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Optimal Placement of Phasor Measurement Unit Using Genetic Algorithm

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Abstract: In order to examine the system's observability, the article suggests installing synchronized Phasor Measurement Units (PMU) in the power system. The best place for PMUs is where the system will have the most redundancy and complete observability with the fewest possible PMUs. The PMU cannot be installed on every power system bus due to economic reasons. The PMU has been positioned in a way that will lower installation costs. The present paper explores the best PMU position for overall observability using a genetic algorithm (GA) based strategy. Obtaining the least amount of PMU necessary for the power system to be completely observable is the first of two parts to this challenge. Another is finding the PMU's best placement to achieve the most observability redundancy. The IEEE-14 bus, 24-bus, 30-bus, and New England 39-bus systems will all be investigated as an outcome.

Key words: PMU, synchronization, genetic algorithm, redundancy, observability

1. INTRODUCTION

The monitoring and control of electric power networks could undergo a radical change thanks to the phasor measuring unit (PMU). This tool can measure current, voltage, and determine the angle between the two. The system's phase angles from nearby buses can then be determined instantly. This is made feasible by time stamping and synchronisation, two crucial advantages over conventional meters. Monitoring the system operating conditions attentively is necessary for safe functioning of power systems [1]. This is often carried out by the state estimator, which is housed in the computer of the control centre and has access to the measurements obtained from various electrical substations in the monitoring network. State estimation function may offer an estimate for all metered and unmetered electrical quantities and network parameters of the power system, detect and filter out gross errors in the measurement set, and detect topology errors in the network configuration by collecting analogue measures and the status information for the circuit breakers from remotely monitored and controlled substations and feeding them as input [2]. To lower the dimension of the location model and the computational work required to determine the ideal placement set, a virtual data elimination pre-processing approach and a Matrix reduction algorithm have been presented [3]. Simulated annealing (SA) is a method for solving optimization problems that involves testing several random variations of the existing solution. With a probability that drops as the computation goes on, a worse variation is accepted as the new solution. The likelihood that the algorithm will find an optimal or nearly optimal solution increases with the cooling schedules or rate of decrease's slowness [4]. The enhance incidence matrix and the TS algorithm are the foundation of a revolutionary topological technique introduced in [5]. The combinatorial OPP problem has a highly robust and minimally computational solution. Because it works with integer values instead of complex matrix analysis, the method is quicker and more practical than traditional observability analysis techniques [6]. A search heuristic called a genetic algorithm imitates the evolution of living things. This heuristic is frequently used to come up with helpful answers to optimization and search challenges. The GA method proposed resolving the OPP problem using various PMU placement criteria, such as the elimination of critical measurements and critical sets from the system, the maximum quality of measurements received in comparison to the initial one, the highest degree of accuracy of estimates, the lowest cost of PMU placement, and the transformation of the network graph into a tree. In order to ensure the minimum number of PMUs, a GA technique calculates the minimum number and locations of PMUs as well as the minimum amount of phasors sensed by the PMU [7]. The GA technique was used to tackle the OPP problem. Using a fitness function for the GA that is the inverse of the cumulative discrepancies between the estimated and real power floe in the system, the estimator's accuracy was ensured.

2. PROBLEM FORMULATION

Bus voltage phasors and branch current phasors are the two types of measurements that PMUs offer. The number of channels required to measure voltage and current phasors will vary depending on the type of PMUs used [8].

2.1 Finding Optimum Location of PMU's

After determining the minimum number of PMUs required, their optimum location is obtained, such that maximum redundancy in the buses observed is achieved [9].

This problem can be formulated as-

Maximize R=sum(A x)-n

Subject to the constraints:

$$Ax \geq v$$

And

$$\sum_{i=1}^{n} x_i = p$$

Where,

p, x, A ,n and v have the same meaning as that in part A of the problem,

Sum (A x) represents the sum of elements of vector (A x), and R is the redundancy in the buses observed.

2.2 IEEE Standard Bus System information

This section contains various simulation examples, which are carried out using the IEEE 14-bus, 30-bus, 57-bus and 118-bus systems. MATLAB software package is used to solve the Integer Linear/Nonlinear Programming problem [10]. Detailed system information and simulation results are given in the following sub-sections.

