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Optimal Placement and Cost Analysis of PMU for Power System State Estimation

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Abstract— The integration of Phasor Measurement Unit (PMU) in power grids can greatly enhance the robustness and reliability of the system. As PMUs are costliear, these cannot be installed at all the buses in a system. Therefore one of the critical problems faced now a days, is the placement of PMU and to find out on which particular bus the PMU has to be placed. The main objective of this paper is to increase the efficiency and observability of the system. In this paper two systems are considered IEEE 14-bus and IEEE 30-bus system and the State Estimation with the insertion of PMU on both the systems are performed using MATLAB 2014 platform. Once the state of the system is obtained , the placement of PMU is done using Genetic Algorithm by taking care of zero-injection buses and radial buses. Simulation results show that proposed algorithm can achieve globally optimum performance, increases the system stability and robustness by reducing the computation time .

Index Terms— State Estimation , Phasor Measurement Unit (PMU), Zero-injection bus(ZIB) , MATLAB 2014, IEEE 14-bus , IEEE 30 –bus.

1 INTRODUCTION

Power systems need to be operated efficiently and economically in a strong competitive environment due to the deregulation of power industry. In order to achieve these objectives it is necessary to monitor the state of the power system as the status of the system won't remain same all the time. In modern control centres, State Estimation is used to obtain the present state of the system. The Remote terminal unit(RTU) provides measurements to substations which has real/reactive power flows, power injections, and magnitudes of bus voltages and branch currents. State estimators are widely used in almost every power system control centre. Whenever the upgradation of old state estimator or new state estimator is put in the service, care need to be taken of its technology associated such that it can make power system not only observable but also remain observable during major contingencies. To get the best location of measurements for state estimation is referred as the optimal placement problem. Making use of PMU for the observability of the system seems attractive but because of it's cost we cannot place it every where as per the requirements,thus care need to be taken such that we can reduce the placement of PMUs by making use of some efficient algorithms. Thus with the reduction of PMUs, the system becomes observable ,reliable and cost effective. Optimal placement of PMU results in measurement redundancy, bad data and topology error processing functions.

In recent decades the Phasor Measurement Unit(PMU) has the capacity of online monitoring and controlling the power system network. PMUs are used to upgrade the traditional grid into smart grid. These PMUs are installed at various buses which provides real time phasor measurement data. These data are gathered by the device called phasor data concentrator which synchronizes the measurement taken at every time instant independent of when the data was received. Then these time synchronized datas are fed to the advanced application software for the analysis of power system.

In this paper, we propose to develop a Genetic Algorithm which aims at the optimal placement of PMU which increases the accuracy of power state estimation. It is done based on mean squared error(MSE) by using weighted least square method(WLS). This is quite different approach from the traditional ones. In addition to the placement of PMUs using Genetic Algorithm (GA), the state estimation is estimated by inserting PMU based on mean squared error(MSE). Here in this, Genetic Algorithm make use of Best Fitness Value and based on the fitness function the allocation of PMU is done by taking care of Zero Injection Buses and Radial Buses. Simulations results show that the performance of the algorithm is very much significant and efficient when compared to traditional methods.

This paper is divided into seven sections. The State Estimation is performed with the insertion of PMU in section 2. Section 3 provides the detailed overview of Genetic Algorithm. The placement of PMU using Genetic Algorithm is explained in section 4. The cost function formulation is explained in section 5. Section 6 has the simulation results and section 7 contains the conclusion of the work.

2 STATE ESTIMATION WITH PMU

Power system State Estimation is a process whereby telemetered data from network measuring points to a central computer, can be formed into a set of reliable data for control and recording purposes. Different methods are used for State Estimation. In this we will be using weighted least square

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method(WLS) to estimate the state of the system. With the help of WLS method, the Mean Squared Error(MSE) is obtained and based on MSE the results are obtained and the graphs are plotted.

State Estimation with the insertion of Phasor Measurement Unit increases the efficiency of the system by reducing the errors. PMU convert the system's critical measurements into redundant ones, thus to render it fully observable. The critical measurements, as opposed to the redundant measurements, are those measurements whose removal in the system results in the system being unobservable and an erroneous critical measurement cannot be detected by the statistical tests based on measurement residual unless it is converted into a redundant measurement .

<u>Algorithm of PMU</u>

1. Initialise the function E3
2. Assign the values of magnitude ,angle, length.
3. Call the Index of voltage and current measurement.
4. Form Measurement vector.
5. Form new Jacobian matrix.
6. Finding out the rotation matrix by obtaining voltage and current phasors.
7. Findout W2 matrix.
8. Findout W matrix i,e W=diag[W1 ,W2] ^{T}
9. Findout new covariance matrix R.
10. State vector using rectangular and polar coordinates are obtained.
11. Bus voltages and Angles using PMU is obtained.
12. Display function is called.

