Optimal Placement of Phasor Measurement Units for Power System Observability Using A Hybrid of Genetic and Cuckoosearch (CS-GA) Algorithm

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Abstract: ***Power system state-owned estimation with limited consumption of synchronous phasor measurements demands that the system should be fully observable by (Phasor Measure Units) PMUs only. The allocation of the PMUs is a major issue which can be formulated as an optimization problem. This paper proposes a method, which is used to find minimum number of PMUs for complete observability of power system network for normal operating conditions. We propose a novel hybrid algorithm of Cuckoo Search and Genetic Algorithm called CS-GA; which is used to optimize the minimum number and optimal locations of PMUs needed to make the system observable without considering zero injection buses. The proposed method is used to benchmark the optimal PMUs placement solution for the IEEE 14-bus, IEEE 24-bus, IEEE 30-bus and IEEE 39-bus test systems. The simulation is presented using the simulation tool, MatlabRa2012 and performances of the proposed method is represented as tables.***

Keywords: Power System, Phasor Measure Unit (PMU), IEEE Bus System, Optimization, Genetic Algorithm, Cuckoo Search, Hybrid Algorithm, CS-GA.

1. Introduction

Power System is a collection of electrical components which is used to transmit and distribute the electrical power. The transmission system carries the power from the generating station, and the distribution system supplies the power to the nearest centers. Power system contains protective devices like relays, circuit breakers which are used to prevent damage or fault occur in the system. Phasor measurement units (PMUs) are one of the most important measuring devices in power system. PMU provides phasor information in real time. It offers new opportunities in power system monitoring, protection, analysis and control [1]. PMU provides minimum

Frequency measurement for three phase AC voltage and current waveforms. It is used to measure the harmonics, estimate the system state and detect the fault and also used in power system oscillations.

The main aim of optimal PMU placement is to determine the less number of PMUs so that the entire system is completely observable. If the system is observable by placing the PMU optimally then the state estimator provides the state of the system in a single iteration. Most of the authors have described a various methods such as Integer Linear Programming method [2], Iterated Local Search (ILS)algorithm [3], Modified Canonical Genetic algorithm [11]etc to solve the optimization problem by the use of optimal PMU placement. In those methods, the measurement of system state was done by placing the PMU in all the buses of a network. This results in increase in cost of PMU and its corresponding system.

Optimization is the process of choosing the best value of the system under certain parameters. Optimization algorithm is used to find the optimal value of the function to be optimized. The most commonly used Optimization techniques are Genetic algorithm, Bacterial Foraging Optimization algorithm, Particle Swarm Optimization algorithm, Cuckoo search algorithm and artificial bee colony algorithm. The Algorithm with the combination of two or three algorithm is known as hybrid algorithm. It combines one algorithm with another algorithm to provide the most efficient algorithms.

This paper proposes the model for the calculation of minimum number of PMUs is presented. Genetic algorithm is used to solve the mixed integer consistency optimization problems. Cuckoo search algorithm is developed as a new optimization algorithm and it is efficient in solving global optimization problem. So, the Cuckoo search algorithm is hybridized with well-known Genetic algorithm called CS-GA algorithm is proposed in this method. Optimal PMU placement is used here to solve the optimization problem for the IEEE 14-bus, IEEE 24-bus, IEEE 30-bus and IEEE 39-bus test systems. CS-GA algorithm is easy to implement and it requires only least amount of control parameter. The system is cost-effective because it requires only minimum number of PMUs. The complete observability and reliability of the system is improved by using the minimum number of PMU. The proposed method is found to be a simple, accurate and more efficient in solving optimization problem.

The organization of paper is as follows: Section 1 is our introduction. Section 2 is our Literature surve y related to the proposed method is discussed. Section 3 provides Optimal PMU placement problems presented in the IEEE N bus systems and the objective functions are defined. The proposed CS-GA algorithm and the application of the proposed CS-GA algorithm for the PMUs placement problem are also presented in Section 4. The detailed Simulation Results and the performance of the proposed method are described in Section 5 and conclusions are summed up in Section 6.

