J. Appl. Environ. Biol. Sci., 4(12S)92-97, 2015

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Optimal Placement of Phasor Measurement Units for Full Observability of the Power System Using Hybrid Genetic Algorithm and Minimum Spanning Tree

Danial Hami, Mohammad Zohour Attar

Department of Electrical Engineering, Gazvin Branch, Islamic Azad University, Gazvin, Iran, danialhami@gmail.com
Department of Electrical Engineering, Shoush Branch, Islamic Azad University, Shoush, Iran

Received: November 21, 2014
Accepted: January 25, 2015

ABSTRACT

An improved genetic algorithm named MST-GA is proposed to minimize amount of PMUs for fully observing huge scale power grid. It adopts minimum spanning tree algorithm to repair unfeasible solutions, and makes use of the topology of power grid in the process of mutation. The simulation results of IEEE30 and IEEE39-bus system show that the algorithm can balance the quality and diversity of solutions better than others.

KEYWORDS- minimum spanning tree algorithm; genetic algorithm; optimal placement, observability; PMU.

I. INTRODUCTION

In addition to SCADA system, recently is raised another system with called the Wide Area Monitoring System (WAMS). The main idea WAMS is centralized processing of data that are collected from the different parts of the system simultaneously and synchronized with each other. The concept that offers to WAMS for power system is very close to the actual conditions of the system. The reason for this can be simply expressed as that due to constant changes in the frequency of power system and its impact on the calculation of angles, buses angles are comparable to each other only when the exactly related to the identical of a moment. Which this is possible in WAMS to using the phasor measurement units (PMU)[1].

Nowadays with the introduction of smart grid technology, power grid has changed from a static infrastructure to a flexible and dynamic infrastructure. Therefore it is important to accurately estimate the state of the network and thus ensure sustainable performance of the network. PMU as one of the main components of the smart grid transformation, are the fundamental solutions for the real time monitoring power grids [2,3]. PMU is able to measure phasor voltage and current with high accuracy and speed [5,6,7] and by conversion of non-linear state estimation equations to linear equations there is no and need for sophisticated computational methods for solve them[6,7], which improves the speed control systems, safety and management systems, that use the results of state estimation[5].

CAI and AI [8] presented a MST algorithm to solve the problem. It gives a new rule of optimization based on depth-first search (DFS) to improve the algorithm. Liu Jie [9] proposed an improved adaptive genetic algorithm to find optimal placement of PMUs full observability of power grid and maximum measurement redundancy. LI and TENG [10] used genetic algorithm to study optimal PMU placement problem (OPP) and their innovative point is the pretreatment which greatly reduced the length of coding. Hybrid optimization strategy is selected to solve the same problem [11].For instance, the approach in [12] combined genetic algorithm with tabu search algorithm.

There are two differences in this paper. The first one is proposing a hybrid approach named MST-GA which combines minimum spanning tree (MST) algorithm with genetic algorithm for minimizing the number of PMUs. The second one is improving the mutation which considers topological information of grid. Experimental results based on IEEE30 and IEEE39-bus system show that the variety and quality of solutions given by MST-GA are better than the regular algorithms such as MST, simulated annealing algorithm (SA), DFS, etc.

DESIGN AND IMPLEMENTATION OF ALGORITHM

1. Observability rules

We use the well-known rules to judge the topological observability of a given grid:

Corresponding Author: Danial Hami, Department of Electrical Engineering, Gazvin Branch, Islamic Azad University, Gazvin, Iran. danialhami@gmail.com

- If a PMU is installed in bus, voltage phasor of that bus and currents phasors of all incident branches to that bus are known. These are called as direct measurements.
- If voltage phasors of both ends of a branch are known then the current phasor of this branch can be obtained directly. These are called pseudo measurements.
- If there is a bus whose all incident branches current phasors are known but one, then the current phasor of the unknown one can be obtained using KCL equations [13-17]

2. Placement the Phasor Measurement units

Since the PMU installed at a bus can be possible the indirect visibility bus of adjacent to himself, it can be reduce the number of PMU installed on the network.
Optimum placement of PMUs for n bus system is formulated with relations (1) [3,4,9]:

$$\text{Min} \sum_{i=1}^{n} x_i$$

$$s.t \quad y = Ax \geq b \tag{1}$$

That in this connection A shows how to connect to other busses and transmission lines such as equation (2), also the PMU installed at bus i in the x_i variable is expressed in equation (3) is a binary variable associated with i bus[3,4,9]:

$$A_{n\times n}(i,j) = \begin{cases} 1 & i = j \\ 1 & \text{if buses i and j are connected} \\ 1 & \text{otherwise} \end{cases} \tag{2}$$

$$x_i = \begin{cases} 1 \text{ if PMU is installeat bus i} \\ 0 \text{ otherwise} \end{cases} \tag{3}$$