1. END

3 OVERVIEW: GENETIC ALGORITHM

Genetic Algorithm is one which generates solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection and crossover. An initial population of individuals (also called "chromosomes") is generated randomly or heuristically. During each iteration step, also called "generation", the individuals of the current population are evaluated and assigned a certain fitness value. In order to form a new population, individuals are first selected, and then produce offspring candidates which, in turn, form the next generation of parents. This ensures that an 'individual' is chosen the expected number of times and is approximately proportional to its relative performance in population. For producing new solution candidates, genetic algorithms use two operators, namely crossover and mutation. Crossover is the primary genetic operator. It takes two individuals, called parents, and produces one or two new individuals, called offspring, by combining parts of the parents. In its simplest form, the operator works by swapping (exchanging) substrings before and after a randomly selected crossover point. The second genetic operator, mutation, is essentially an arbitrary modification which helps to prevent premature convergence by randomly sampling new points in the search space. In the case of bit strings, mutation is applied by simply flipping bits randomly in a string with a certain probability called 'mutation rate'.

Genetic Algorithm to determine the optimum number of phasor measurement units in a power system network. The rules of observability analysis and the fitness function based on the parameters NH (the number of the buses that are not observables) and NPMU (the number of PMUs in the network);

The best results were obtained using a=1, b=2 and c=1.

f = aNPMU + bNH + cNPMUNH where a, b and c are constants

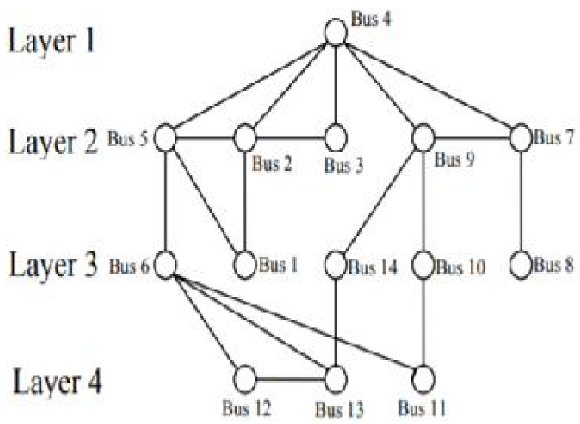
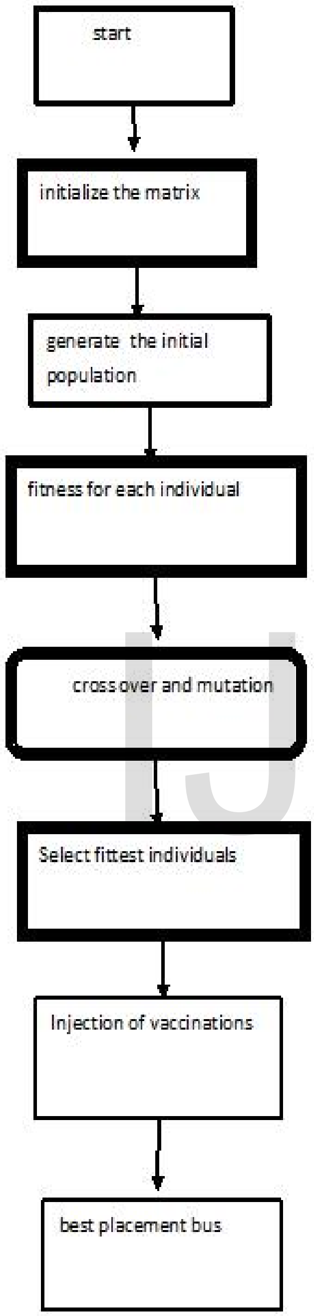


Figure IEEE 14 Bus System

Flow Chart for Genetic Algorithm



4. PLACEMENT OF PMU USING GENETIC ALGORITHM

The placement of PMU is done using Genetic Algorithm(GA). The objective of the algorithm is to findout minimum number of PMU placement at different buses. The second objective is to find the power flow through the system and PMUs are used to monitor it at different buses. This is done by finding the number of zero injection buses (ZIB), generator and load buses. The placement of PMU is done on the buses which has most of its branches as unobservable i,e the bus whose in-degree is maximum by excluding zero injection buses, generator buses and load buses.