2. Literature Survey

Vahid Behravesh, and Zahra Moravej[1] has proposed a concept of 'Optimal placement of Phasor Measurement Units in Khosran Network using a Hybrid Intelligent. In this paper a new method is adopted based on the tecnnique of BISA-GA and considering the impact of Zero injection buses has been solved.This algorithm was applied to 400 KV Khosran network under normal operation mode. Bei Gou [2] has proposed an Integer linear programming concept by using simple optimal placement algorithm of PMUs in power systems. Conventional power flow and injection measurements were considered as cases in this work. These cases were formulated as the Integer Linear programming which has saved the CPU computation time greatly. M. Hurtgen et.al [3] proposed a PMU placement method used to minimize the number of PMUs required. The PPA and ILS algorithm showed that a PMU placed at one node was capable of measuring all current phasor leaving the node. The Iterated Local Search (ILS) algorithm was used to minimize the size of the PMU configuration needed to view the network. The algorithm was tested on IEEE test networks with 14, 57 and 118 nodes.

Bindeshwar Singh et.al has proposed an application of PMU [4] in electric power system networks included in FACTS controllers for advanced power system monitoring, protection, and control. This proposed method was useful to there searchers for finding out the relevant references in the field of the applications of PMUs in electric power system networks built-in with FACTS controllers. N. M. Manousakis [5] has proposed a mathematical programming, heuristic, and meta-heuristic optimization techniques to solve the Optimal PMU Placement(OPP)problems. They had also proposed a Comprehensive literature review on the OPP problem and the solution methodologies.

Rahul H. Shewale et.al has proposed a simple heuristic search method [6] for optimal placemat of PMU, which made the system completely observable. They had used their proposed method based on the network information for determination of minimum set of PMUs. When considering zero injection buses; this proposed method has conquered the limitation of the conventional integer programming method, which has produced the system independent optimal solution. B.K. Saha Roy et.al have proposed an optimal PMU placement method [7] using network connectivity information. This method was initially considered PMU in all buses of the network. The three stage algorithm was used (i) less important bus locations from where PMUs were eliminated and (ii) strategically important bus locations where PMUs were retained (iii) of the algorithm further minimizes the number of PMU using pruning operation. This proposed method has obtained the minimum number of PMUs required for complete observability of power systems.

Vassilis Kekatos [8] has proposed a relaxation method for optimum PMU placement. This method was developed by using combinatorial search. On every bus the installation cost of PMU was currently prohibited. An optimum power flow, system control, contingency analysis, visualization and integration of renewable resources tasks was used in power networks with PMU. Optimal experimental design task was originating the PMU placement. In the tests performed on standard IEEE 14-, 30-, and 118-bus benchmarks, Nikolaos M. Manousakis et.al have proposed an optimization methods [9] applied to the OPP problem. This problem aim was to provide the minimum PMU installations to ensure full residency of the power system. Mathematical and heuristic algorithms were used to solve the OPP problems. The IP and the SA algorithm are frequently used techniques for the solution of the OPP problems. They had proposed state of the art of the optimization methods applied to the OPP problem. Benchmark system the IEEE bus systems (14-bus to 300-bus system) was used.

Vahidhossein Khiabani et.al has proposed a PMU placement approach [10] was used to Maximum coverage of the power network. PMUs model goal was to find the best placement in order to reach the maximum coverage limited. This model was used linear programming approach to solve the problem. The optimization model is solved for IEEE 14, 30, 57, 118 and 2383 standard test systems incorporating the zero-injection buses. Rodrigo Albuquerque Frazao et.al proposed a Modified Canonical Genetic Algorithm (MCGA) [11] was used in electrical power system. The goal of the algorithm was determined the minimum number of PMU. If there was more than one solution, a strategy of analysis of the design matrix rank was applied to determine the solution. They had proposed placement and modifications were made. To improve the performance the restrictive hypotheses in the search space was used to solve the optimization problem. The proposed method is applied on the IEEE 118-bus test system. Billakanti.S and Venkaiah.C [12] have presented the investigation of Optimal placement of Phasor Measuring Units (PMU) and the use of reduced number of PMUs for ensuring Power system full observability. The Optimal PMU Placement (OPP) was considered for different contingencies such as single PMU or line outage to ensure full system observability. The PMU Channels, which limit the number of measurements at the installed bus was also taken into account in OPP formulation. MATLAB Simulations were carried out by Binary Integer Linear programming (BILP) method and tested on standard IEEE 14-bus, IEEE 30-bus, IEEE 57-bus and IEEE 118-bus systems. The results presented were compared with the recent literature and found the effectiveness of proposed method with regard to number of PMUs and execution time was appreciable.

Linda. O et al. [13] have proposed a novel solution to the Optimal Placement of PMUs problem using a Memetic Algorithm (MA). The implemented MA has combined the global optimization power of genetic algorithms with local solution tuning using the hill-climbing method. The performance of the proposed approach was demonstrated on IEEE benchmark power networks as well as on a segment of the Idaho region power network. It was shown that the proposed solution using a MA features significantly faster convergence rate towards the optimum solution.