Since the minimum number of PMU should be enough for at least one time every bus is observable, the matrix b is shown in equation (4) [3,4,9]:

$$b_{n\times 1} = [1\ 1\ 1 \ldots 11]^T \tag{4}$$

3. Design of GA

(1) Chromosome encoding

The importance of all nodes should be analyzed before encoding. The set of selected nodes will be encoded by binary coding. If the value of one node is 1, it means that a PMU has been put on it. And if the value is 0, there is no PMU put on this node.

(2) Fitness function

The value of fitness is used to be positive number. And the bigger value means the better fitness. Therefore, the fitness function in this paper is as follow:

$$f = C - \text{sum PMU} \tag{5}$$

Where C is the sum of buses in the power grid, and sum PMU is the number of PMUs installed in buses under the case of full observability.

(3) Selection operation

This paper selects roulette wheel selection as selection operation. And the best individual must be inherited to the next generation. The strategy of keeping best is to identify whether the elite individual in population is better than previous generation. Replace the best individual with the elite individual in this generation if the answer is yes. Else, keep the best individual and replace the worst individual with the best individual.

(4) Crossover operation

The operation of crossover is the main way to generate new individuals. This paper selects single-point crossover. Firstly, algorithm will select two individuals randomly to crossover according to crossover probability. Secondly, algorithm will select the single-point for crossover. After that two new individuals generate.

(5) Mutation operation

The operation of mutation is the side way to generate new individuals. Basic allelic mutation is often selected in genetic algorithm. That is, every location in binary string will be judged whether to be mutated. When the random number is smaller than mutation probability, the value in this location should be changed. If the value is 0, then it will be changed to 1 and vice versa.

The method of mutation presented by this paper takes topology of power grid into consideration. Firstly, select a node randomly from the set of nodes where PMUs have been installed. Secondly, remove the PMU in the selected node. Then, find all nodes connecting to this selected node and remove nodes where PMUs can't be installed. At last, select randomly in rest nodes of the previous step to install a PMU in it. The mutation operation will make sure the observability of individuals in a large extent.

As the figure 1(a) shows, PMUs have been installed in bus 1, 4and 6. Supposing the bus 6 is selected to be mutated, we can do this by moving the PMU to the bus 3 and 7 randomly because the buses 3, 7 and 8 are connected to it and the bus 8 is incompletely built. The figure 1(c) shows the result of moving the PMU on the bus 6 to the bus 3.

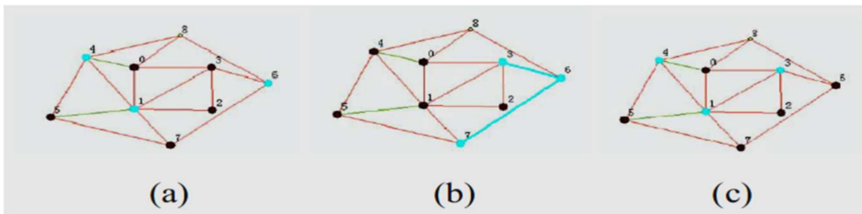

Figure.1 Test Data

4. Repairing unfeasible solutions

The set of PMU locations which could not make the entire grid observable is unfeasible solution. The method to repair unfeasible is selecting suitable buses and putting PMUs on them until the power grid is completely observable. A MST algorithm is used to repair unfeasible in this paper. It finds the bus which can make the recent PMU placement monitor the most branches and put a PMU on this bus. Similarly, cycle this process until the power system is observable. The flow chart [23,24] is shown in figure 2.