Along with the placement of PMU, we are going to findout the Best Fitness Value f(x), Mean Fitness Value, Power Generation of Generator(Pgg), Time elapsed for the placement of PMU and also the cost function associated with it. In addition to that the condition is checked i,e whether the voltage magnitude is within the safe range or not. As PMU will be operating at safe range otherwise not.

<u>Algorithm for the placement of PMU</u>

1. Start
2. Placement of PMU is done on the buses which makes most of the branches observable.
3. Formation of admittance matrix 'A' of order [14*14] .
4. Observability equation f(x)= (A . X) is obtained from the admittance matrix.
5. The condition is checked, whether the system is completely observable or not.
6. If condition is satisfied , it stops else cursor moves to second step and the process repeats.

5. COST FUNCTION FORMULATION

The main aim is to make the entire system observable with the appropriate placement of PMU. As PMUs are not cost effective ,we cannot place them at all the buses. Thus optimal placement of the PMU in a particular system is very much needed. The minimization function can be given as $\sum WiXi$ subject f(x) ≥ 1 where W is the cost of PMU at bus i. f(x) = Non zero; if the bus voltage is within safe limit, otherwise it is zero.

Xi=1 (PMU installed at bus i)

Xi=0 (PMU not installed at bus i)

6. SIMULATION RESULTS

In this section, we present the simulation results by using two IEEE bus configurations. The simulations are performed by using MATLAB 2014 software. In the simulation we have considered the standard IEEE-14 bus and IEEE-30 bus data and performed the load flow analysis and state estimation.

Fig 1 represents the State Estimation with PMU i,e voltage and angle values when PMUs are inserted into the system. Fig 2 represents the graphs of Voltage Angle and Voltage Magnitude Error with the insertion of PMU at IEEE 14-bus system. Fig 3 provides the graphs of voltage angle error and voltage magnitude error with PMU for IEEE-30 bus system. Fig 4 gives the Fitness Function obtained from Genetic Algorithm. Fig 5 provides the Best Fitness Value and Power Generation of Generator. Fig 6 gives the placement of PMU at various buses and the number of zero injection buses present in a system. Fig 7 represents the graph of Best Fitness Value and Current Best Individual obtained from Genetic Algorithm. From all the figures we can visualize that the traditional methods make use of more number of PMUs which increases the cost of the system. But by making use of Genetic Algorithm we can reduce the number of PMUs, thus making the system cheap and affordable.

State Estimation with PMUs

Bus No	V pu	Angle Degree
1	1.0584	0.0000
2	1.0451	-5.0258
3	1.0046	-12.7546
4	1.0083	-10.2142
5	1.0118	-8.7264
6	1.0700	-14.4443
7	1.0457	-13.2372
8	1.0800	-13.2371
9	1.0305	-14.8206
10	1.0299	-15.0364
11	1.0461	-14.8553
12	1.0533	-15.2946

Fig. 1. The state estimation of IEEE-14 bus system using PMU

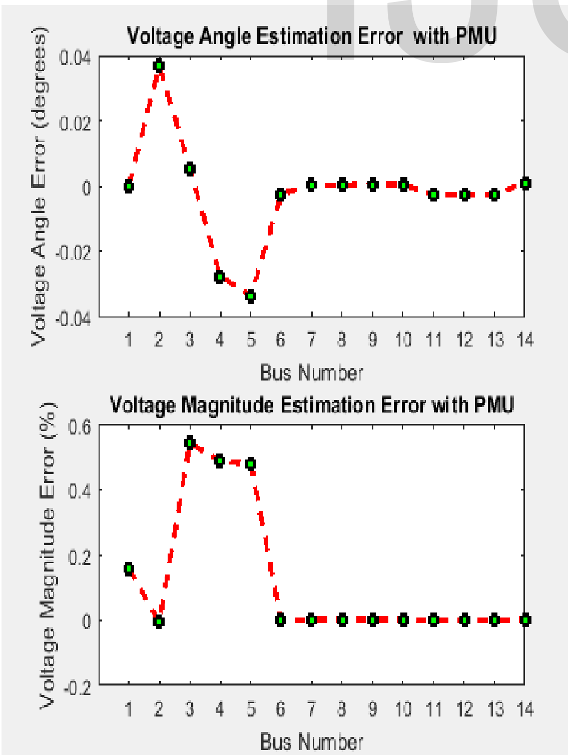


Fig. 2. The voltage angle error and voltage magnitude error with PMU for IEEE-14 bus system

