PAPER • OPEN ACCESS

Integer linear programming and genetic algorithm (GA)for the optimum placement of phasor measuring units for smart grid

To cite this article: R. Nafeena et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 993 012070

View the article online for updates and enhancements.

You may also like

- <u>A Clustering Based Approach for</u> <u>Observability and Controllability Analysis</u> <u>for Optimal Placement of PMU</u> Ch Murthy, MIEEE, D K Mohanta et al.
- Connectivity Matrix Algorithm: A New Optimal Phasor Measurement Unit Placement Algorithm A I Al-Odienat, K Al-Awasa, M Al-Momani et al.
- <u>An Incomplete Observability-Constrained</u> <u>PMU Allocation Problem by Using</u> <u>Mathematical and Evolutionary Algorithms</u> Nikolaos P. Theodorakatos, Rohit Babu and Angelos P. Moschoudis





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 3.133.159.224 on 12/05/2024 at 06:37

Integer linear programming and genetic algorithm (GA) for the optimum placement of phasor measur ing units for smart grid

R.Nafeena¹, M.Ettappan², M.Monica³, K. Chandrasekar⁴, M.Rathi⁵, A. Abdul Munaf

¹Associate Professor, Department of Electronics and Communication Engineering, Kings Engineering College, Chennai, crescent.research2011@gmail.com

²Professor, Department of Electrical and Electronics Engineering, Chennai Institute of Technology, Chennai, ettappanm@gmail.com

³Assistant Professor, Department of Electrical and Electronics Engineering, Rajalakshmi Institute of Technology, Chennai, mmonica1490@gmail.com

⁴Professor, Department of Mechanical Engineering, PSN College of Engineering and Technology, Tirunelveli.,kcstv176@gmail.com

⁵Professor, Department of Electronics and Communication Engineering, Kings Engineering College, Chennai, rathiraghav24@gmail.com

⁶Associate Professor, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, munaf.rafan@gmail.com

Abstract. For the optimal replacement of phasor measuring units (PMUs) in the presence of conventional measurements, the integrated linear programming (ILP) and genetic algorithms are proposed. In fact, the power system remains fully measurable for the lines and measuring instruments during all conceivable single contingencies. In doing so, a process of equations entirely utilizes the capability of circuit equations related to standard measurements and PMUs, and the system topology, to attain the minimum possible amount of required PMUs.

Keywords:Phasor Measurement Unit, Integer Linear Programming, Genetic Algorithms, Smart Grid

Introduction 1

Until recently, there is no common time reference to find measurements in distant locations of a large power grid. The PMU is, more importantly, a GPS synchronized device which makes it more reliable than RTU because of a time tag attached with its measurement. The RTU measurements are prone to have time skew between them due to communication delays apart from the general noise inherent in the measurements

(Abido2002). Phasor measuring units (PMUs) are instruments that calculate power system voltage and current synchrophasors with precision in the order of 1 microsecond.PMUs are the most appropriate instruments for output of Wide Area Monitoring System (WAMS). Operators may however intend to integrate PMUs with existing conventional measurements to increase the executive ability of the power system monitoring.Manyresearchers had suggested that a system of linear equations may be generated by zero injection equations. Using combination methodology, the equations for zero injection are considered since equations system. From Figure 1 it's observed that for checking of the 4 bus systems, only 2 PMUs are sufficient. Here PMUs are positioned at 2 buses, which allow the entire observability of the 4 buses. All of a lot and DGs are linked to the power grid through smart meters.



Figure 1 Typical 4 bus smart grid

2. Related works

Phadke (1993)[1] Discussed the synchronized phasor measurement in power system. The value of measurements of phasor and phase angle between remote points of a device was recognized. There have been many attempts to synchronize the phasor measurements. One of the applications of phasor measurement is performed for monitoring and secure operation.

Baldwin *et al.* (1993) [2] implemented minimum phasor calculation of the power system observability. The system observability is assessed through numerical and topological. The PMU placement issue had addressed in a few literatures. The issue was initially released in this work.

BeiXu& Ali Abur (2004) [3] explained the analysis about the observability and phasor measurement placement of system. The research also creates a linear estimator based on PMU measurements and focuses on the device output and the issue of bad data processing. Simulations are used to detect and identify PMU failures.