Fesharaki.F.H et al. [14] have developed an organized method for partitioning the WAMS as well as proposed a new algorithm for the simultaneous optimal placement of

PMUs and PDCs. In the proposed method, first it was assumed that PMUs were installed at all of the system buses. Then, redundant PMUs were omitted sequentially to provide the system observability with the maximum communication reliability. The IEEE 30-bus, and 118-bus systems were used to demonstrate the proposed algorithm. Contingencies such as PMU loss and line outage are considered in power system observability achievement. Finally, in order to show the applicability of the methods to real dimensional power systems, the IEEE 300-bus power system was also analyzed in the normal operating condition.

Rather.Z.H et al. [15] have presented a realistic cost-effective model for optimal placement of phasor measurement units (PMUs) for complete observability of a power system considering practical cost implications. The proposed model has considered hidden or otherwise unaccounted practical costs involved in PMU installation. Consideration of these hidden but significant and integral part of total PMU installation costs was inspired from practical experience on a real-life project. The proposed model focussed on the minimization of total realistic costs instead of a widely used theoretical concept of a minimal number of PMUs. The proposed model has been applied to IEEE 14-bus, IEEE 24-bus, IEEE 30-bus, New England 39-bus, and large power system of 300 buses and real life Danish grid. A comparison of the results with those reported by traditional methods has also been shown in order to justify the effectiveness of the proposed model with regard to its realistic and practical nature.

Bei Gou and Kavasseri.R.G [16] have presented a unified algorithm for optimal phasor measurement unit (PMU) placement in power system state estimation. A unified algorithm of PMU placement for state estimation combining observability analysis and bad data detection into a single iterative procedure is presented. In each iteration, PMU placement was performed to make the system observable, or make critical measurements become non-critical, or make critical pairs become non-critical pairs, respectively. This work presented an improved optimal PMU placement algorithm wherein each iteration was performed by a significantly smaller integer linear programming (ILP) model whose size was governed by the rank deficiency of the Jacobian matrix resulting from the configuration of conventional measurements. The proposed formulation thus leads to a far smaller and simpler ILP problem compared to existing methods. Additional results were also presented to identify critical measurement pairs. The proposed approach was illustrated on the IEEE 14- and 118-bus systems.

Lei Huang et al. [17] have proposed an optimal phasor measurement unit (PMU) placement model considering power system controlled islanding so that the power network remains observable under controlled islanding condition as well as normal operation condition. The optimization objectives of proposed model were to minimize the number of installed PMUs and to maximize the measurement redundancy. These two objectives were combined together with a weighting variable so that the optimal solution with minimum PMU number and maximum measurement redundancy would be obtained from the model. In order to reduce the number of required PMUs, the effect of zero-injection bus was considered and incorporated into the model. Furthermore, additional constraints for maintaining observability following single PMU failure or line loss were also derived. At last, several IEEE standard systems and the Polish 2383-bus system were employed in order to test the presented model. Results were presented to demonstrate the effectiveness of the method.

Vahidossein Khiabani, Ergin Erdem, Kambiz Farahmand, and Kendall Nygard[18] have presented ‘Smart Grid PMU Allocation Using Genetic Algorithm, technique considering a Genetic Algorithm based methodologyto tackle reliability based PMU placement model with two conflicting objective of maximization of the overall system reliability. This proposal is implemented for 14, 30, 57, 118 and 2383 bus power system with PMU reliabilities.

A.G Phadke[19] presented the use of time synchronizing techniques, coupled with the computer-based measurement technique, to measure phasor and phase angle differences in real time is reviewed, and phasor measurement units are discussed. Many of the research projects concerned with applications of synchronized phasor measurements are described. These include measuring the frequency and magnitude of phasor, state estimation, instability prediction, adaptive relaying, and improved control. Synchronized Phasor Measurement and their applications present the historical development of the synchronized phasor measurement technology, which is the most accurate wide area measurements technology for power systems and points the path for the applications of these measurements to be realized in coming years. The synchronized phasor measurement concept was introduced by the authors and has been developing at a steady space through the research of the authors as well as their colleagues throughout the world. It is now a mature technology with products being offered by leading manufactures of electric power equipment.