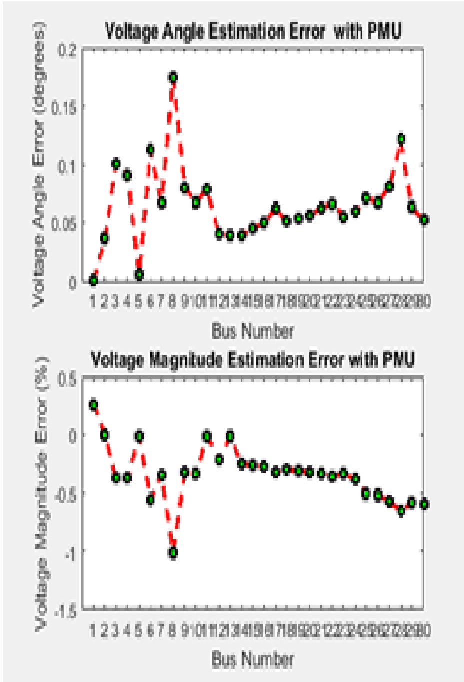


Fig. 3. The voltage angle error and voltage magnitude error with PMU or IEEE-30 bus system

Command Window | Workspace

Generation	f-count	Best f(x)	Mean f(x)
1	100	3191	8.299e+04
2	150	915.5	1.929e+05
3	200	891.5	1.642e+05
4	250	891.5	3.105e+05
5	300	891.5	7.74e+04
6	350	883.5	1.043e+05
7	400	883.5	7.417e+04
8	450	876.6	3.298e+04
9	500	876.6	7.205e+04
10	550	876.6	6.706e+04
11	600	876.6	8.467e+04
12	650	876.6	9.283e+04
13	700	876.6	6.299e+04

fx Optimization terminated: time limit exceeded.