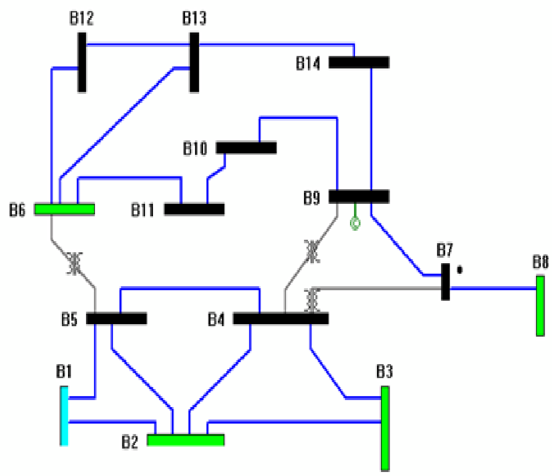

Fig 1. IEEE 14-bus system

IEEE 14-bus system is shown in Figure 1. The Information of the system and zero injections are given in the Table 3.1.

Table 1 System information of IEEE 14-bus system

System	No of branches	No of zero injections	Zero injection buses
IEEE 14-bus	20	1	7
IEEE 30-bus	41	5	6, 9, 11, 25, 28
IEEE 57-bus	78	15	4, 7, 11, 21, 22, 24, 26, 34, 36, 37, 39, 40, 45,46, 48
IEEE 118-bus	179	10	5, 9, 30, 37, 38, 63, 64, 68, 71, 81

3 GENETIC ALGORITHMS FOR OPTIMAL PMU PLACEMENT

An optimization method based on the principles of genetics and natural evolution is known as a genetic algorithm. A GA enables the evolution of a population made up of numerous individuals according to predetermined selection criteria in order to maximize "fitness". The traditional methods of optimization sometimes become stuck at local optimal points instead of the global optimum point. Like other optimization algorithms, GA starts by defining the optimization variable and the cost function (also known as the objective function). Similar to other optimization algorithms, it comes to an end by checking for convergence.

The genetic algorithm parameters are utilized in this case is mentioned as below

Population size = 64, Crossover rate = 0.5 (50%), Mutation rate = 0.1 (10%). No of bits parameter = 1.

It was first transformed into an unconstrained optimization problem before utilizing GA method. In the GA programme, the variables' lower and upper bounds were set to 0 and 1, respectively. By applying the penalty technique to incorporate the bus observability requirements into the objective function, the problem was transformed into an unconstrained optimization problem. 64 chromosomes were created at random as a population. Only one bit per parameter is required for representation because the variables in this problem might have a value of either zero or one. So, seven bits are chosen at random to make up each chromosome. Since each variable can be represented by a single bit, mapping is not necessary during iterations. Using the fitness function, the population was run through. Given that the objective function is one of minimization, the chromosome with the lowest value is the most appropriate one. Fitness was used to classify the population. The parent chromosomes are the chromosomes that survive and have a greater fitness value. Crossover was done using them.

Parent chromosomal pairs were designed to mate. It was done using a straightforward top-to-bottom pairing procedure. There was a single point crossing. The crossing location was chosen at random. Between the parent chromosomes, bits were switched. The crossover rate remained at 50%. To create the population for the following generation, the parent and child chromosomes were combined with the offspring. All generations maintained the 64-person population. After crossing, the "mutation" was implemented. The bit was chosen at random from the chromosome for the mutation, and its complement was used in place of the original bit. A 10% mutation rate was assumed. Following mutation, the following iteration is launched.

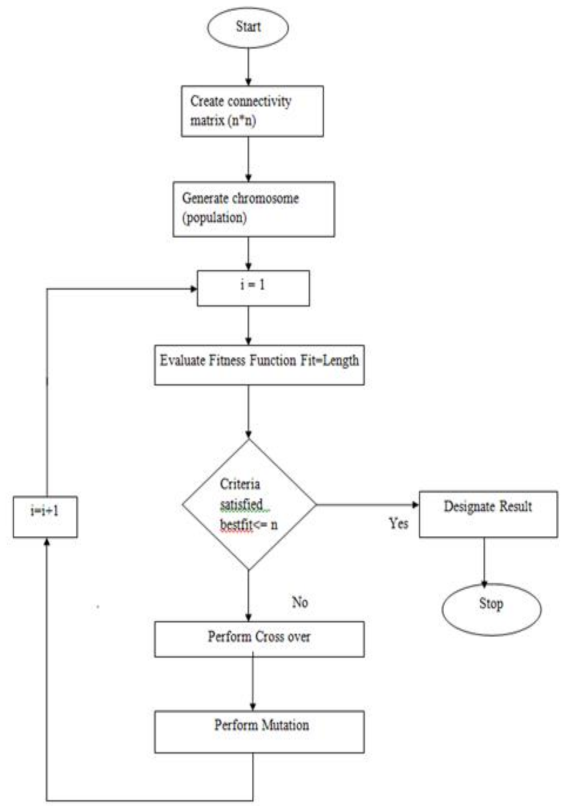

Fig 2 GA Flow Chart for PMU placement

4. RESULTS AND DISSCUSIONS

For the IEEE-14 bus, IEEE-24 bus, IEEE-30 bus, and New England 39-bus test system, simulation has been done. For the test systems of the IEEE -14 bus, 24 bus, 30 bus, and New England 39 bus, respectively, the performance results of the proposed method are presented. The proposed method yielded the desired results. The outcomes of the proposed method in comparison to the current method

