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PMU OPTIMAL PLACEMENT IN POWER SYSTEM USING BINARY PSO ALGORITHM

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***Abstract*:** This paper presents a new method for minimizing the number of PMUs and their optimal placement in power systems. The proposed methodology results in a reduction in the number of PMUs even though the system topological observability is complete. In this paper, an overview of PMU and their optimal placement is given. Further, a survey and optimal placement different techniques such as index based and Meta-heuristic is explained. The Meta-heuristic algorithm got lot of attention in the modern era because it is provide optimal solution based on their behavior. In this paper PMU optimal placement is done using genetic and Binary PSO algorithm on MATLAB. The results reflect that binary PSO gives optimal placement as compared to genetic algorithm in terms of execution time.

Keywords: Optimal Routing, PMU, genetic Algorithm, Binary PSO.

I. INTRODUCTION

A phasor measurement unit is a device which measures voltage and current phasor on an electricity grid. PMUs are provided with the Global Positioning System (GPS) to give the time synchronized (real time) measurement of voltage and current phasor [1]. The device gives the 48 samples of resulting measurements per second which depicts its accuracy. The total error in the measurement of phasor (magnitude and angle) is less than 1 %. Individually magnitude and phasor contributes error < 1 % and < 0.573o respectively. The results obtained by the device are known as a synchrophasor. That's why the terms "PMU" and "synchrophasor" are sometimes used interchangeably though they are two separate technical terms.

1.1 Applications of PMU

- Wide-area situational awareness
- Voltage monitoring and trending
- State estimation
- Power oscillation monitoring

1.2 Optimal Placement of PMUs

Phasor measurement units (PMUs) provide time-synchronized (real-time) phasor measurements in power systems [2]. With the increasing demand of quality power, the use of phasor measurement units (PMUs) hasincreased a lot ever since it came into existence in 1980s. With this advanced meter, the operation,protection, monitoring and control of power system becomes accurate and easy. Using the PMUs data in state estimation (SE) equation make the SE algorithm linear which is easy to solve as compared to the non linear state estimation equations. Since it makes the SE algorithm linear, no iteration is required in getting the solution. Because of PMUs promising accuracy, its role is very crucial in SE algorithm. It is predicted that in the coming days SE technique will rely more on results of PMUs. However due to expensive nature of device (Rs. 27 lacs/PMU) they cannot be installed at all the buses. Therefore, a suitable technique is required to minimizethe number of PMUs with complete observability of power system. A power system is said to be completely observable when the phasor voltage of all the buses in the system can be determined uniquely either directly or indirectly [3,4]. Therefore observability study in the PMUs placement problem is important before the deployment of PMUs. After assuring the complete system observability, it is necessary to find the optimal locations of the PMUs to maximize the measurement redundancy. The term "measurement redundancy" for a particular bus represents the number of times that bus is observed by PMUs. For example, if a bus observed by one PMU is make to observe by one more PMU, then the measurement redundancy of that bus will increase by one. The increase in value of measurement redundancy will ensure the observabilityof system in case of branch outage or PMU failure.Current energy management systems (EMSs) require accurate monitoring of power system state variables, such as the voltage phasor at all buses.

After establishing complete system observability, it is necessary to determine the optimal places of the PMUs to maximize measurement redundancy. A power system has measurement redundancy when its buses are observed by more than one PMU or the number of observable buses is maximized. In other words, some of the PMUs can be removed from the measurement system while all of the buses remain observable.

2. LITERATURE SURVEY

In this section review on PMU optimal placement algorithms is done.

Dolly Chouhan and Varsha Jaiswal [5], in the power system the un-stability is a big concern. The power measurement units are used for continuous monitoring so, optimum placement of PMU in power system required. In this paper, survey on different methods is done such as conventional methods, Heuristic methods, and Meta-

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heuristic methods. Also, show some real time application of PMU.

Tapas Kumar Maji and ParimalAcharjee [6], in their algorithm they are improving searching capability using inertia-weight-coefficient technique. Also, two innovative mathematical equations are used for updates the particles positions. For the quick and reliable response two useful filtration techniques are applied that can facilitate multiple solutions.

To make the system observable placement sites of PMU placement is problem in the electric power grid. **Aminifar, *et al.* [7],** worked on immunity genetic algorithm for placing PMU (Phasor Measurement Units) in an electric power grid. They are using genetic algorithm property like preserving the condition; utilize the same characteristics to improve the efficiency of the algorithm. They also verified their proposed technique with IEEE standard systems.

