Optimal Placement of PMUs in a Microgrid

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***Abstract*—Improvements in power system control and protection is achieved by utilizing real time synchronized phasor measurements. The trend in recent years is the steady increase of Phasor Measurement Unit (PMU) installations worldwide for various applications those targeted for State Estimation enhancement. In this paper, Power System Analysis Toolbox (PSAT) is used for power system analysis and control. PSAT is used to solve the PMU placement problem using different methods for a 2MW Microgrid formed with the help of IEEE 14 bus system.**

Keywords—Synchrophasors, Phasor Measurement Unit, Microgrid, OPP

I. INTRODUCTION

Electric power system is network of electrical devices, transmission and distribution and also component of electric system for use of good quality of power at the load end. Electric power system is network of electrical component that supply a region, homes and industries with power. Power system is a grid Electricity is associated with the presence of flow of electric charge. Electric power is product of two different quantities that is electric current and electric voltage. These both quantities varies with time and also kept at constant values in DC. Because most of our daily appliances use A.C. and some other like computer and digital equipment use D.C. power. A.C. power is a practical choice because it is easy to transform and generate. But D.C. remains practical choice for DC systems and it is more economical for transmit over high voltage. Electricity can be generated in different ways in different power plant like, solar energy system, hydroelectric energy plant, thermal power generation plant, wind power system, nuclear energy power plant etc.

In hydro power plant we use water for the production of electricity by making dams. In this kinetic energy is used to convert to electric energy. In solar power plant we use solar energy to produce electric energy. In solar power generation we use solar cell to convert solar energy into electric energy. Solar cells are act as transducers. Which convert one form of energy into other? Solar cell produces DC output voltage at the end. In wind power plants we convert wind energy into electric energy. For that we use wind turbines and then mechanical power generators for production of electricity. But there are some limitations with it that they are used at places where high speed of wind is present.

Thermal power plants are used to convert coal energy in electric energy. In this we burn the coal and generate steam from that and then that steam is used to rotate the turbine and that energy is converted into electric energy.

In nuclear power plant is we convert nuclear energy into electric energy. In these plants we generate heat to produce steam and then that steam is used to rotate the turbine system and then mechanical energy of turbine is converted into electric energy using generator.

In today's world most of the countries in the world have been affected by number of power failure, blackouts and faults. These are caused by lack of investment in protection equipment and controlling system infrastructure, improper maintenance and continuously increase in demand of electric power that overset the power transmission and distribution system limits. And due to these companies who invest in power system are suffering from losses of billions of dollars. To achieve batter reliability and for continuous operation of power system new technologies are used to prevent the blackouts. Today we are implementing state of then art technologies, to get the good controllability and high reliability we do the state estimation from measurements obtain from PMUs. It is used to get the high controllability, high reliability and for real time monitoring of power system and to satisfy the consumers also by providing good quality of power.

II. BASIC STRUCTURE OF PMU

PMU is a device which measure the real time voltage and current and voltage phasor of a network and state estimate the measurements to get all the required variables for controlling and monitoring purpose and frequency of a given node. Due to wide area of possible applications many PMUs have been installed. Today the rapidly evolving scenario of distribution grid where the increasing the presence of distribution generators asked for increasing measurement accuracy faster reporting rate and higher communication capabilities. PMU measure both the magnitude and the phasor of the waveform and give output which is used to find the unknown components used for controlling and monitoring purpose.