Nuqui&Phadke (2005) [4]provides the concept level of unobservability. The results of the tests show that the PMUs are located and that the gap between overlooked and unserved buses is not too big. To address the problem of restricted PMU placement the simulated recycling technique is used.

Milosevic &Begovic (2003)[5]addressed an optimal phasor measuring device putting non-dominated genetically sorted algorithm that addresses the issue by means of two

competing goals, such as PMU number minimization and redundancy calculation maximization.

Chen &Abur (2006)[6] presented the minimization of strategically located PMUs the eliminate measurement critically in the entire system. The placement problem is then taken into account standard measurements as candidates for placement. Problems may be used where a necessary degree of local redundancy is needed to decide the optimal locations. This makes the creation of systems that are vulnerable to measurement errors and bad data at various levels.

Gou (2008)[7] presented the optimal placement of PMUs by integer linear programming considering and without considering zero injections. The problem is modeled as the linear problem and solved by integer linear programming.

Penget *al.* (2006)[8] presented Tabu search algorithm for optimal PMU placement. The merits of a phasor measurement unit have to give synchronize with a real system and share the parameter of the system and different to the traditional SCADA measurement devices. Computationally the OPP problem is nonlinear, non continuous and multimodal having a non convex, non smooth. The observability conditions that have to be met for selecting the placement sets are discussed.

PathirikkarGopakumar*et al.* (2013)[9]provides the Novel Multi Stage Simulated Annealing for optimum Placement of PMU along with Conventional Measurements. A phasor measurement unit used to achieve the observability and redundancy in the power grid network. Indian grid network is used as test systems in this work.

Jamuna&Swarup (2011) [10] presented the optimal location for protection restricted state estimates in measurements by PMU&SCADA has been addressed. In power system the utilization of supervisory control data acquisition and synchronized method for monitor and control the system. In normal operation the genetic algorithm is used for optimal placement of measurement unit using integer programming method. The Jacobian matrix is used to decrease the PMU and to get the desired condition. The heuristic method has utilized with and without contingency for reducing the placement of PMU.

Ali Enshae*et al.* (2012) [11] implemented a new approach for optimum PMU placement using linear binary integer programming to ensure complete power system observability as well as maximum measuring reliability in the max-imaging framework. In addition, in the case of the single PMU failure or single interruption, the issue of the optimum location of these units is investigated. The proposed wording also considers a realistic cap for the maximum number of PMU channels. In all the investigations, the result of zero injection buses in the energy system was considered. The effectiveness of the suggested method was evidenced in conditions that are different.

Chakrabarti&Kyriakides (2008) [12] provides the number of re-compulsory PMUs to make full network measurable for both regular and outage transmission line or PMUs decreases the integer-quadratic-optimization problem and maximizes the reliability measurements of all system buses.

Seyed Mahdi Mazhari*et al.* (2013) [13]introduces the positioning approach in the electric transmission networks of multi-objective phasor measurement units (PMUs). The early PMU formulations to simultaneously specify the minimum number of PMUs and the maximum reliability of measurement. In addition, a new observability evaluation approach, including line interruptions and PMU losses, is introduced under containment. In the presence of traditional non-synchronous measurements, the general feature for the allocation of PMUs is also added. With the Cellular Learning Automatics (CLA), new local CLA rules are being implemented to improve the optimization process. The optimization problem is solved.

3. Proposed Work:

Here is presented an Integer linear programming (ILP) structure for optimum positioning of phasr measuring units (PMUs). The power system for lines and measuring devices rem ains fully measurable during all single contingencies. The method is applied on several IEEE test systems already fitted with conventional measurements. In the presence of traditional measurements, the contrast between the results obtained from the work shows its uniqueness in modeling robust PMU placement problem (OPP) [14]. Assume the PMU installed at bus i measure that bus's voltage phasor directly. If this PMU also calculates current line phasor, an equation shall be obtained as follows:

$$g(V_{i,}V_{j}) = \frac{D_{i,j}}{B_{i,j}}V_{i} + \left(C_{i,j} - \frac{A_{i,j}D_{i,j}}{B_{i,j}}\right)V_{j} = I_{i,j}$$
(1)

Based on Kirchoffs Current Law the following equation is constructed

$$g(V_{1,\ldots,N}V_N) = \sum_{i \in B} Y_{k,i}V_i = \frac{S_k}{V_k^*}$$
(2)

Additionally, $Y_{k,i}$ is the k-ith entry of the matrix for network admission.Direct measurements is measurement obtained from PMU, indirect measurements are calculated measurements. Both can be used to reduce the number of PMU.