3. PROPOSED METHODOLOGY

The PMUs can be placed optimally by following two methods:

3.1 Index Method

3.2 Metaheuristic Optimization Techniques

3.1 Index Method: The index method, uses an indices called connectivity index, to determine the number of favorable bus locations, depending on their connectivity with the rest of the system. Then, the selected locations are assigned as optimal locations for PMUs placements.

Since an HMD installed at a bus makes the entire buses incident on it to be observable, all such observable buses can be determined by defining the binary connectivity matrix as

$$\mathbf{A}(i, i) = 1, \text{ for all buses}$$

$$\mathbf{A}(i, j) = 1, \text{ if bus } i \text{and bus } j \text{ are connected}$$

$$\mathbf{A}(i, j) = 0, \text{ if bus } i \text{and bus } j \text{ are not connected}$$

The index method starts with selecting the *terminal bus* in the system. The *terminal bus* is the bus which is connectedto only a single bus of the entire system. A PMU installedat the terminal bus cannot observe more than two buses, the terminal bus itself and the bus connected to that terminal bus. Thus, to observe any terminal bus, the PMU is placed at the bus connected to it. After placing the PMU on the adjacent bus to the terminal bus, a unique bus having the highest *connectivityindex*, if any, is found. The *connectivity index* of a bus is defined as the number of unobserved buses that can be observed by placing an PMUat that particular bus. For the *i*th bus, it will be given by the sum of all elements of the *i*th row of matrix **A**minus one.

3.2 **Metaheuristic Optimization Techniques :**A metaheuristic is a higher-level procedure or heuristic designed to find, generate, or select a heuristic (partial search algorithm) that may provide a sufficiently good solution to an optimization problem, especially with incomplete or imperfect information or limited computation capacity.Metaheuristic sample a set of solutions which is too large to be completely sampled. Metaheuristic may make few assumptions about the optimization problem being solved, and so they may be usable for a variety of problems. There are a number of metaheuristic techniques, however, in this synopsis, following metaheuristic techniques are taken:

i) Genetic Algorithm (GA)

ii) Binary Particle Swarm Optimization (BPSO)

2.2.1 Genetic Algorithm (GA): Genetic Algorithms (GA) are direct, parallel, stochastic method for global search and optimization, which imitates the evolution of the living beings, described by Charles Darwin. GA are part of the group of Evolutionary Algorithms (EA). The evolutionary algorithms use the three main principles of the natural evolution: reproduction, natural selection and diversity of the species, maintained by the differences of each generation with the previous. The Genetic Algorithms works with a set of individuals, representing possible solutions of the task. The selection principle is applied by using a criterion, giving an evaluation for the individual with respect to the desired solution. The best-suited individuals create the next generation. The large variety of problems in the engineering sphere, as well as in other fields, requires the usage of algorithms from different type, with different characteristics and settings. Main ingredients of GA are :

i) *Chromosomes:* For the genetic algorithms, the chromosomes represent set of genes, which code the independent variables. Every chromosome represents a solution of the given problem. Individual and vector of variables will be used as other words for chromosomes.

ii) *Selection:* In the nature, the selection of individuals is performed by survival of the fittest. The more one individual is adapted to the environment - the bigger are its chances to survive and create an offspring and thus transfer its genes to the next population. In GA the selection of the best individuals is based on an evaluation of fitness function or fitness values.

iii) *Recombination (Crossover):* The first step in the reproduction process is the recombination (crossover). In it the genes of the parents are used to form an entirely new chromosome. The typical recombination for the GA is an operation requiring two parents, but schemes with more parents area also possible.

iv) *Mutation:*The newly created by means of selection and crossover population can be further applied to mutation. Mutation means, that some elements of the DNA are changed. Those changes are caused mainly by mistakes during the copy process of the parent's genes. In the terms of GA, mutation means random change of the value of a gene in the population.

2.2.2 Binary Particle Swarm Optimization (BPSO) : This is binary version of PSO developed by Kennedy and Eberhart in 1997 [8] which can handle discrete binary variables.PSOshares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called *lbest*. when a particle takes all the

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population as its topological neighbors, the best value is a global best and is called *gbest*.
The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its p*best* and *lbest* locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

4. SIMULATION RESULTS AND DISCUSSION

In this paper, the proposed binary particle swarm optimization algorithm determines minimum number of strategic bus locations where PMU must be placed for complete observability of the power system. The algorithm has been tested on IEEE 14-bus, 18-bus, 24-bus, 30-bus, 34-bus, IEEE 69-bus and 118-bus radial distribution system to validate the effectiveness of the proposed method. Detail systeminformation and single line diagram for each of the above networks is available in [9-12].
The result obtained with proposed binary particle swarm optimization algorithm is compared with genetic algorithm technique. The parameters required for the implementation of genetic algorithm and binary particle swarm optimization algorithms are shown in Table 1 and Table 2 respectively.