J.L.Wang, L.Xia,[20] presented the character of the power flow equation can be described by Incidence Matrix because of the similar character of the Y-matrix and the Incidence Matrix. Here on the method of the optimal PMU placement for the direct solvable power flow is proposed based on incidence matrix. The validity and flexibility of the proposed algorithm are tested with typical standard power system and the results show that the less amount of PMU is needed to realize direct solution of power flow.

V.Siyoi,S.Kariuki and M.J Saulo[21] have presented the technique of Strategic PMU Placement for stability enhancement. In this methodology they brought the concept of Wide Area Monitoring Protection and Control (WAMPAC). Wide Area Monitoring forms the basis of wide area protection and control. Synchronized wide area measurements enhance the integrity of measurement data for various power system Analyses.The PMU was use in this paper for the purpose of WAMs. .The utility of PMUs in adata mining is therefore realized through its high sampling rate. The applications of data mining techniques are explored, where power system analysers will be able to realize the benefits of learning from past record data. The contribution of this paper is that it provides a methodology for identifying strategic placement locations of WAM devices for the purpose of designing the WAP scheme.

3. Phasor Measurement Units

Phasor Measurement Unit (PMU) is a measuring device used in the power system which provides information of bus voltage and branch current phasor in real time. It is used to measure the positive sequences of voltage and current, frequency, harmonics and the status of the switch. PMU is used in the system state estimation which provides the real time state of the system. The allocation of the PMU in the system network is a major problem and it is considered as an optimization problem. In this paper, optimization is designed for finding the best location among various buses in the system to place the PMU under certain parameters. So the optimal PMU placement is presented in this paper to solve the optimization problem for various bus systems such as IEEE 14-bus, IEEE 24-bus, IEEE 30-bus and IEEE 39-bus systems. Optimal placement of PMUs provides the maximum benefit for the state estimation function. If the power system network is visible when placing the PMU optimally then the state estimator provides the system state in a single iteration. By using this optimal PMU placement, the total number of PMU required is reduced so that the cost of the system is decreased and the complete observable of the system is improved.

3.1 Zero Injection Bus Model

Zero Injection Buses (ZIBs) are the buses modeled for the PMU placement problem from which no current is being injected into the system. It does not have any generator or any load for the system operation. ZIBs have the potential to minimize the number of PMU required for complete observability of the system. In figure.1, the buses 1, 2 and 4 are connected with the bus-3 with the currentI_{13}, $I_{23}$and I_{43} respectively, whereas the ZIB bus-5 is connected with the bus-3 with no current.

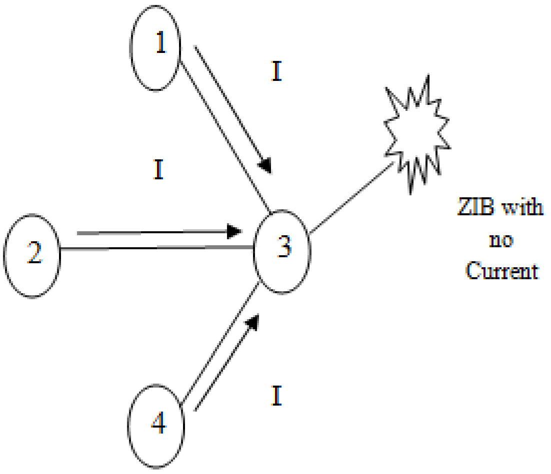

Figure 1: Example Bus system with Zero Injection Bus

3.2 PMU placement problem formulation for IEEE N-bus system

In the optimal PMU placement problem, IEEE 14-bus system is considered for IEEE N-bus system. The topology for IEEE 14-bus system is given below.

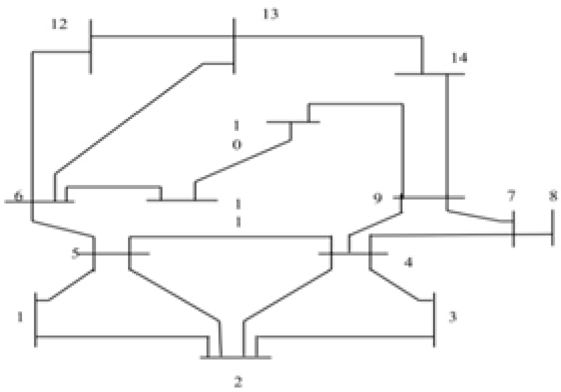

Figure 2: Connection Topology of IEEE 14-bus System

is the cost of the PMU installed at the *i*-th bus and F(*x*) is the observability constraint vector function, then the optimal PMU placement problem is obtained as follows:

$$\min \sum_{i=1}^{N} w_i\, x_i \text{ s.t. } F(x) \geq b \qquad (1)$$

Where b is an unit vector of length N, i.e. b= $[1\ 1\ 1\ldots.]^T$ and x is the binary variable for PMU placement and its entries are defined as,

