience includes significant projects with over forty companies. He has developed and implemented one of the first electric energy market simulators for EPRI using genetic algorithms to simulate competing players.