Optimal Location of Phasor Measurement Units for Complete Power System Observability using Binary Particle Swarm Optimization

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Abstract— This paper presents a method to find optimal location of PMU to make power system observable using binary particle swarm optimization. This optimization problem modifies particle swarm optimization using binary numbering method combined to make binary particle swarm optimization method. MATLAB code has been developed using this method and applied to different IEEE test systems up to 118 buses. Moreover OPP is offline optimization problem. The number of PMUs required depends upon zero injection bus and the topology of the network.

Key words: Phasor measurement unit (PMU), optimal PMU placement (OPP), binary particle swarm optimization (BPSO), wide area measurement system

I. INTRODUCTION

With the increasing interest in the Wide Area Monitoring and Control and to minimize the occurrence of blackouts in future, there is a growing interest in the microprocessor based relay and disturbance recorders to provide an additional Phasor Measurement Unit (PMU) measurement. PMUs become more and more attractive to power engineers because they can provide synchronized measurements of real-time phasor of voltage and currents. State estimator plays an important role in the security of power system.

Phasor Measurement Unit (PMU), which is based on the GPS technique, is able to provide precise measurements of voltage magnitude along with phase angle (Complex Voltage), which was not directly possible to measure prior to development of this technology.

As installation of PMU is costly, the first step to reap the benefits of PMU is to locate PMU optimally so that voltage magnitude and phasor angle of all the buses are measureable i.e. power system network is observable. Engineers and mathematicians have developed a variety of algorithms to determine the best locations for PMU installation. One of the most important issues that need to be considered in the emerging technology of PMUs is site selection. The intended system application influences the required number of installations. The cost of PMUs limits the number that will be installed. The placement sites are also limited by the available communication facilities, the cost of which might get higher than that of the PMUs. Proper choice of location of PMU is necessary to meet the criteria of cost and the intended PMU applications.

PSO simulates the behaviour of bird flocking. Each individual and swarm finds optimum location and adjusts their direction towards optimum solution. PSO properties have speed advantage and can be operated simply. Binary particle swarm optimization (BPSO) was put forward by Kennedy and Eberhardin 1997 which can resolve the discrete space optimization problem. An equivalent n-dimensional discrete space containing L particles is considered.

A binary PSO proposal was also given in this paper [1]. It is population based optimization method in which a potential solution is assigned a randomised velocity and then flows through problem hyperspace.

Simulated Annealing has been used for randomly selecting No. of PMU and is based on already known good solution as being used in the referred paper [2]. Also, the time taken for reaching the optimum solution depends on the initial solution and cooling schedules. This paper describes novel multi stage simulated annealing for optimal PMU placement in conjunction with conventional measurement.

The paper described optimal placement of PMU in power system based on bacterial foraging algorithm [3]. In this paper ILP is performed based on network observability and bacterial foraging method is used for optimal placement of PMU. [4]

II. PHASOR MEASUREMENT UNIT MODEL

PMU model and block diagram is almost similar to that of Microprocessor based on Numerical relays except a GPS receiver. The analogue inputs are obtained from PT’s and CT’s placed at all buses and feeders originating from substation. All the three phases are used so that positive sequence measurements could be carried out. The current voltage signals are then brought down to match the requirement of analogue to digital converters [5].

III. OPP PROBLEM FORMATION

This paper uses BPSO to solve Optimal PMU placement problem for complete network observability. Rules for Optimal PMU Placement [3]

1. All buses connected to a directly observable bus are observable themselves.
2. If a bus without injection is observed and all but one of its connecting buses is observed, then the unobserved bus becomes observed.
3. An unobserved bus without injection connected only to observed buses is itself observable.
4. If all the buses neighbouring buses with injection are observable, then that bus is also observable provided injection measurements available at this bus is available i.e. it can also be treated like zero injection bus.
The needs of the network topology information can be expressed as a bus adjacency matrix (BM) and the scheme of PMU placement can be expressed as an array (PA). BM can be designed to be a diagonal symmetry matrix for a network with n nodes. PA is designed to be an N-dimensional array. Binary encoding is adopted for both the matrix BM and the array PA as follow:

**BM = 1** if node I and j are adjoining,

Else, **BM = 0**,

**PA = 1** if node i with PMU

Else, **PA = 0** if node i without PMU

### IV. BINARY PARTICLE SWARM OPTIMIZATION FOR OPP

Particle swarm optimization is based on the behaviour of a colony or swarm of insects, such as ants, termites, bees, and wasps, a flock of birds, or a school of fish.

