IJCTA, 9(2), June 2016, pp. 1437-1441

A Review on Phasor Measurement Unit Placement Techniques for Power System Observability in Smart Grids

Nisha Tayal*

ABSTRACT

Smart Grid has been deployed across various nations with the impact of cutting edge technology; still there are some more essentials to be accentuated to endeavor an ingrained operative system. An important aspect of Smart grid is measurement of power system parameters. PMU data are most significant among them which are utilized for the efficient operation of smart grids. This paper presents a review of various research works done in this field and compares the pros and cons of the approaches used in the past.

Index term: Smart Grid, PMU placement, Power System, State Estimation

1. INTRODUCTION

With the growing ultimatum of electrical power, Quality of Service (QoS) and continuity of supply has been the utmost primacy for all major power utility sectors across the world, prior to the global market strategy. Smart Grid is predominantly proposed as the quantum leap in harnessing communication and information technologies to enhance grid reliability, and to enable integration of various smart grid resources such as renewable energy, demand response, electric storage and electric transportation. It allows greater competition between the providers, enabling greater use of intermittent power resources, establishing the wide area automation and monitoring capabilities needed for both bulk transmission over wide distances and distributed power generation, empowering more efficient outage management, streamline back office operations, aiding the use of market forces to drive retail demand response and energy conservation. Smart Grid technology underscores factors like policies, regulation, and efficiency of market, costs and benefits, and services that normalize the marketing strategy, by restructuring the global power scenario in a very dynamic approach. In addition to this, the concerns like secure communication, standard protocols, advance database management and efficient architecture with ethical data exchange, adds to its requisites. The development of Information and Communication Technology (ICT) has updated the technology by supporting dynamic real-time two-way energy and information flow, facilitating the integration of renewable energy sources into the grid, empowering the consumer with tools for optimizing their energy consumption, by introducing Advance Metering Infrastructures (AMI), Virtual Power Plant (VPP) and other such incipient implements. In addition, it helps grid to continuously self-monitor and self-adjust to achieve self-healing function, so as to monitor all kinds of turbulences, carry on compensations,redeploy the power flow, avoid the intensification of accident and make each kind of different intelligent devices to realize the network communication topologies. Power engineers across have developed a curiosity in decarburizing the electrical power while minimizing the dependency of the fossils. Such interest has fortified the growth of renewable energy by ensuing the efficiency and economy of the power grids. Integrated distributed power sources, includes renewable energy such as Fuel cells, Photovoltaic cells, Wind turbine, Micro hydro generators etc. could prolific the needs like power stability, improve grid efficiency, recruit use of the Plug-in EVs, support

* Assistant Professor, Department of Electrical and Electronics Engineering, UIET, Panjab University, Chandigarh, India.

customer in changing their energy usage patterns, by reduction in power consumption and saving money. High power electronics is also a key technology to build the smart grid technology in an eventual way by adding new DC grids and AC Var sources at the T&D level, serving as backbones and additional stability pillars to existing grids.

The backbone to deliver electric power from the generation station to the loads and consumers' side, the transmission network has frolicked vital role and has been highly recognized entity of power system engineering. Commencing of the transmission of electric power to be a direct current (DC) transmission, the scope of the transmission has been diversified to HVAC, HVDC transmission at various voltage levels along with profuse complex network topologies. Up-gradation of transmission network by increasing high capacity multi-circuit/bundle conductor lines, High Surge Impedance Loading (HSIL) Line, high capacity HVDC system, High Temperature Low Sag (HTLS) Line, etc. facilitates the quality of power transmission with the crux of reliability and economy of the system. But still thriving challenges and issues which are being faced off by today's transmission network such as environmental challenges, market/customer needs, infrastructure challenges and innovative technologies. With the state of art technology advances in the areas of sensing, communication, control, computing and information technology, it has quarried a unique vision of the future smart transmission grids by identifying the major smart characteristics and performance features to handle the challenges. A major challenge is the measurement of power system parameters for complete observability of Smart Grid, hence PMU data becomes significant.