$x_i = 1$ if PMU is placed at ith bus

0 otherwise where, i=1, 2….N (2)

The entries are one when the buses are observable at the *i*-th bus otherwise it is considered as zero. If w_i is assumed as one, then the optimal PMU placement is defined by,

$$\min \sum_{i=1}^{N} x_i \text{ s.t } F(X) \geq b \qquad (3)$$

The constraint vector function is formed using the binary connectivity matrix (A) which represents the bus connectivity information of the power system. The elements of the connectivity matrix A are defined by the following conditions.

$a_{m,n} = 1$ if m=n

f w_i

1 if bus m is connected to bus n (4)

0 otherwise

The equation (4) represents the elements of the connectivity matrix becomes one either the bus m is equal to bus n or bus m is connected to bus n and zero otherwise. The constraint vector function for the bus test system and the particular *i*-th bus is given by,

$$F(X) = A(X) \geq b \qquad (5)$$

$$f_i = a_{i,1}x_1 + \cdots + a_{i,i}x_i + \cdots + a_{i,N}x_N \qquad (6)$$

If $a_{i,n}$ is zero then f_i becomes zero and it will not appear. If any x_i is non zero then $f_i$becomes observable. Finally if all f_i in F is non zero then the system is completely observable. The performance table for IEEE 14-bus system is shown below 14-bus system is shown below:

Table 1: Connection Matrix for IEEE 14-bus System

Connection Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
2	1	0	1	1	1	0	0	0	0	0	0	0	0	0
3	0	1	0	1	0	0	0	0	0	0	0	0	0	0
4	1	1	1	0	1	0	1	0	1	0	0	0	0	0
5	0	1	0	1	0	1	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	0	0	0	0	1	1	1	0
7	0	0	0	1	0	0	0	1	1	0	0	0	0	0
8	0	0	0	0	0	0	1	0	0	0	0	0	0	0
9	0	0	0	1	0	0	1	0	0	1	0	0	0	1
10	0	0	0	0	0	0	0	0	1	0	1	0	0	0
11	0	0	0	0	0	1	0	0	0	1	0	0	0	0
12	0	0	0	0	0	1	0	0	0	0	0	0	1	0
13	0	0	0	0	0	1	0	0	0	0	0	1	0	1
14	0	0	0	0	0	0	0	0	1	0	0	0	1	0

4. Hybrid of Genetic and Cuckoo Search Algorithm

4.1 Basics of Genetic Algorithm

Genetic Algorithm (GA) is a search strategy [12-13] that is used to provide a best solution for the optimization problem. It strikes a balance between the exploration and exploitation of the domain and the solutions respectively. The major steps for the Genetic Algorithm are comprised as follows:

1. Population
2. Reproduction
3. Crossover
4. Mutation

4.2 Basics of Cuckoo search Algorithm

Cuckoo search Algorithm (CS) is an optimization algorithm [14] which is based on the behavior of some cuckoo species. CS algorithm is a combination of the Levy flight behavior of some birds and fruit flies. The cuckoo species mostly lay their eggs in the nest of other host bird. The host bird found that the eggs are not its own; then the eggs are destroyed by the host bird. This results the development of the cuckoo eggs which mimic the eggs of the local host birds. Thus, the CS algorithm is mostly used for the various optimization problems. Major steps involved in the CS algorithm are:

1. Population
2. Levy flight
3. Host Egg elimination
4. New egg generation

4.3 Hybrid Cuckoo search and Genetic Algorithm (CS-GA)

CS-GA algorithm is a combination of Genetic algorithm and Cuckoo search algorithm which is a population based algorithm used to provide the global solution. In CS-GA algorithm, the initial population is generated randomly and the initial solution is given to the entire space. At first, the crossover and the mutation process will be placed for each generation of the algorithm. After each generation the best value is selected by applying some form of elitism. Before the end of each generation Levy flight will perform to increase the exploration of the solution for next generation. The more detailed algorithm is represented in Algorithm.1.