4.1. Radial Buses for Test Systems

Table 2. Radial Bus system

S.No	Bus Systems	Number of Radial Buses	Location of Radial Buses
1	IEEE-14 bus	1	8
2	IEEE-24 bus	1	7
3	IEEE-30 bus	3	11,13,26
4	New England 39 bus	9	30,31,32,33,34,35,36,37,38,

4.2. Zero injection buses for test system

Table 3. Zero injection bus system

S.No	Bus Systems	Number of Zero injection Buses	Location of Zero injection Buses
1	IEEE-14 bus	1	7
2	IEEE-24 bus	4	11,12,17,24
3	IEEE-30 bus	6	6,9,22,25,27,28
4	New England 39 bus	12	1,2,5,6,9,10,11,13,14,17,19,22

4.3 Optimal location of PMU for complete observability using Genetic Algorithm

Table 4. Optimal location of PMU using GA

S.No	Bus Systems	Number of PMU	Optimum location of PMU
1	IEEE-14 bus	3	2,6,9
2	IEEE-24 bus	6	1,3 ,10,12,16,21
3	IEEE-30 bus	9	2,4,7,10,12,15,21,25,27
4	New England 39 bus	11	2,3,6,7,9,13,14,16,19,22,23

4.4 Optimal location of PMU for complete observability using Heuristic Approach

Table 5. Optimal location of PMU using HA

S.No	Bus Systems	Number of PMU	Optimum location of PMU
1	IEEE-14 bus	4	2,6,9,11
2	IEEE-24 bus	7	3,10,17,21,1,9, 14
3	IEEE-30 bus	11	2,3,6,7,9,13,14,16,19,22,23
4	New England 39 bus	13	3,6,8,16,2,26,4,10,22,38,32,37,39

4.5. Comparison of Genetic Algorithm and Heuristic Approach

Table 6. Comparisons of GA and Heuristic Approach

S.No	Bus Systems	Proposed Method	Existing Method
		Number of PMU	Number of PMU
1	IEEE-14 bus	3	4
2	IEEE-24 bus	6	7
3	IEEE-30 bus	9	11
4	New England 39 bus	11	13

4.6. Optimal PMU placement and measurement redundancy for IEEE 14-bus system.

Table 7. Measurement of redundancy

Optimal PMU location	Number of times each bus observed													
2,6,9	1	1	1	3	2	1	2	1	2	1	1	1	1	1
2,10,13	1	1	1	2	1	1	1	1	2	1	1	1	1	1
2,11,13	1	1	1	2	1	2	1	1	1	1	1	1	1	1

4.7. Measurement reliability test for IEEE 14-bus system

Table 8. Measurement of reliability

Optimal PMU location	Number of buses													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2,6,9	1	1	1	3	2	1	2	1	2	1	1	1	1	1
2,10,13	1	1	1	2	1	1	1	1	2	1	1	1	1	1
2,11,13	1	1	1	2	1	2	1	1	1	1	1	1	1	1

5. CONCLUSION

A process for obtaining the smallest possible set of PMU that allows for full system observation. Buses with zero injection are regarded as virtual measurements. The primary innovation of this project is the method for determining the minimal set that is based on a genetic algorithm. When considering zero injection buses, the proposed method effectively overcomes the limitations of conventional methods in order to produce system independent optimal solutions. When compared to an exhaustive search approach, the proposed method's automatic elimination of numerous unnecessary combinations during the search process lessens the computational burden. When compared to current heuristic methods, the proposed method is much faster at providing the best solution. The approach is universal and can be used with any power network. The effectiveness of the suggested method in identifying the minimal ideal number of PMU bus locations for thorough observability assessment of the power system is demonstrated by simulation results for various networks. It demonstrates how GA can determine the smallest number of PMUs necessary to make the system observable as well as the PMUs' ideal placement. The optimal solution can be found with a very small population size and with a lot less iteration because only one bit is needed to represent each variable. This drastically shortens the time.

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