2. RELATED WORK

Roy, BK Saha *et al.* [1] implements a three stage optimal PMU placement method is presented in this paper using network connectivity information. The method initially considers PMU in all buses of the network. Stage I and Stage II of the algorithm iteratively determine (i) less important bus locations from where PMUs are eliminated and (ii) strategically important bus locations where PMUs are retained. Stage III of the algorithm further minimizes the number of PMU using pruning operation. The set of PMUs obtained after Stage III is an optimal set of PMU locations for network observability. Proposed method is further extended for assuring complete observability under single PMU outage cases. Simulation results for IEEE 14-bus, 24-bus, 30-bus, 57-bus, 118-bus and New England 39-bus test systems are presented and compared with the existing techniques. Results show that the proposed method is simple to implement and accurate compared to other existing methods.

Madani, V., M. Parashar *et al.* [2] 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 sitting 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

Jian-jun, Xu, Xu *et al.* [3] proposes Differential Evolution and Particle Swarm Optimization (DEPSO) algorithm in view of the system failure rate. The improved DEPSO algorithm is global optimization; the algorithm takes the constraint condition of fault rate into account during the course of seeking optimal solutions. At the end, through the examples show that the algorithm compares with the existing optimization methods, which can reduce the number of PMU configuration and achieve completely observability of the system, at the same time, and stable operation of the system, through the simulation results verify feasibility and validity of the algorithm. Election are formulated and described.

Zhao, Zheng *et al.* [4] has done a study in which both Integer Linear Programming method and Genetic Algorithm are implemented to optimize the PMU placement considering number of analog channels. The proposed methods are tested on IEEE-14 and IEEE-30 buses systems. Detailed placement strategies are presented for the test systems. In conclusion, a comparison and discussion of the usability of both methods are concluded.

Bhonsle, J. S *et al.* [5] attempts to solve the optimal PMU placement problem and a novel approach is proposed in order to determine the optimal number and locations of PMUs to make the power system observable. The PMU placement problem is formulated as a binary integer linear programming, in which the binary decision variables (0, 1) determine where to install a PMU, preserving the system set observability, such as full or partial. The proposed approach integrates the impacts of both existing conventional power injection/flow measurements (if any) and the possible failure of single or multiple PMU / communication line into the decision strategy of the optimal PMU allocation. The network topology and hence network connectivity matrix remains unaltered for the inclusion of conventional measurements. Program is developed usingMatlabsoftware and is tested on sample seven-bus system and IEEE 14 bus system.

Mahaei, S. Mehdi *et al.* [6] presents a new method for minimizing the number of PMUs and their optimal placement in power systems. The proposed method provides suitable constraints for power systems with two adjacent injection measurements (IMs). In addition, suitable constraints for considering the connection of two buses to each other and to an injection bus are proposed. The proposed constraints result in a reduction in the number of PMUs even though the system topological observability is complete. Existing conventional measurements are also considered. First, the number of PMUs is minimized in such a way that the system topological observability is complete. Then the optimal placement is done to maximize the measurements redundancy. The resulting phased to be installed in multiple stages. The optimal number of PMUs that ensure system topological observability under failure of a PMU or a line is also simulated. Simulations are performed on IEEE 30, 57 and 118 bus test systems by binary integer programming. The results show that the number of PMUs is equal to or less than the corresponding results of recently published papers, while the system topological observability is complete, and measurement redundancy is increased.

Aminifar, Farrokh, Mahmud Fotuhi *et al.* [7] solves the optimal PMU placement problem in ac/dc systems subjected to the system observability is presented in this paper by applying a mixed-integer programming model. In practice, the cost of each PMU is variable as a function of PMU measurement channels. This attribute is incorporated in the proposed model as well. In addition, the number of PMU measurement channels is deemed to be technically limited; thus, the common assumption concerning allocation of one PMU device to a single node is relaxed. The objective in the proposed optimization model is to minimize the total installation cost of PMUs when considering the observability of ac/dc transmission systems in the base case and contingency conditions. Numerical analyses are conducted for the IEEE standard test systems and a large-scale system, and the results are discussed.