Algorithm.1. Pseudo Code for the CS-GA Optimization Algorithm

Begin
Objective function f(x);
Step 1: Initialization. Set the generation counter t=1; initialize population randomly.
(Initialize Np number of host nests randomly each host nest have an egg corresponds to a potential solution to the given problem);
Step 2: Fitness evaluation. Evaluate fitness f(x);
While (t< Max Generation) or (stop criterion); / New population /
Generate new population via genetic operators (selection, crossover and mutation)

Evaluate fitness (the best individual perform Lévy flight)
Generate a new solution (say x_{new}) via Lévy flights;
Evaluate its quality/fitness Fx_{new};
Choose a solution (say x_j) randomly among N_{pnew} and evaluate its fitness (F_j);
If (Fx_{new}<F_j) then
Replace j by a new solution;
end if
Store the best solution;
t = t+1;
Step 3: end while
Step 4: Retrieve the best solution among the current best solution stored in each generation
End

In this paper, CS-GA optimization algorithm is proposed to minimize the fitness function *F(X)* i.e. number of PMUs required to observe the complete details of the buses presented in the IEEE *N* bus system. Initially, connection matrix *A* is generated for the given IEEE N bus system and initial population is generated to in order to compute the fitness function. In first generation, optimal location of one PMU is optimized by using the crossover and mutation operators as shown in figure.3. When various locations are comfortable with the placement for one PMU, initial locations are sorted based on the fitness function. Therefore, new generation of the PMU locations are created by using the crossover and mutation operations. In the proposed CS-GA algorithm, mutation probability of the new population is calculated by the Levy Flights step of the CS algorithm. These steps are followed to select the optimum locations of one PMU and accordingly, combinations of the PMUs are taken into the next generations of the CS-GA algorithm. Therefore, combinations of the locations are generated in the initial populations and new generations to define the optimal locations of *N*-PMUs in IEEE-*N* bus systems.

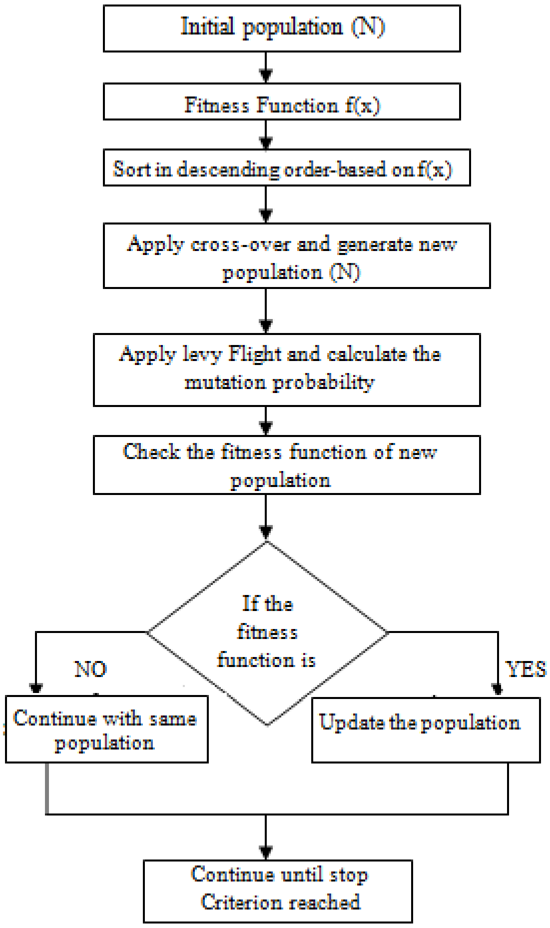

Figure.2. Flow chart of the proposed CS-GA algorithm

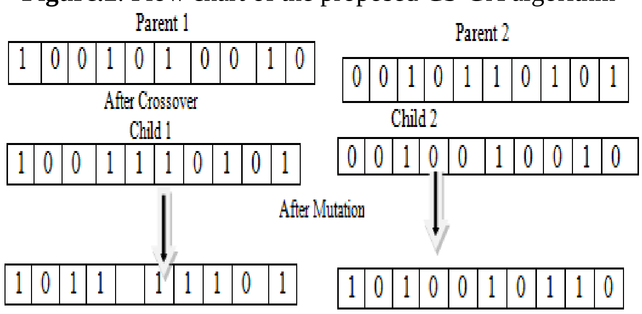

Figure 3: Crossover and Mutation operations in CS-GA algorithm

Simulation Results

In this section, we present the results of the optimal no. of PMUs and their optimal locations optimized using the proposed CS-GA algorithm. To prove the efficiency of the proposed method, we benchmark the connection and bus data of the IEEE-14, IEEE-24, and IEEE-30 and IEEE-39 bus systems. In table.2, the optimal no. of PMUs required for the IEEE-14 bus system using the proposed CS-GA algorithm is presented. To measure the full observability,3 PMUs are needed and their optimal locations are also presented in table.2 as 5, 4 and 6 respectively.