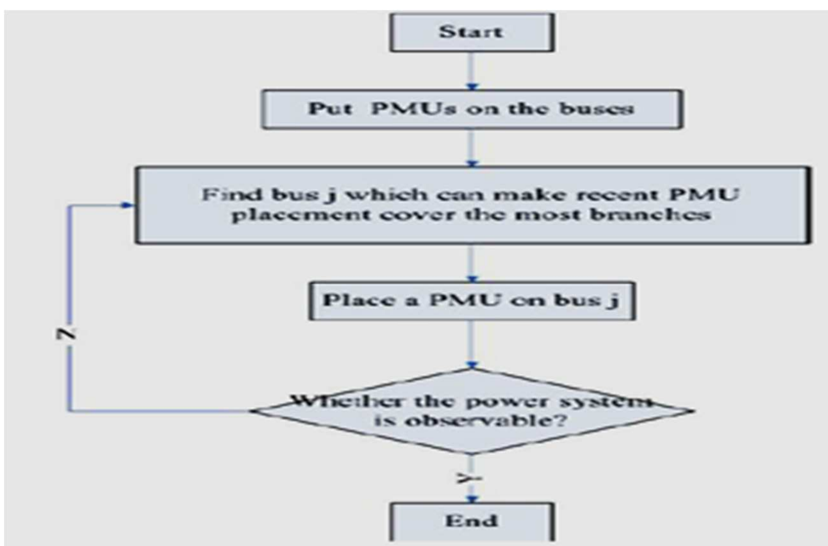

Figure.2 Flowchart of MST

III. CASE STUDIES AND SIMULATION RESULTS

To make the details clear, The IEEE 30 and 39-bus systems are used for simulation purposes, then compare the simulation results to the reference.

A. Case 1

IEEE30-bus system is shown in Figure 3. When using the algorithm of MST-GA, the best solution contains 6 PMUs. Table1gives the simulation results:

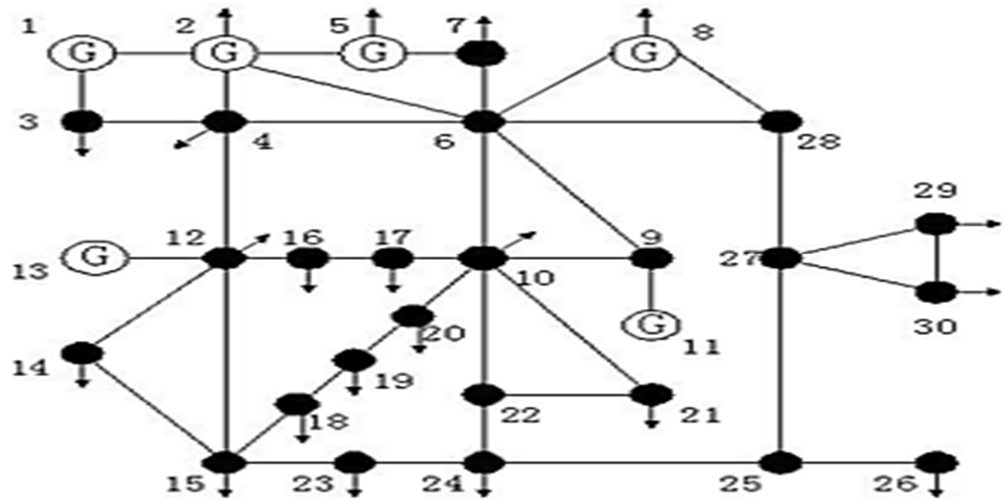

Figure 3 IEEE30-bus systems

TABLE1. SIMULATION RESULTS OF IEEE30-BUS SYSTEMS

Solution	No. of PMU	Location of PMUs
1	6	2,10,12,15,18,27
2	6	2,10,12,15,20,27
3	6	2,10,12,19,24,27
4	6	2,10,12,18,23,26
5	6	2,10,12,18,24,30
6	6	2,10,12,18,24,30

Table (2) shows the optimal location of PMUs using DFS, SA, MTS and MST-GA algorithm proposed in this paper:

TABLE2. COMPARATIVE ANALYSIS RESULTING FROM MST-GA AND OTHER OPTIMIZATION ALGORITHM

Algorithm	Number of PMU	Number of solutions	Location of PMUs
DFS	2	1	3,5,6,11,12,17,18,20,21,24,26,27
SA	7	1	2,4,10,12,19,24,27
MTS	7	9	–
MTS-GA	6	6	–

Table 3 shows the optimal location of PMUs using MTS algorithm. This case shows that MST-GA algorithm not only provides fewer PMUs but also diverse solutions. From table 3, the fewest number of PMU is 7 while the number of solutions is 9 when using MST algorithm. When it comes to MST-GA algorithm, though the number of solutions is 6 the number of PMUs is 6. MST-GA algorithm can get fewer PMUs than MST algorithm.