Singh, Bindeshwar *et al.* [8] presents a critical review on different application of Phasor Measurement Units (PMUs) in electric power system networks incorporated with FACTS controllers for advanced power system monitoring, protection, and control. Also this paper presents the current status of the research and developments in the field of the applications of PMUs in electric power system networks incorporated with FACTS controllers. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of the applications of PMUs in electric power system networks incorporated with FACTS controllers.

Gómez, Oscar, and Mario *et al.* [9] addresses two aspects of the optimal Phasor Measurement Unit (PMU) placement problem. Firstly, an ILP (Integer Linear Programing) model for the optimal multistage placement of PMUs is proposed. The approach finds the number of PMUs and its placement in separate stages, while maximizing the system observability at each period of time. The model takes into account: the available budget per stage, the power system expansion along with the multistage PMU placement, redundancy in the PMU placement against the failure of a PMU or its communication links, user defined time constraints for PMU allocation, and the zero-injection effect. Secondly, it is proposed a methodology to identify buses to be observed for dynamic stability monitoring. Two criteria, which are inter-area observability and intra-area observability, have been considered. The methodology identifies coherent groups in large power systems by using a new technique based on graph theory. The technique requires neither full stability studies nor a predefined number of groups

Khiabani, Vahidhossein *et al.* [10] proposes a genetic algorithm (GA) based approach for reliability placement of phasor measurement units (PMUs) in smart grid is proposed. The algorithm combines two conflicting objectives which are maximization of the reliability of observability and minimization of the number of PMU placements for ensuring full system observability. The multiobjective problem is formulated as a nonlinear optimization problem and genetic algorithm approach is employed for solving the large scale bus systems. The optimization model is solved for IEEE 14, 30, 57, 118, and 2383 standard bus systems. The effectiveness of the proposed approach has been demonstrated by comparing results with exact algorithms for smaller problem sizes. The results suggest that by employing genetic algorithm, the system reliability of observability is improved by approximately 48% as compared to traditional optimal PMU placement. According to results, the proposed approach achieve significant cost savings (~17%-~50%) compared to available reliability based models

Pal, Arnab, Gerardo *et al.* [11] presents a phasor measurement unit (PMU) placement scheme that provides real-time monitoring of key buses of the network. High-voltage lines, substations relevant for transient and dynamic stability of the network, and buses with high connectivity are given the highest priority while placing the PMUs. Binary integer programming and “depth of unobservability” are used to find the relevant PMU placement set. The placement scheme has been tested on the IEEE 118-bus system, IEEE 300-bus system, a 283-bus model of the Central American Power Transmission System, and a complex 996-bus network describing the Northern and the Eastern power grids of India. The results indicate that the proposed technique will be useful to utilities that want to initially protect the most important buses of their system on their way to attaining complete observability.

Mazhari, Seyed Mahdi *et al.* [12] proposes a multi-objective phasor measurement units (PMUs) placement method in electric transmission grids. Further consideration is devoted to the early PMU placement formulations, to simultaneously determine minimum number of PMUs, as well as maximum measurement redundancy. Moreover, a new methodology is presented for valuation of observability under contingencies, including line outages and loss of PMUs. Furthermore, a generalized observability function is introduced to allocate the PMUs in presence of conventional non-synchronous measurements. The resultant optimization problem is solved using Cellular Learning Automata (CLA), introducing new CLA local rules to improve the optimization process. The developed method is conducted on IEEE standard test systems as well as the Iranian 230- and 400-kV transmission grids, followed by a discussion on results.

Wen, Miles HF *et al.* [13] proposes a novel optimization model to maximize the power system observability by placing phasor measurement units (PMUs) in a multistage manner. The problem is constrained by the financial budgets available at each installation stage. The budget may be spent on purchasing and installing new PMUs and relocating PMUs already installed in the power system. This problem is very difficult to solve when the problem size becomes big. Therefore, a newly developed meta-heuristic, called chemical reaction optimization (CRO), is used to solve this optimal multistage PMU placement problem (OMPP), and numerical studies are carried out on the IEEE 57-bus, 118-bus, and 300-bus systems.

