Optimal Placement of PMU in a Transmission Network using Genetic Algorithm

Dr. J. Vijaya Kumar[1], P. Suneetha[2], and P. Veerendra [3]
[1, 2, 3] *Department of Electrical Engineering*
Anil Neerukonda Institute of Technology and Sciences (Autonomous), Visakhapatnam
India- 531162.
E-mail: jvkeee@gmail.com

Abstract- **In this paper the best placement of PMUs problem is solved by Genetic Algorithm (GA) and compared with Linear Programming Integer method. In order to evaluate the performance of proposed method, IEEE-7 bus and IEEE-14 bus systems are considered and from the simulation results it is observed that the suggested method overcomes the problem of held in local minima and takes lees time which saves the CPU computation time greatly.**

***Keywords*-Observbility, optimal placement, phasormeasurement units, stateestimation, genetic algorithm.**

I. INTRODUCTION

At present due to increased power demand, fast growth of generation, transmission and development in power systems congested the existing networks and therefore stability margin of these networks are decreased. In this position to guarantee exact and steady operation of the power system, an exact measurement and system states observing is needed. It can possible with SCADA system, where it aims for system states depends on uncontrolled measurement. These measurements have errors such as telemetry bias and measurement.

To overcome these shortcomings in the SCADA, Wide Area Monitoring Protection and Control (WAMPAC) system is introduced. It hast Phasor Measurement Units (PMUs) as main components which produce controlled and practical voltages and currents phasor measurement. Global Positioning System Satellite (GPS) allows reference timing signals to determine control of sampling voltage and current waveform with respect to this reference time [1]. For a particular where PMU is connected directly measures voltage and current phase. Hence to find the exact number of PMUs and its location for entire noticeable of the system plays a major role. A clear proper technique is needed to obtain the exact number of the PMUs which will fully observe the power system.

A proper methodology is needed to find the optimal locations of PMUs in a power system. A power system is called completely noticeable only when all of its states can be exactly calculated [2], [3]. Analysis of -1, i.e., normal system minus one element contingencies, has been the standard practice in many utilities [4].

In recent years, there has been a important research activity on the problem of finding the minimum number of PMUs and their exact locations. In [5], a bisecting search technique is used to find the minimum number of PMUs to make the system noticeable. The simulated annealing method is developed to randomly select the location sets to test for noticeable at each step of the bisecting search. In [6], there is, however, in this search process a possibility that a placement set that can make the system observable be overlooked.

Integer programming method is used to determine the minimum number of PMUs. The method, however, may suffer from the problem of being trapped in local minima. One more disadvantage is that, starting from an initial guess, the method may lead to only one solution, while more than one solution may exist In [7] and [8]. Multiple targets, such as less number of PMUs and improving the measurement redundancy, cannot be managed by integer programming. The authors in [9] use the condition number of the normalized measurement matrix as a criterion for selecting candidate solutions, in addition to binary integer programming for PMU location but the final solution, however, is not exactly optimal, and the number of PMUs required is more than what is presented.

This paper aims for genetic algorithm based search method which consists of using genetic algorithm program as well as genetic algorithm tool box to find the minimum number and exact location of PMUs for complete system observability.

The paper is prepared as follows: The formulation of the problem and the suggested technique is discussed in is described in Section II. The MATLAB simulation results are covered in section III and Section IV deduces the paper.

II. PMU PLACEMENT METHODOLOGY

The objective of this paper is to make use of a less number of PMUs in order to make the system fully noticeable. Initiation of PMUs will be a gradual process, requiring decisions on the best possible locations for a limited number of PMUs at the beginning. Hence, a regular method is required to find the best locations for new PMUs in the midst of other existed PMUs and/or conventional measurements. This paper investigates this issue and provides a practical solution for the PMU placement problem.

The problem is formulated and solved by using integer programming and genetic algorithm. First, a numerical method based on integer programming will be presented. The formulation of the problem facilitates analysis of network noticeable without zero injection bus and line flow measurements, with zero injection bus and line flow measurements. The procedure can also be covered to account for loss of single PMUs. The efficiency of this method increases with the number of already existing measurements. By placing PMUs at the strategic boundary buses and merging the few existing observable islands, an observable system will be quickly rendered. Next followed by Genetic Algorithm method where exact location of PMU is without zero injection bus and line flow measurements.