TABLE3. PMU LOCATION OF MST ALGORITHM

Solution	Location of PMUs
1	1,7,10,12,19,23,27
2	1,5,10,12,19,23,27
3	1,5,10,12,19,23,27
4	1,5,10,12,19,24,29
5	1,5,10,12,15,20,27
6	1,2,10,12,19,23,27
7	1,5,10,12,18,23,27
8	1,5,10,12,15,19,27
9	1,5,10,12,19,23,27

B. Case 2
IEEE39-bus system is shown in Figure 4, when using MST-GA, the best solution contains 9 PMUs. Table4 gives the simulation results:

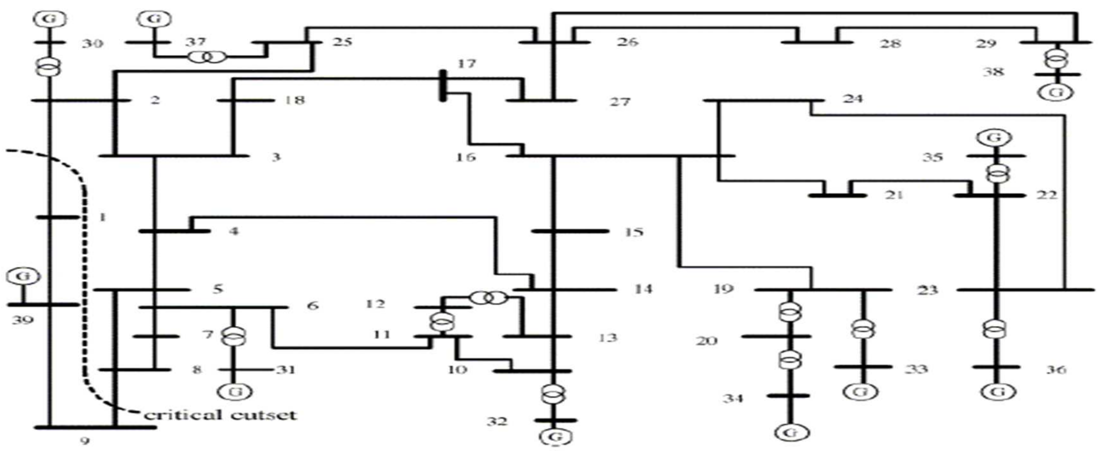

Figure 4. IEEE39-bus system

TABLE4. SIMULATION RESULTS OF IEEE39-BUS SYSTEMS

Solution	No. of PMU	Location of PMUs
1	9	1,8,13,16,20,23,25,26,29
2	9	2,8,13,16,18,20,23,25,29
3	9	1,8,13,16,20,23,25,27,29
4	9	1,8,13,16,18,20,23,25,29
5	9	6,13,20,21,23,25,27,29,39
6	9	2,8,13,20,21,23,25,27,29
7	9	1,3,8,13,20,21,23,25,29

Table5 shows the simulation results of DFS ,SA,MST and MST-GA algorithm:

TABLE5. COMPARATIVE ANALYSIS RESULTING FROM MST-GA AND OTHER OPTIMIZATION ALGORITHM

Algorithm	Number of solution	No. of PMUs	Location of PMUs
DFS	16	1	2,6,8,10,12,14,16,18,20,23,26,30,32,34,36,39
SA	9	1	2,3,8,12,16,20,23,25,29
MTS	9	2	1,3,8,10,16,20,23,25,29
			2,3,8,10,16,20,23,25,29
MST-GA	9	8	-

In this case, though the number of solutions obtained by MST-GA algorithm is not smaller than other algorithms, it has a great advantage in the diversity of the solution. The OPP problem is formulated to minimize the number of PMUs installation subject to full grid observability and to maximize the redundancy at the power system buses. It means that we should make sure full observability when changes happened in power grid. MST-GA algorithm proposed in this paper makes contribution to solving the problem.

CONCLUSION

This paper proposes a new genetic algorithm. It breaks through common improvements. This new algorithm adopts MST algorithm to repair unfeasible solutions and well balances between efficiency of reparation and quality of solutions. The new algorithm take topology of power grid into consideration which is ignored by others. So observability of individuals will be kept as much as possible after mutation, which reduces time spent on repairing unfeasible solutions.

Simulation results of IEEE30 and IEEE39-bus system show that the proposed algorithm provide a variety of minimal set of PMUs under the case of full observability and can be used in practice.

REFERENCES

[1] Phadke, A. G., Thorp, J. S.," Synchronized Phasor Measurements and Their Applications". New York: Springer, 2008.

[2] Amiri, S., Zahedi, h., optimal placement of phasor measuring unit using ICA algorithm for observability of system" , EPDC, 17th, Tehran, Iran, 2012 (in Persian)

[3] NIST, "NIST Framework and Roadmap for Smart Grid Inoperability Standards", Release 1.0, NIST Special Publication 118, US Department 2010.

[4] Anjio, M., Jiaxi, Y., Zhizhong, G, "PMU placement and data processing in WAMS that complements SCADA", IEEE In Power Meeting, Vol. 1,12-16, pp. 780-783, June 2005 .