3. CONCLUSION

Various literatures relating to the role of PMU’s in Smart Grid has been thoroughly reviewed in this paper and their pros and cons have been discussed. Smart Grid suffers from a major challenge of obtaining various states of the parameters and PMU’s provide the best results but are very costly. Researchers have worked for optimal placement of the PMU's and utilized various meta-heuristic approaches. State estimation is another field which has been attempted using Bayesian approaches.

REFERENCES

[1] Roy, BK Saha, A. K. Sinha, and A. K. Pradhan. "An optimal PMU placement technique for power system observability." *International Journal of Electrical Power & Energy Systems* 42, no. 1 (2012): 71-77.

[2] Madani, V., M. Parashar, J. Giri, S. Durbha, F. Rahmatian, D. Day, M. Adamiak, and G. Sheble. "PMU placement considerations—A roadmap for optimal PMU placement." In *Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES*, pp. 1-7. IEEE, 2011.

[3] Jian-jun, Xu, Xu Yan-chao, Yan Li-mei, Z. H. A. O. Hai-long, S. U. N. Zhi-gang, and B. A. I. Li-li. "Research on the Method of Optimal PMU Placement." *International Journal of Online Engineering* (2013).

[4] Zhao, Zheng, and Elham B. Makram. "Optimal PMU placement considering number of analog channels."In *North American Power Symposium (NAPS), 2011*, pp. 1-5.IEEE, 2011.

[5] Bhonsle, J. S., and A. S. Junghare. "A novel approach for the optimal PMU placement using binary integer programming technique." *International Journal of Electrical and Electronics Engineering (IJEEE)* 1, no. 3 (2012): 67-72.

[6] Mahaei, S. Mehdi, and M. TarafdarHagh. "Minimizing the number of PMUs and their optimal placement in power systems." *Electric Power Systems Research* 83, no. 1 (2012): 66-72.

[7] Aminifar, Farrokh, Mahmud Fotuhi-Firuzabad, Amir Safdarian, and Mohammad Shahidehpour. "Observability of hybrid AC/DC power systems with variable-cost PMUs." *Power Delivery, IEEE Transactions on* 29, no. 1 (2014): 345-352.

[8] Singh, Bindeshwar, N. K. Sharma, A. N. Tiwari, K. S. Verma, and S. N. Singh. "Applications of phasor measurement units (PMUs) in electric power system networks incorporated with FACTS controllers." *International Journal of Engineering, Science and Technology* 3, no. 3 (2011).

[9] Gómez, Oscar, and Mario A. Ríos. "ILP-based multistage placement of PMUs with dynamic monitoring constraints." International Journal of Electrical Power & Energy Systems 53 (2013): 95-105.

[10] Khiabani, Vahidhossein, K. Erdem, K. Farahmand, and Kendall E. Nygard. "Smart grid PMU allocation using Genetic Algorithm." Journal of Network and Innovative Computing 2, no. 2014 (2014): 030-040.

[11] Pal, Arnab, Gerardo A. Sanchez-Ayala, Virgilio A. Centeno, and James S. Thorp. "A PMU placement scheme ensuring real-time monitoring of critical buses of the network." Power Delivery, IEEE Transactions on 29, no. 2 (2014): 510-517.

[12] Mazhari, Seyed Mahdi, Hassan Monsef, Hamid Lesani, and Alireza Fereidunian. "A multi-objective PMU placement method considering measurement redundancy and observability value under contingencies."Power Systems, IEEE Transactions on 28, no. 3 (2013): 2136-2146.

[13] Wen, Miles HF, Jin Xu, and Victor OK Li. "Optimal multistage PMU placement for wide-area monitoring." Power Systems, IEEE Transactions on28, no. 4 (2013): 4134-4143.