Table 2: Optimal PMU Placement results for IEEE-14 bus system

System	Optimal PMU	Connection	Total Coverage
IEEE-14 bus	1	4	5
	2	4,13	8
	3	5,4,6	11

In table.3, the optimal no. of PMUs required for the IEEE-24 bus system using the proposed CS-GA algorithm is presented. To measure the full observability, 8 PMUs are needed and their optimal locations are also presented in table.3 as 17, 8, 3, 16, 1, 10, 23 and 9respectively. From these results, we can see that the variation of the CS-GA algorithm with different set of bus systems since optimal location of one PMU is different for both the IEEE-14 and IEEE-24 bus systems. However, it brings the best solution when required PMUs are increased w.r.t. the size of the connection matrix.

Table 3: Optimal PMU Placement results for IEEE-24 bus system

System	*Optimal PMU*	*Connection*	*Total Coverage*
IEEE-24 bus	1	9	5
	2	10,16	9
	3	10,16,12	13
	4	16,10,11,15	15
	5	12,21,9,15,16	18
	6	10,9,15,16,11,21	19
	7	16,17,23,15,10,12,9	21
	8	17,8,3,16,1,10,23,9	22

Table.4. Optimal PMU Placement results for IEEE-30 bus system

System	*Optimal PMU*	*Connection*	*Total Coverage*
IEEE-30 bus	1	6	7
	2	10,6	12
	3	6,10,12	16
	4	10,6,15,2	19
	5	2,10,27,12,6	21
	6	25,6,10,6,15,27	22
	7	4,25,12,7,10,6,15	26
	8	6,2,15,25,27,12,4,10	29
	9	15,2,12,24,25,6,9,10	29

Table.5. Optimal PMU Placement results for IEEE-39 bus system

System	*Optimal PMU*	*Connection*	*Total Coverage*
IEEE-39 bus	1	16	5
	2	16,2	9
	3	26,6,16	13
	4	16,2,6,13	16
	5	6,16,2,26,3	19
	6	16,6,2,19,11,26	22
	7	29,17,2,16,22,6,5	24
	8	17,16,2,23,25,14,6,29	25
	9	16,25,2,6,23,26,22,10,14	26
	10	19,26,3,16,11,29,10,23,2,6	31
	11	22,19,25,8,23,6,2,3,11,16,26	32
	12	26,29,11,10,2,6,22,19,16,23,3,25	34

In table.4 and table.5, the performance of the proposed CS-GA is resented for the IEEE-30 and IEEE-39 bus systems respectively. For IEEE-30 bus system, totally 9 PMUs are required while 12 PMUs are needed to observe the full topology of IEEE-39 bus system.

5. Conclusion

In this paper, a hybrid of the Genetic algorithm and Cuckoo Search algorithm was presented in order to combine the advantages of the both optimization algorithms. The proposed CS-GA algorithm was presented to solve the optimization problems in the PMUs placement for the power system. The proposed CS–GA approach can find better optimal solutions for the IEEE N bus systems. The overall optimal solution obtained was efficient to take care of system observability under normal operating condition as well as for single PMU loss cases. The proposed method has only required minimum number of PMUs to cover complete observability of power systems. Experimental results have shown that the proposed CS–GA was more comfortable for finding the optimum no. of PMUs and their optimal locations in the IEEE-14, IEEE-24, and IEEE-30 and IEEE-39 bus systems.