OPP is characterized as finding the minimum number of required PMUs in order to make the network completely observable by their proper positioning. The more the number of buses that can be detected by standard calculation equations and zero injections, the fewer the number of buses that must be observed using PMUs. Therefore, it is necessary and sufficient for a rigorous OPP to deploy the entire potential of the network equations.

3.1 OPP considering limitation of measurement channels

Constraint included to limit number of Channels is

$$\sum_{i \in B} a_{i,j} C_{i,j} \leq C_j^{MAX}$$
(3)

Consequently, the constraint of observability per bus is as follows:

$$f_{i} = \sum_{j \in B} a_{i,j} C_{i,j} + \sum_{j \in M} a_{i,j} y_{i,j} + \sum_{j \in M} a_{i,j} r_{i,j} \forall_{i} \in B$$
(4)

4. Results and discussions

In this work, all the cases were carried out for optimal placement of PMUusing the evolutionary algorithm. For simulations MATLAB 12 in Intel i5 processor 2.5 GHz and 6 GB RAM has been used.

The final conclusion is technique reduces the computational time of the cases and permits a computationally efficient algorithm to be developed. To verify our proposed approach, all the simulations are carried out using the test system data such as IEEE 57, IEEE118system.

4.1 test systems

To verify our proposed approach the test system data used are IEEE57, IEEE118, shown in Figure 2

a)IEEE 57 BUS DIAGRAM



Descriptions:

The IEEE 57 bus system has 7 generating units,42 load lines and 76 branches.

4.1 algorithm result

a)Branch and Bound Technique (57 Bus System)

Table 1 gives number of PMU computation time and fitness value of 57 bus system using branch and bound technique including zero injection bus.

Table 1 Branch and Bound Technique (57 Bus System)

Fitness value	No. of PMU	Elapsed time
222	32	1.54 sec

b) Genetic Algorithm (57 Bus System)

Table 2 gives number of PMU computation time and fitness value of 57 bus system using Genetic Algorithm including zero injection bus.

Table 2 Genetic Algorithm (57 Bus System)				
Fitness value	No. of PMU	Elapsed time		
91	26	5.61 sec		

b) IEEE 118 BUS SYSTEM



Fig 3 IEEE 118 bus system

Descriptions:

Figure 3IEEE 118 bus system has 186 branches,91 load sides,54 thermal units.

By comparing the two algorithms we understand that the fitness value is reduced from 222 to 91 and the number of PMUs in the genetic algorithm is reduced from 32 to 26 but the time needed for iteration is increased from 1.54 sec 5.61sec.

c) Branch and Bound Technique (118 Bus System)

Table 3 gives number of PMU computation time and fitness technique of 118 bus system using branch and bound technique including zero injection bus.

Table 3 Branch and Bound technique (118 Bus System)					
Fitness value	No. of PMU	Elapsed time			
380	64	2.83 sec			

d) Genetic Algorithm (118 Bus System)

Table 4 gives number of PMU computation time and fitness value of 118 bus system using Genetic Algorithem including zero injection bus.

 Table 4 Genetic Algorithm (118 Bus System)

 8		
Fitness value	No. of PMU	Elapsed time
304	50	8.98 sec

By comparing both algorithms we understand that the fitness value is reduced from 380 to 304 and that the number of PMUs in genetic algorithm is reduced from 64 to 50 but the elapsed time is increased from 2.83sec to 8.98sec.

4.2 Fitness Generation a) Fitness- Generation (57 Bus Sy





Figure 4Fitness - Generation (57 Bus System)

The figure 4 shows the Fitness-Generation graph for a 57 bus system. The Genetic Algorithm gives the best fitness value as 91. The next figure shows the Genetic Algorithm stop criteria.



b) Fitness-Generation (118 Bus System)

The figure 5 shows the Fitness-Generation graph for a 118 bus system. As of 304, the Genetic Algorithm gives the best fitness value. The next figure shows the Genetic Algorithm stop criteria.