A. Probem Formulation

The objective functions of the exact location of PMU as follows:

$$\text{Min.} \sum_{k=1}^{N} x_k$$

$$\text{S.T } T_{PMU} X \geq b_{PMU}$$

$$X = [x_1 x_2 \ldots x_N]^T$$

$$x_i \in \{0,1\}$$

Where $b_{PMU} = [11\ldots1]^T_{N\times1}$

x_i is the PMU location variable and

N is number of buses.

B. *Genetic Algorithm*

Genetic algorithm (GA) is adjustive trail -and -error search algorithm that repeats the process of natural evolution. This process is used to generate result to optimization and also search problems. The non-dominated selecting genetic algorithm suggested in solves the optimal placement of PMUs problem with objectives, such as to minimize of the number of PMUs and maximize the calculated layoff. This optimization method finds the Pareto optimal solutions. The proposed algorithm first follow graph theory and simple GA procedure to obtain individual solution and then finds most desirable solution which may choose the decision-maker using Non dominated selected Genetic Algorithm (NSGA). The main benefit of this NSGA is that it gives the best Pareto-optimal solution instead of one solution, and could provide large search space for multi-objective optimization problems.

GA was encouraged by the natural evolution of species. In natural evolution, each species find beneficial adaptations in an ever-changing atmosphere. It evolve, new genetic Information is encoded in the chromosomes. This information changes by the modification of chromosomal material breeding (crossover) and also mutation. From the engineering standpoint, if we have two solutions with good approximation for a given problem, their combination might lead to a better solution. So, GA finds search algorithms with an iteration of generation-and-test. With the characteristics of easier application, greater robustness, and better parallel processing than most classical methods of optimization, GA has been widely applied for various applications.

Algorithm for GA:

1. **[Start]** Start random population of *n* chromosomes
2. **[Fitness]** find the fitness *f(x)* of each chromosome *x* in the population
3. **[New population]** start a new population by repeating following steps until the new population is complete
   a. **[Selection]** opt two parent chromosomes from a population based on fitness (the better fitness, the bigger chance to be selected)
   b. **[Crossover]** With a crossover probability cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.
   c. **[Mutation]** With a mutation probability mutate new offspring at each locus (position in chromosome).
   d. **[Accepting]** Place new offspring in a new population.
4. **[Replace]** generated population for a further run of algorithm.
5. If the end condition is met, **stop**, and return the best solution in current population.
6. **[Loop]** Go to step **2.**

Design and Implementation of Algorithm

Observability rules

The rules are adopted to find the topological observability of a given grid:

If a PMU is located in a bus, voltage phasor of that bus and currents phasors of all incident branches to that bus are known. These are known 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 known as pseudo measurements.

If there is a bus and all incident branches current phasors are known but one, then the current phasor of the unknown one can be obtained using KCL equations.

Formulation of OPP

The aim of the PMU placement problem is to minimize the number of PMUs that can make the system noticeable, and it can be stated as follows.

Design of GA

(i) Chromosome encoding

The need of all nodes should be finding before encoding. The set of chosen 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.

(ii) Fitness function

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

$f = C – \text{sum (PMU)}$

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

(iii) Selection operation

It uses roulette wheel selection and the best individual must be taken to the next generation. The game of retaining 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 solution is yes. Else, retain the main individual and replace the worst individual with the main individual.

(iv) Crossover operation

The process of crossover is to generate new individuals. Here it uses single-point crossover. Initially, algorithm will select two individuals randomly to crossover according to crossover probability. Then, algorithm will chose the single-point for crossover. After that two different individuals generate.

(v) Mutation operation

Basically in this paper the method of mutation adopted by topology of power grid into consideration. Initially, select anode randomly from the set of nodes where PMUs have been installed. Then, remove the PMU in the selected node. Then, find all nodes connecting to this chosen 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.

III. SIMULATION RESULTS

In order to find the execution of proposed method for obtaining the less number of PMUs and their location, IEEE-7 bus and IEEE-14 bus systems are taken in account.

The simulations are being carried out using MATLAB environment with following specifications: Intel i5 processor and 3 GB RAM, MATLAB 12.0 version. Optimization tool box/solver gives the minimum number of PMUs to render each test system fully observable. This gives the plot of the best fitness function in GA method.