References

[1] Vahid Behravesh, and Zahra Moravej'Optimal placement of Phasor Measurement Units in Khosran Network using a Hybrid Intelligent Technique' Journal of modeling and simulation in Electrical and Electronics Engineering(MSEEE) volume1, Number 1, Feb 2015..
[2] BeiGou," Optimal Placement of PMUs by Integer Linear Programming", IEEE Transactions on power systems, Vol.23, pp. 1525-1526, 2008
[3] M. Hurtgen, J.C. Maun," Optimal PMU placement using Iterated Local Search", Elsevier Electrical Power and Energy Systems, Vol.32,pp. 857–860, 2010
[4] Bindeshwar Singh ,N.K. Sharma , A.N. Tiwari, K.S. Verma, and S.N. Singh, "Applications of phasor measurement units (PMUs) in electric power system networks incorporated with FACTS controllers", International Journal of Engineering, Science and Technology,Vol.3,pp.64-82,2011
[5] N. M. Manousakis, G. N. Korres, and P. S. Georgilakis, "Optimal Placement of Phasor Measurement Units: A Literature Review", pp. 1-6, 2011.
[6] Rahul H. Shewale, Balakrishna Kethineni, Uma P Balaraju, S. K. Bhil, Prashant D and More, "Optimal Placement of Phasor Measurement Unit for Power System Observability By Heuristic Search Method", International Journal of Advanced Technology & Engineering Research, Vol. 2, pp. 128-133, 2012
[7] B.K. Saha Roy, A.K. Sinha, A.K. Pradhan, "An optimal PMU placement technique for power system observability" Elsevier Electrical Power and Energy Systems, Vol.42, pp. 71–77, 2012
[8] Vassilis Kekatos,Georgios B. Giannakis, and Bruce Wollenberg, "Optimal Placement of Phasor Measurement Units via Convex Relaxation", IEEE Transactions on power systems, Vol.27,pp. 1-15, 2012
[9] Nikolaos M. Manousakis, George N. Korres, and Pavlos S. Georgilakis, "Taxonomy of PMU Placement Methodologies", IEEE transactions on power systems,Vol.27,pp. 1070-1077,2012.
[10] Vahidhossein Khiabani & Kambiz Farahmand," Max Covering Phasor Measurement Units Placement for Partial Power System Observability", Engineering Management Research, Vol.2, pp.43-54, 2013
[11] Rodrigo Albuquerque Frazao, Aurélio Luiz Magalhães, Denisson Oliveira, Shigeaki Lima and Igor Santos," Optimal Placement of Phasor Measurement Units Using a Modified Canonical Genetic Algorithm for Observability Analysis", Mechanics Engineering and Automation, Vol.4, pp.187-194, 2014
[12] Billakanti.S and Venkaiah.C, "An effective binary integer linear programmed approach for optimal placement of PMUs in power systems", In proceedings of IEEE International Conference on Smart Electric Grid, pp. 1-8, 2014.
[13] Linda. O., Wijayasekara.D, Manic. M. and McQueen. M, "Optimal placement of Phasor Measurement Units in power grids using Memetic Algorithms", In proceedings IEEE 23rd International Symposium on Industrial Electronics, pp. 2035-2041, 2014.
[14] Fesharaki.F.H, Hooshmand and Khodabakhshian.A, "Simultaneous Optimal Design of Measurement and Communication Infrastructures in Hierarchical Structured WAMS", IEEE Transactions on Smart Grid, Vol. 5, pp. 312-319, 2014.
[15] Rather.Z.H, Zhe Chen, Thogersen.P and Lund. P, "Realistic Approach for Phasor Measurement Unit Placement: Consideration of Practical Hidden Costs", IEEE Transactions on Power Delivery, Vol. 30, pp. 3-15, 2015.
[16] Bei Gou and Kavasseri.R.G, "Unified PMU Placement for Observability and Bad Data Detection in State Estimation", IEEE Transactions on Power Systems, Vol. 29, pp. 2573-2580, 2014.
[17] Lei Huang, Yuanzhang Sun, Jian Xu and Wenzhong Gao, "Optimal PMU Placement Considering Controlled Islanding of Power System", IEEE Transactions on Power Systems, Vol. 29, pp. 742-755, 2014.
[18] Vahidossein Khiabani, Ergin Erdem, Kambiz Farahmand, and Kendall Nygard 'Smart Grid PMU Allocation Using Genetic Algorithm, Journal of Network and Innovative Computing ISSN 2160-2174 volume 2 (2014) pp.030-040
[19] A. G. Phadke, "Synchronized phasor measurements in power systems", IEEE Transactions on Computer applications in power, vol. 6, pages. 10-15, April 1993.[8] A. G. Phadke, J. S. Thorp, and K. J. Karimi, "State Estimation with Phasor Measurements", IEEE/PES on power systems conference and exposition, pages. 1-7, March 2009.
[20] J.L.Wang, L.Xia, "Optimal PMU placement of the power system based on incidence matrix for direct solution of power flow", Vol. 15, pp. 869-876, 2012.
[21] V.Siyoi,S.Kariuki and M.J Saulo"Strategic PMU placement for stability enhancement' International Journal of Energy and Power Engineering", 2015;4(2-1): 81-94

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