[5] Mortezavi, S. S.,Heidari, M., Mirabbasi, D., " GA and BIP based Optimal Allocation of Phasor Measurement Units (PMUs) for Khouzestan Transmission Network compete observability ,Considering Ddouble Redundancy for Sensitive Substations", International Conference ,10, Istanbul,Turkiy,4-7, Sep 2011.

[6] Wang, B., Liu, D., Xiong, L., "An improved ant colony system in optimizing power system PMU placement problem", Asia-Pacific Power and Engineering Conference, pp 1_3, 2009

[7] Dongjie, X., Renmu, A., Peng, W., Tao, X., "Comparison of several PMU placement algorithms for state estimation", Developments in Power System Protection. Vol.1.2004, pp. 3 - 35 April 2004.

[8] CAI Tian, Ai Qian. "Research on optimal PMU placement in power systems [J]". Power system technology, 2006, 30(13)： 32-37

[9] Liu Jie. "Optimal Location of Phasor Measurement Unit for Complete Observability Based on Improved Adaptive Genetic Algorithms [J]". GUANGDONG Electric Power, 2008, 21 (12):13-18.

[10] Li Xinzhen, Teng Huan. "Improved Adaptive Genetic Algorithm on Minimizing PMU Placement [J]". The 24th Annual Conference Proceedings of Power System and Automation in Chinese Colleges, 1238-1243.

[11] WANG L. "Aplication of intellectual optiimizate algorithm [M]". Beijing: Tsinghua University Press, 2001:36-50. (in Chinese)

[12] Yu Bo, Peng Lin, Sun Guanglei. "Optimum Distribution of PMU Based on Improving Heredity-Taboo [J]". Taiyuan Science and Technology, 2012, 217 (2): 100-104.

[13] Jia Hongjie, Lv Yinghui, Zeng Ruan. "Optimal PMU Placement in Power System [J]". JOURNAL OF ELECTRIC POWER SCIENCE AND TECHNOLOGY, 2010, 25 (1):54-61.

[14] T.L.Baldwin, L.Mili, M.B.Boisen, R.Adapa. "Power system observability with minimal phasor measurement placement [J]". IEEE Trans. Power Syst, 1993, 8(2): 707-715.

[15] Yu Er-keng. "Power system state estimation [M]". Beijing: Hydraulic and Electric Power Press, 1985.

[16] Ahmadi, A., Alinejad-Beromi, Y., Moradi, M., "Optimal PMU Placement for Power System Observability Using Binary Particle Swarm Optimization and Considering Measurement Redundancy, Expert Systems with Applications", doi: 10.1016/j. eswa. 2010. 12.025

[17] Tian Wei, Wang Hongxi, Sun Tiejun. "PMU optimization configuration based on improved genetic simulated annealing algorithm [J]". EAST CHINA ELECTRIC POWER, 2007, 35 (11): 78-81.

[18] Abbasy, N ., Ismail, H., "A unified approach for the optimal PMU location for power system state estimation", IEEE Transactions on Power Systems, Vol. 24, No2, pp. 806-813, May 2009.

[19] Aminifar, F., Khodaei, A., Fotuhi-Firuzabad, M., Shahidehpour, M, "Contingency-Constrained PMU Placement in Power Networks", IEEE Transactions on Power Systems, vol. 25,NO. 1, pp 516-523, February 2010.

[20] Anjio, M., Jiaxi, Y., Zhizhong, G, "PMU placement and data processing in WAMS that complements SCADA", IEEE In Power Meeting, Vol. 1,12-16, pp. 780-783, June 2005 .

[21] Mortezavi, S. S.,Heidari, M., Mirabbasi, D., " GA and BIP based Optimal Allocation of Phasor Measurement Units (PMUs) for Khouzestan Transmission Network compete observability ,Considering double Redundancy for Sensitive Substations", International Conference ,10, Istanbul,Turkiy,4-7, Sep 2011.

[22] Naghshbandi, H., Khavari, A., "optimal placement of phasor measuring unit for observability of system, PSC, 25th, pp: 1-10, 2010. (in Persian)

[23] Lu Zhigang, Liu Junyong, Xie Lianfang. "Analysis and Comparison of Algorithms of Optimizing PMU Placement in WAMS [J]". Modern Electric Power, 2009, 26 (3):19-22.

[24] Xia Haiwen, Xue Wei. "Research on Optimal Allocation of PMU in Power System [J]". Computer& Digital Engineering, 2011, 39 (9):37-40.

[25] Han Jing, Xu Lijie,Su Ling.An, "On-line reactive power optimization method for electric power system[J]". Electric Power Science and Engineering, 2005,1 (1): 8-12 (in chinese).