A. *IEEE-7 bus system*

IEEE–7 bus system is considered as a test system 1 to determine the less number of PMUs and the placement of PMUs as shown in Fig.1.

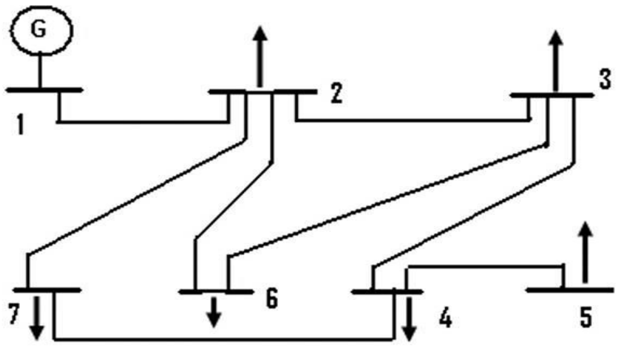

Figure 1.IEEE-7 bus system

Fig. 2 shows the objective function of PMU where program has to be written by using function. The function is entered in toolbox as shown in Fig.3 and it is called by the program function. After running the program the following are the results obtained from the MATLAB GA tool box as shown in Fig.4.

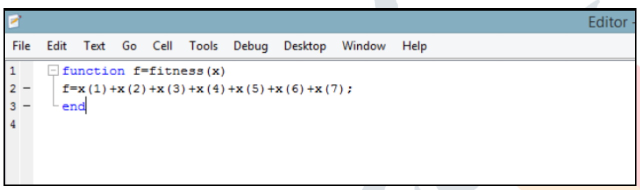

Figure2. Objective function of PMU

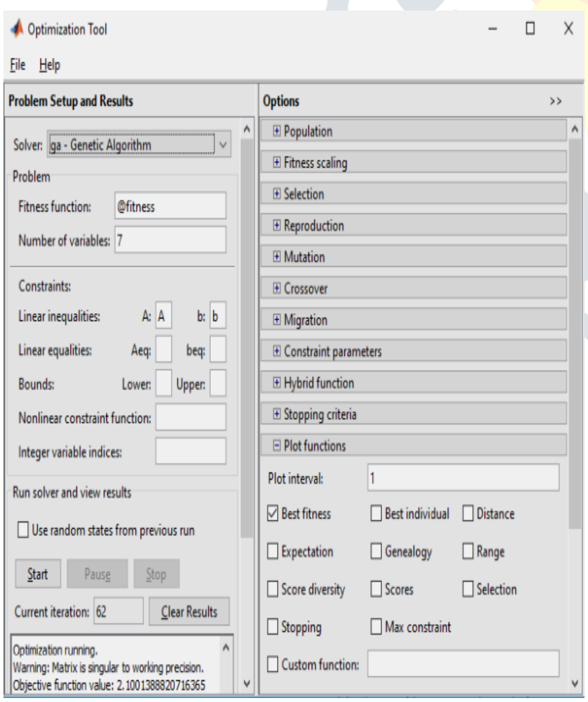

Figure3. GA Tool box

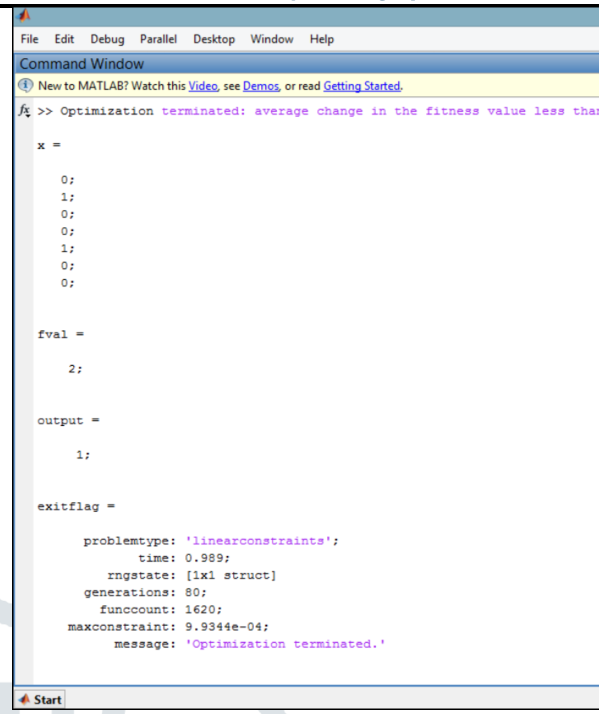

Figure4. Output of GA Tool Box

From the Fig.3 it is observed that the minimum numbers of PMUs needed for IEEE-7 bus system are 2 and they should be at placed Bus-2 and Bus- 4 for the complete observability of the given power system network. The graph is obtained from optimization tool box using GA method compares the highest fitness value. Fig.5 shows the convergence characteristics to reach the best fitness value by passing through number of generations.