Fig. 4. Fitness Function obtained from Genetic Algorithm

```
F =

   876.5991


Pgg =

   125.6911    80.0000    48.0509    24.3122     6.3456     5.6210
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Fig .5. Best Fitness Value and Power Generation of Generator

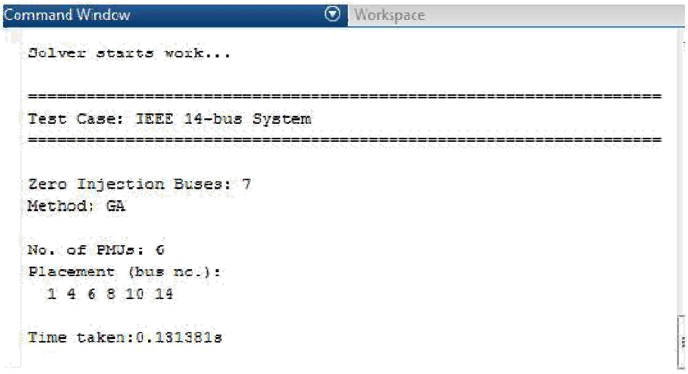

Fig.6. Placement of PMU at various buses & No of Zero Injection Buses.

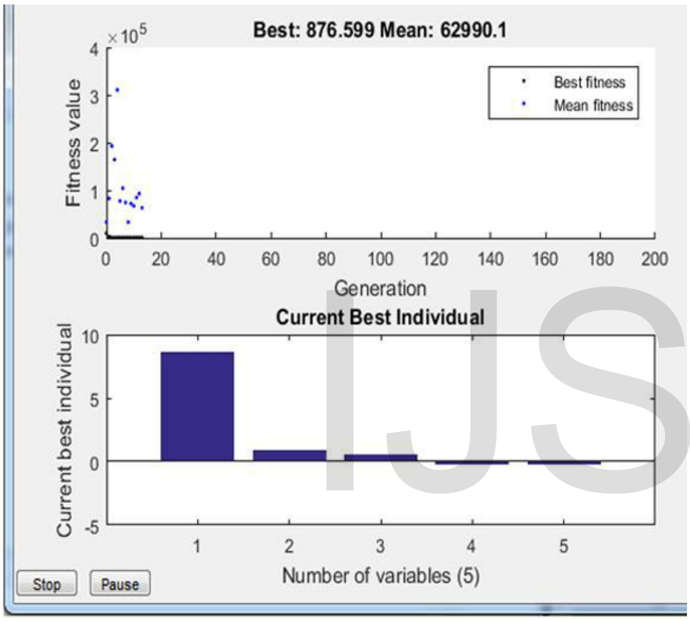

Fig .7. Graph represents Best Fitness Value and Current Best Individual

The average overall cost per PMU (cost for procurement , installation and commissioning) ranged from $40,000 to $180,000. For our calculation lets consider $40,000 as the cost per PMU and based on this assumption, the cost associated with traditional method and Genetic Algorithm is obtained and compared as shown below in Table 1. With the observations made in the below table, we can say that the cost of installation is very much high in traditional method as it make use of more number of PMUs for making the system observable whereas the cost associated with Genetic Algorithm is quite less , thus making the system observable , affordable and cheaper.

TABLE 1
COMPARISION OF COST ASSOCIATED FOR THE INSTALLATION OF PMU WITH TRADITIONAL METHOD AND WITH GENETIC ALGORITHM

Criteria	Cost associated with Traditional Method	Cost associated with Genetic Algorithm
14 Bus system	560,000 $	240,000 $
30 Bus system	1,200,000 $	400,000 $

The PMU placed for different bus systems using Genetic Algorithm is as shown in the below Table 2. The Table shows the no. of PMUs to be used in a system, with their locations and also the time elapsed for the placement of PMUs i,e for IEEE 14-Bus and IEEE 30-Bus system.

TABLE 2
PMU PLACEMENT FOR DIFFERENT BUS SYSTEMS

Test Systems	No. of PMUs	Location of PMUs	Elapsed time
14 Bus	6	1,4,6,8,10,14	0.131381 s
30 Bus	10	1,5,6,10,11,12,18, 24,26,27	0.318318 s

CONCLUSION

A methodology to determine minimum number of PMUs to be used in a system, such that system can be made observable, affordable and cheaper. This is done with the help of Genetic Algorithm which is implemented on IEEE-14 Bus and IEEE-30 Bus system. The main aim of this paper is propose optimal solution for the placement of PMU and to compare the obtained results with traditional method and the proposed one. The test results suggest that traditional method is very much costliear when compared to proposed one. It provides comparision between the two systems and also useful for the researchers working in the optimal placement of measurement devices in power systems

REFERENCES

[1] M. K. H. Pulok, M. O. Faruque, "Real-time dynamic state estimation using synchrophasor data,"*North American Power Symposium*, pp. 1-6, 2015.

[2] M. Pignati, M. Popovic, S. Barreto, R. Cherkaoui, G. D. Flores, J. L. Boudec, M. Mohiuddin, M. Paolone, P. Romano, S. Sarri, T. Tesfay, Tomozei, L. Zanni, "Real-time state estimation of the EPFL-campus medium-voltage grid by using PMUs, "*Innovative Smart Grid Technolo- gies Conference, IEEE Power and Energy Society*, pp. 1-5, 2015.

[3] H. Mosbah, M. El-Howary, "Multilayer artificial neural networks for real time power system state estimation, "*Electrical Power and Energy Conference*, pp. 344-351, 2015.

[4] F. C. Schweppe, J. Wildes, "Power system static-state estimation, part I: exact model," *Transactions on Power Apparatus and Systems*, vol. Pas-89, pp. 120-125, 1970.

[5] F. C. Schweppe, D. B. Rom, "Power system static-state estimation, part II: approximate model," *Transactions on Power Apparatus and Systems*, vol. Pas-89, p.p 125-130, 1970

[6] J. Chen and A. Abur, "Placement of pmus to enable bad data detection in state estimation," *IEEE Trans. on Power Systems*, vol. 21, no. 4, pp. 1608–1615, Nov 2006.

[7] Q. Li, T. Cui, Y. Weng, R. Negi, F. Franchetti, and M. D. Ilic, "An information-theoretic approach to pmu placement in electric power sys- tems," *IEEE Trans. on Smart Grid*, vol. 4, no. 1, pp. 446–456, March 2013.

[8] Q. Li, R. Negi, and M. D. Ilic, "Phasor measurement units placement for power system state estimation: A greedy approach," in *IEEE Power and Energy Society General Meeting*, July 2011, pp. 1–8.

[9] O. Kosut, L. Jia, R. J. Thomas, and L. Tong, "Malicious data attacks on the smart grid," *IEEE Trans. on Smart Grid*, vol. 2, no. 4, pp. 645–658, Dec 2011.

[10] A. G. Phadke, J. S. Thorp, R. F. Nuqui, and M. Zhou, "Recent develop- ments in state estimation with phasor measurements," in *IEEE Power and Energy Society Power Systems Conf. Expo.*, March 2009, pp. 1–7.

[11] B. Xu and A. Abur, "Observability analysis and measurement placement for systems with pmus," in *IEEE Power and Energy Society Power Systems Conf. Expo.*, Oct 2004, pp. 943–946 vol.2.

[12] A. S. Costa, T. Piazza, and A. Mandel, "Qualitative methods to solve qualitative problems in power system state estimation," *IEEE Trans. on Power Systems*, vol. 5, no. 3, pp. 941–949, 1990.