The particle swarm optimization algorithm mimics the behaviour of these social organisms. The word particle denotes, for example, a bee in a colony or a bird in a flock. Each individual or particle in a swarm behaves in a distributed way using its own intelligence and the collective or group intelligence of the swarm. And hence, if one particle discovers a good path to food, the rest of the swarm will also be able to follow the path instantly even if their location is far away in the swarm.[6]

For PMU placement problem, the position array X of a particle in PSO algorithm gives the information of PMU installation location. This is a binary bit array with the length of the number of buses in the target power system. Value “1” of one bit means an installation of PMU at the corresponding bus, while value “0” means no PMU installation at the corresponding bus.[7] The binary version of PSO should be used with the help of following equations:

\[ t+1 \rightarrow V(t) + c_1 \times r_1 \times (P_{best} - X(t)) + c_2 \times r_2 \times (G_{best} - X(t)) \]  

(1)

\[ c_1, c_2 \] is the learning factor, or accelerated variable. \( r_1 \) and \( r_2 \) are the random number between 0 and 1. \( P_{best} \) is the local optimum solution. \( G_{best} \) is the global optimal solution. 50 No. of swarms are taken with 1000 No. of iterations. \( \rho \) is a stochastic number arranged between 0 and 1. In the binary coding of discrete variables, X should take 0 or 1, but from formula, we can see that the results may not be an integral. In order to limit the outcome to set (0, 1), Kennedy introduced fuzzy function: \( \text{Sig}(x) \), which is defined as:

\[ \text{Sig}(x) = \frac{1}{1 + \exp(-x)} \]  

(2)

\[ X_{t+1} = 0 \text{ if } \rho < \text{Sig}(V_{t+1}) \]  

(3)

\[ X_{t+1} = 1 \text{ if } \rho < \text{Sig}(V_{t+1}) \]  

(4)

In binary coding PSO algorithm, \( V_{t} \) only stands for a probability, which lost the original meaning of evolutionary formula and was just changed managed to meet the needs to solve the problem. [8].

### V. TEST RESULTS OBTAINED

The binary particle swarm optimization for OPP is now applied to different IEEE test system to validate the code developed in MATLAB. The important details for OPP for IEEE test systems are listed below.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Test System</th>
<th>No. of PMU</th>
<th>PMU Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IEEE 14 Bus System</td>
<td>5</td>
<td>2 5 6 7 9</td>
</tr>
<tr>
<td>2</td>
<td>IEEE 30Bus</td>
<td>12</td>
<td>1 4 7 9 10 12 13 18 22 25 27 28</td>
</tr>
<tr>
<td>3</td>
<td>IEEE 57 Bus System</td>
<td>15</td>
<td>1 4 6 13 20 22 25 27 29 32</td>
</tr>
<tr>
<td>4</td>
<td>IEEE 118Bus System</td>
<td>35</td>
<td>3 7 9 11 12 17 21 25 28 34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>37 41 45 49 53 56 58 62 63</td>
</tr>
</tbody>
</table>

Table 1: Result of Opp Using Bpso without Considering Zero Injection Bus for Various Ieee Test System
Table 2: Result of Opp Using Bpso Considering Zero Injection Bus of Various Ieee Test System

![Graphical Representation Showing Convergence of Bpso For Opp Without Considering Zero Injection Bus For Ieee 14 Bus System](image1)

![Graphical Representation Showing Convergence Of Bpso Considering Zero Injection Bus For Ieee 14 Bus System](image2)

VI. CONCLUSION

Binary particle swarm optimization method is used here successively for OPP. The result of various IEEE test system indicates that the number of PMU requirement is depends on network topology and number of zero injection buses present in the system. The convergence rate of BPSO is good and can be conveniently used for optimal placement of PMU for complete observability of network.

VII. REFERENCES