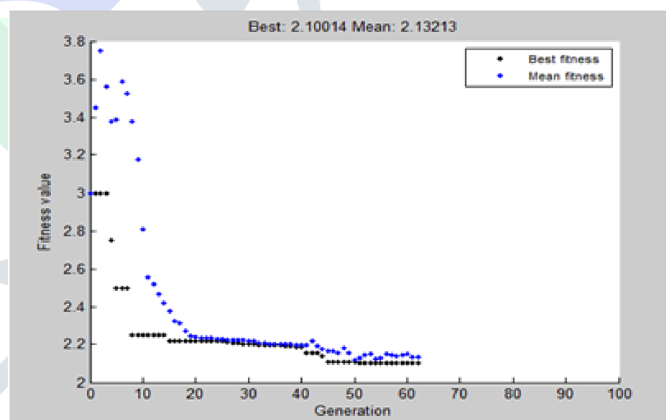

Figure4. Convergence characteristics

B. *IEEE-14 bus system*

IEEE–14 bus system is considered as a test system 2 to find the less number of PMUs and the placement of PMUs as shown in Fig.5.

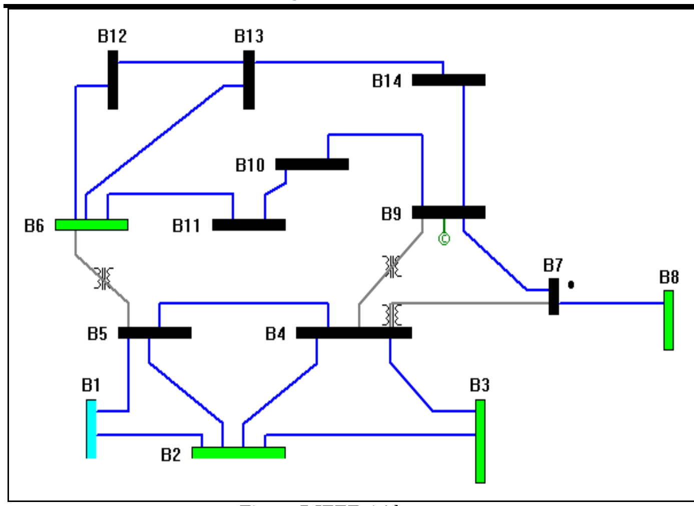

Figure 5.IEEE-14 bus system

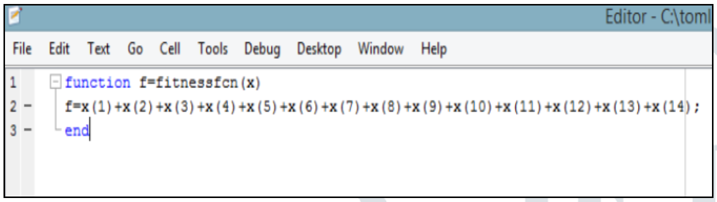

Figure6. Objective function of PMU

Fig. 6 shows the objective function of PMU where program has to be written by using function. The function is entered in toolbox as shown in Fig.7 and it is called by the program function. After running the program the following are the results obtained from the MATLAB GA toolbox as shown in Fig.8. By observing the result, we can say that the less number of PMUs required for IEEE-14 bus system is 4 and these PMUs can be placed in 5 ways. (2, 6,7, 9), (2, 6,8,9), (2,8, 10,13), (2,7, 11, 13), (2, 7,10,13).