PMU consists of three basic units can be given a

i. Synchronization Unit with clock
ii. Measurement Unit which measure voltage and current waveforms
iii. Data Transmission Unit to transmit data

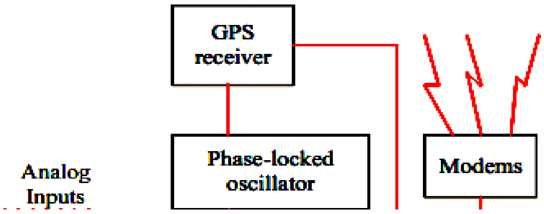

Fig. 1. Structure of PMU

III. INSTALLATION OF PMU

PMU installation is a part of wide area monitoring system network consisting of locating of PMUs throughout the electricity grid at strategic locations in order to cover the entire grid. A Phasor data concentrator at central location collects information from PMUs, and passes that to supervisory control and data acquisition system after time aligning the same. A complete WAMS network needs rapid data transfer within frequency of sampling of phasor data samples of phasor measurements at PMU are time stamped at each location. GPS installed at PMU location provide accurate time along with time synchronization among different PMUs. PMU components: The main components of a PMU are data acquisition module, communication module and GPS signal receiver.

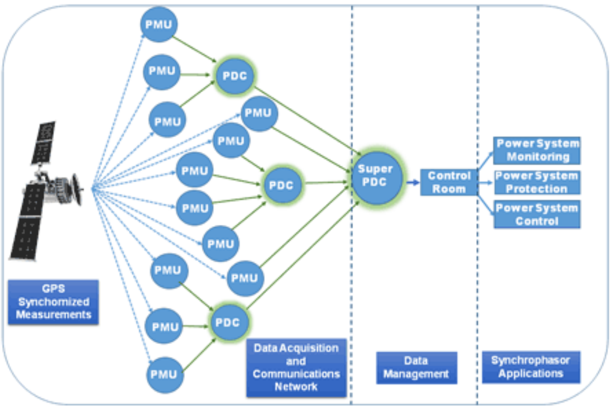

Fig. 2. Basic Structure of Wide-Area Monitoring System

The analog inputs to the device are currents and voltages obtained from the secondary windings of the current and voltage transformers located in a substation. All three phase currents and voltages are used so that positive-sequence measurement can be carried out. The current and voltage signals are converted to voltages with appropriate shunts or instrument transformers to match with the requirements of the analog to digital converters.

The sampling rate chosen for the sampling process dictates the frequency response of the anti-aliasing filters. Anti aliasing filters ensure that all the analog signals have the same phase shift and attenuation, thus assuring that the phase angle differences and relative magnitudes of the different signals are unchanged.

The GPS system is used in determining the coordinates of the receiver, although for the PMUs the signal, which is most important is the one pulse per-second. This pulse as received by any receiver on earth is coincident with all other received pulses to within 1 microsecond.

IV. PSAT MODEL OF A 2MW MICROGRID

PSAT is a MATLAB toolbox for electric power system analysis and control. The command line version of PSAT is also GNU Octave compatible. PSAT includes power flow, continuation power flow, optimal power flow, and small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides a user friendly tool for network design.

PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed. These routines are:

1. Continuation power flow;
2. Optimal power flow;
3. Small signal stability analysis;
4. Time domain simulations;
5. Phasor measurement unit (PMU) placement.

The test system in which the study is performed is shown in Fig. 3. The simulation studies here were carried out in the PSAT. The distributed generating sources are integrated in the bus 15 and bus 16 with the existing system. The power rates of the units forming the MG system have been selected as follows. PV had 1 MW and the wind model had 0.5 MW power rates.