Table 1: Genetic algorithm parameters

Parameters	Value Taken
Chromosomes Taken	5*Nbus
Iterations	1000
Crossover Probability	0.4
Mutation Probability	0.2
Weight, w1	0.7
Weight, w2	0.3

Table 2: Binary particle swarm optimization algorithm parameters

Parameters	Value Taken
Particles Taken	5*Nbus
Iterations	1000
Measurement Redundancy	4
Acceleration Constant	2
Weight, w1	0.7
Weight, w2	0.3

The optimal location of PMUs for different bus systems along with the number of PMUs are shown in Table 3. The results obtained by both the methods i.e genetic algorithm as well as binary particle swarm optimization algorithm are compared and is shown in the table 3. For IEEE 14-bus system, the number of PMUs for optimal placement is obtained as 4 by both the methods. However, the time taken in execution of program by binary particle swarm optimization algorithm is less as compared to that in genetic algorithm. The number of PMUs obtained for IEEE 18-bus, 24-bus, 30-bus, 34-bus systems by both the methods are same. Also, the time taken in the execution of genetic algorithm code is always more than the binary particle swarm optimization algorithm. For smaller systems like IEEE 14-bus or IEEE 18-bus system, the code execution time between both the algorithms have not significant difference, therefore, any one of the methods can be applied practically. However, with the increase of complexity of systems, the execution time keeps on increasing for genetic algorithm as compared to binary particle swarm optimization algorithm. As we can observe from the table 3 that the execution time of genetic algorithm for IEEE 118 bus system is 54.6 seconds as compared to that by binary particle swarm optimization algorithm which took only 19.4 seconds for the same bus system. Therefore, for larger bus systems, binary particle swarm optimization algorithm is more efficient as compared to genetic algorithm.
Apart from more execution time issue, it can also be observed from the table 3 that the number of PMUs obtained by genetic algorithm is one more for IEEE 69-bus and IEEE 118-bus systems as compared to that obtained by binary particle swarm optimization algorithm. Therefore, for larger and complex systems, binary particle swarm optimization algorithm provides more optimal results as compared to genetic algorithm.

Table 3: Optimal PMUs placement for different bus systems

System	Optimal PMU Locations by BPSO	Optimal PMU Locations by GA	No. of PMUs with BPSO	No. of PMUs with GA	Time taken by BPSO (in sec)	Time taken by GA in (sec)
IEEE 14-bus	2,6,7,9	2,6,7,9	4	4	1.1	4.3
IEEE 18-bus	2,4,6,9,13,15,17	2,4,6,9,13,15,17	7	7	1.6	6.90
IEEE 24-bus	2,3,8,10,13,16,21,23	2,3,8,10,13,16,21,23	8	8	2.3	8.31
IEEE 30-bus	2,3,6,9,10,12,15,19,25,27	2,3,6,9,10,12,15,19,25,27	10	10	3.0	11.2
IEEE 34-bus	2,6,9,10,12,14,17,19,20,22,23, 25,29	2,6,9,10,12,14,17,19,20,22,23, 25,29	13	13	3.6	13.7
IEEE 69-bus	2,5,7,11,13,15,17,20,22,25,27, 29,32,34,38,42,45,48,51,54,56, 60,64	2,5,7,11,13,15,17,20,22,25,27, 29,32,34,38,40,42,45,48,51,54, 56,60,64	23	24	10.06	27.87

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IEEE 118-bus	2,5,9,12,13,17,21,23,26,28,34, 37,41,45,49,53,56,62,63,68,71, 75,77,80,85,86,90, 94,101,105,110,114	2,5,9,12,13,17,21,23,26,28,34, 37,41,45,49,53,56,62,63,68,71, 75,77,80,83,85,86,90,94,101,105,110,114	32	33	19.4	54.6

5. CONCLUSION

The optimal placement of PMUs is performed in this paper using binary particle swarm optimization algorithm and the results have been compared with genetic algorithm technique. The binary particle swarm optimization algorithm gives the minimum number of PMUs and also increases the measurement redundancy of the system.The results obtained by genetic algorithm is similar to that of binary particle swarm optimization algorithm for smaller systems, however, it is quite different and time consuming for larger systems. Therefore, the Numerical results on the IEEE test systems indicated that the proposed binary particle swarm optimization algorithm method is capable of providing anefficient and optimal number and locations for the placement of PMUs.

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