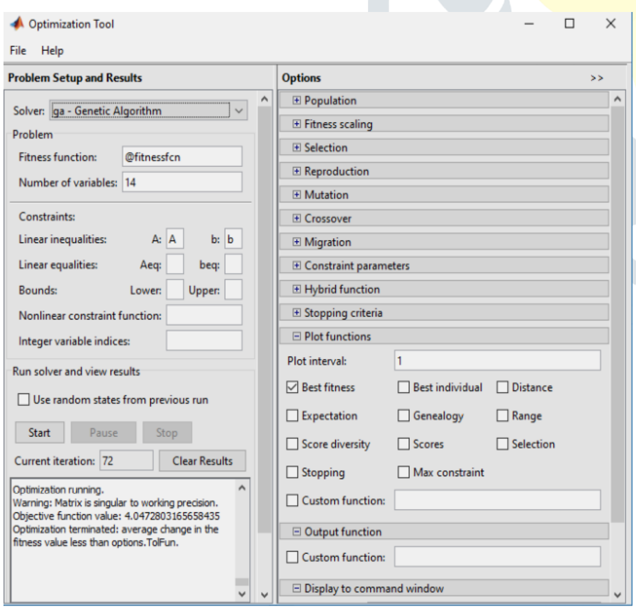

Figure7. GA Tool box

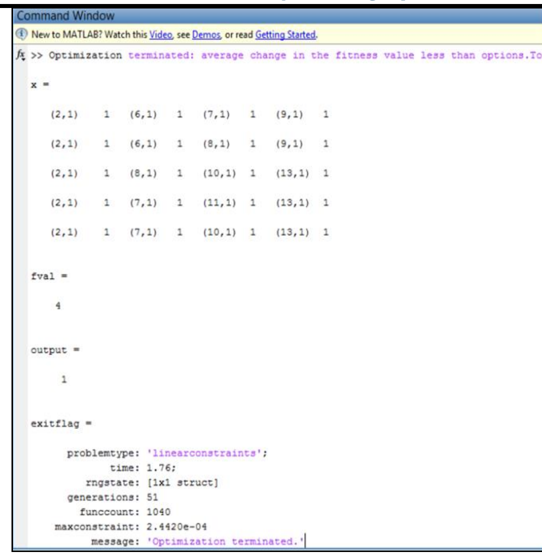

Figure8. Output of GA Tool Box

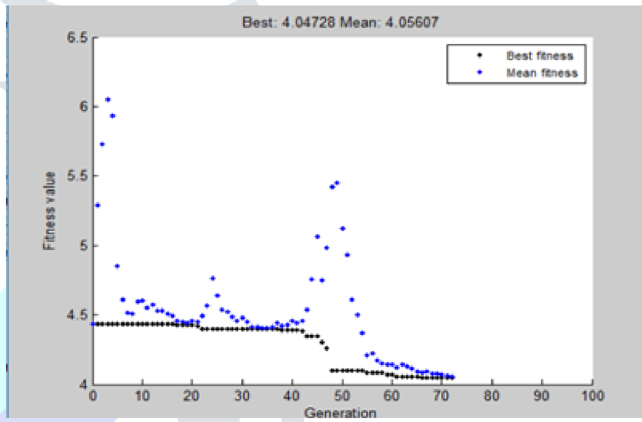

Figure9. Convergence characteristics

The graph is obtained from optimization tool box using GA method compares the highest fitness value. Fig.9 shows the convergence characteristics to reach the best fitness value by passing through number of generations. Table I shows the comparison of proposed method with Integer programming method. From the results it is observed that the proposed GA requires minimum no. of PMUs when compared to Integer linear programming method and the proposed method takes less convergence time when compared to the Integer linear programming method.

Table I comparison of results

Test system	GA	Integer Linear Programming
IEEE7-bus	2	4
IEEE14-bus	3	6
Time (sec.)	0.3906	0.989

IV. Conclusions

The present paper suggest genetic algorithm based search method which consists of using genetic algorithm program as well as genetic algorithm toolbox to determine the least number and exact location of PMUs for complete system noticeable. The suggested method overcomes the limitations of the evolutionary algorithms and integer programming in finding the minimum number of PMUs for state estimation, and their exact locations. The suggested method also taken less time for iteration in order show the robustness.

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