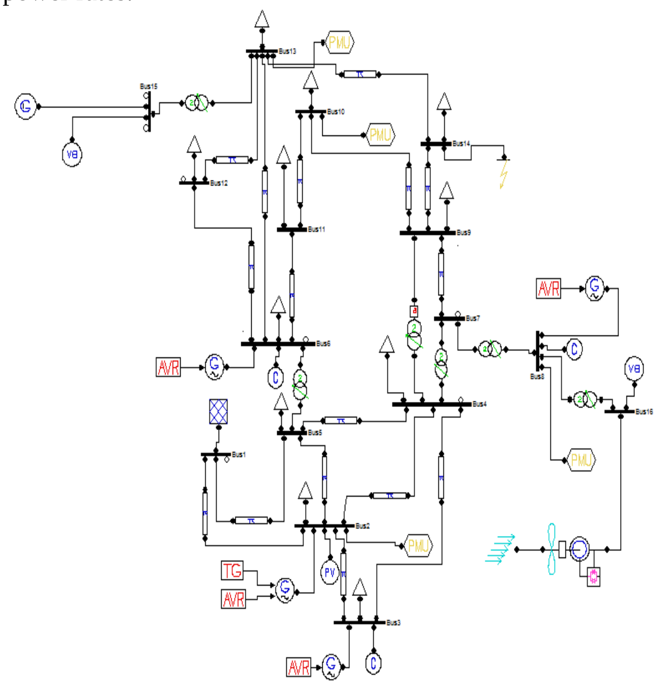

Fig. 3. PSAT model of a small (2MW) Microgrid

V. POWER FLOW RESULTS

TABLE I. POWER FLOW IN THE 2 MW MICROGRID

Bus	V	phase	P gen	Q gen	P load	Q load
	[kV]	[rad]	[MW]	[MVar]	[MW]	[MVar]
Bus1	0.429525	0	1.115354	-0.47202	0	0
Bus10	0.463606	-0.10841	-1.4E-13	6.78E-14	0.0615	0.0426
Bus11	0.456247	-0.09413	-8.3E-15	2.55E-14	0.0225	0.01171
Bus12	0.416237	-0.05752	7.05E-14	6.34E-14	0.0327	0.0139
Bus13	0.396572	-0.00073	-3.9E-14	2.71E-13	0.078	0.0428
Bus14	0.432601	-0.08291	-1.4E-13	3.35E-13	0.1073	0.04
Bus15	0.415	0	0.324357	-0.85276	0	0
Bus16	0.415	0	0.30404	-0.02923	0	0
Bus2	0.437825	-0.06291	0.12	0.399497	0.0502	0.0012
Bus3	0.42745	-0.12971	-3.4E-14	-0.18544	0.6579	0.143
Bus4	0.450316	-0.1107	-6.2E-13	-3.5E-13	0.3376	0.023
Bus5	0.423436	-0.07428	-1.4E-13	3.17E-13	0.0522	0.0012
Bus6	0.4482	-0.07424	6.9E-14	-1.01686	0.0844	0.053
Bus7	0.459013	-0.11047	1.7E-12	2E-12	0	0
Bus8	0.4399	-0.1102	3.39E-13	2.857135	0	0
Bus9	0.470346	-0.11109	6.43E-14	4.95E-12	0.2325	0.1167

TABLE II. TOTAL GENERATION, LOAD AND LOSSES IN THE 2 MW MICROGRID

TOTALGENERATION	
REAL POWER[MW]	1.863751
REACTIVE POWER [MVar]	0.700325
TOTAL LOAD	
REAL POWER[MW]	1.7168
REACTIVE POWER [MVar]	0.48911
TOTAL LOSSES	
REAL POWER[MW]	0.146951
REACTIVE POWER [MVar]	0.211215

VI. COMPARISON OF DIFFERENT TECHNIQUES FOR OPTIMAL PLACEMENT OF PMU

For optimal placement of PMU, there are several methods like Depth First, Graph theory, Simulated Annealing, Rec. (N-1) spanning Tree procedure (Kaur et al. 2016). Here all the methods of optimal placement of PMU are compared using the simulation of the model of a small (2 MW) Microgrid with the help of Power System Analysis Toolbox (PSAT) and the analysis of their merits and demerits are carried out. Different optimization techniques like Depth First, Graph theory, Simulated Annealing, Rec. (N1) spanning Tree and their algorithms of optimization are described in the paper (Manousakis et al. 2011; Sutar and Verma 2013). The optimal placement of PMU decreases the number of PMUs which reduces the cost and obtains better power network operation and monitoring (Venugopal et al. 2010; Sadeghi-Mobarakeh et al. 2018).

TABLE III. COMPARISON OF DIFFERENT TECHNIQUES FOR OPTIMAL PLACEMENT OF PMU

Method	Elapsed time	Number of PMUs	Placement
Depth First	0.075335s	7	1,4,6,8,10,14, 15
Graph theory	0.078537s	7	1,4,6,10,14 ,15,16
Simulated Annealing	0.67597s	4	2,8,10,13
Rec. (N-1)spanning Tree	0.17209s	8	1,3,4,6,8,10,13,14

It is seen that if we use simulated annealing method for optimal placement of phasor measurement unit then we required a minimum number of phasor measurement unit (Table III). So the cost will be reduced.

VII. CONCLUSIONS

PMU and their application have brought revolution in wide area monitoring system. Optimal placement of PMU is one step towards the concept of the smart grid. Practically, it is not possible to place PMU in all buses in a system, because PMUs are still expensive. Therefore, it is now very important to select the minimal number of PMUs and their locations for complete system observability. The optimal placement of PMU decreases the number of PMUs which results in the reduction of costs. Use of PMUs in the power system increases the reliability of the power system. It is, therefore, possible to fully monitor the system by using fewer numbers of PMUs than the total number of buses present in the system.

REFERENCES

[1] V. Terzija et al., “Wide-area monitoring, protection, and control of future electric power networks,” Proc. IEEE, vol. 99, no. 1, pp. 80–93, Jan. 2011.
[2] A. G. Phadke and J. S. Thorp, Synchronized Phasor Measurements and Their Applications. New York, NY, USA: Springer, 2008.
[3] K. G. Khajeh, E. Bashar, A. M. Rad, and G. B. Gharehpetian, “Integrated model considering effects of zero injection buses and conventional measurements on optimal PMU placement,”IEEE Trans. Smart Grid, vol. 8, no. 2, pp. 1006–1013, Mar. 2017.
[4] M. Esmaili, “Inclusive multi-objective PMU placement in power systems considering conventional measurements and contingencies,” Int. Trans. Elect. Energy Syst., vol. 26, no. 3, pp. 609–626, Mar. 2016.
[5] D. J. Brueni and L. S. Heath, “The PMU placement problem,” SIAM J. Discr. Math., vol. 19, no. 3, pp. 744–761, Dec. 2005.
[6] C. Rakpenthai, S. Premrudeepreechacharn, S. Uatrongjit, and N. R. Watson, “An optimal PMU placement method against measurement loss and branch outage,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 101–107, Jan. 2007.
[7] N. M. Manousakis and G. N. Korres, “Optimal PMU placement for numerical observability considering fixed channel capacity—Semidefinite programming approach,” IEEE Trans. Power Syst., vol. 31, no. 4, pp. 3328–3329, Jul. 2016.
[8] M. H. F. Wen, X. Jin, and V. O. K. Li, “Optimal multistage PMU placement for wide-area monitoring,” IEEE Trans. Power Syst., vol. 28, no. 4, pp. 4134–4143, Nov. 2013.
[9] J. Xu, M. H. F. Wen, V. O. K. Li, and K.-C. Leung, “Optimal PMU placement for wide-area monitoring using chemical reaction optimization,” in Proc. IEEE ISGT, Washington, DC, USA, Feb. 2013, pp. 1–6.
[10] C. X. Zhang, Y. W. Jia, and Z. Xu, “Optimal PMU placement for voltage control,” in Proc. IEEE SmartGridComm, Dec. 2016, pp. 747–751.
[11] J. Gao, Y. Xiao, J. Liu, W. Liang, and C. L. P. Chen, “A survey of communication/networking in smart grids,” Future Gener. Comput. Syst., vol. 28, no. 2, pp. 391–404, Feb. 2012.
[12] N. E. Wu and M. Ruschmann, “Toward a highly available modern grid,” in Chapter 10 of Control and Optimization Theories for Electric Smart Grids, A. Chakrabortty and M. Ilic, Eds. New York, NY, USA: Springer, 2011.