5. Conclusion

PMU is one of the most essential measurement products in the future of energy systems. The difference comes from the unique power of its in supplying synchronized phasor measurement of currents and also voltages from extensively dispersed locations in an electrical energy grid. The optimum number of PMU for different test systems obtained for normal operation, including ZIB and contingency is simulated. The results obtained were compared with and without redundancy. The comparison of the result with previous studies shows the number of PMUs are reduced in the proposedmethod. Comparing converging trend using single objective algorithms of Branch and bound and GA, GA to be one of the best hunt strategies down expansive, complex, and misty inquiry space. Additionally, the algorithm time is less compared with past studies.

References

- [1]. Phadke, A.G. 1993, 'Synchronized phasor measurements in powersystems', IEEE Comput. Applicat. Power, vol.**6**, no.2, pp.10-15.
- [2]. Baldwin, T.L, Mili, L, Boisen, M.B&Adapa, R, 1993, 'Power system observability with minimal phasor measurement placement', IEEE Transactions on Power Systems, vol. 8, no. 2, pp.707-715.
- [3]. Xu B &Abur A 2004, 'Observability analysis and measurement placement for systems with PMUs', In: Proceedings of the IEEE PES power systems conference and exposition, vol. 2, pp. 943–6.
- [4]. Nuqui, R.F&Phadke, A.G 2005, 'Phasor measurement unit placement techniques for complete and incomplete observability', IEEE Transactions on Power Delivery, vol. 20, no. 4, pp.2381-2388.
- [5]. Milosevic.B and Begovic.M, "Nondominated sorting genetic algorithm for optimal phasormeasurement placement," IEEE Trans. Power Syst., vol. 18, no. 1, pp. 69–75, Feb. 2003.
- [6]. Chen, J &Abur, A 2006, 'Placement of PMUs to enable bad data detection in state estimation', IEEE Trans. Power Syst., vol. 21, no. 4, pp. 1608–1615.

- [7]. Gou.B, "Optimal placement of PMUs by integer linear programming," IEEE Trans. Power Syst., vol. 23, no. 3, pp. 1525–1526, Aug. 2008.
- [8]. Peng.J , Sun.Y, and Wang H.F , "Optimal PMU placement for full Network observability using Tabu search algorithm," Elect. Power Syst. Res., vol. 28, no. 4, pp. 223–231, May 2006.
- [9]. Gopakumar, P, Chandra, G.S, Reddy, M.J.B&Mohanta, D.K 2013, 'Optimal placement of PMUs for the smart grid implementation in Indian power grid—A case study', Frontiers in Energy, vol. 7, no. 3, pp.358-372.
- [10]. Jamuna, K &SwarupK.S 2011, 'Optimal Placement of PMU&SCADA measurements for security constrained state estimation', International Journal of Electric Power & Energy system, vol. 33, pp. 1658-1665.
- [11]. Enshaee, A, Hooshmand, R.A&Fesharaki, F.H 2012, 'A new method for optimal placement of phasor measurement units to maintain full network observability under various contingencies'. Electric Power Systems Research, vol. 89, pp.1-10.
- [12]. S. Chakrabarti and E. Kyriakides, "Optimal placement of phasormeasurementunits for power system observability," IEEE Trans. Power Syst., vol. 23, no. 3, pp. 1433-1440, Aug. 2008.
- [13]. Mazhari, S.M, Monsef, H, Lesani, H & Fereidunian, A 2013, 'A multi-objective PMU placement method considering measurement redundancy and observability value under contingencies', IEEE Transactions on Power Systems, vol. 28, no. 3, pp.2136-2146.
 [14]. Nafeena. R, WilljuiceIruthayarajan. M, "Modified Spectral Clustering based Redundant
- [14]. Nafeena. R, WilljuiceIruthayarajan. M, "Modified Spectral Clustering based Redundant Placement of Phasor Measurement Unit Using Multi Objective Non Dominated Sorting Evolutionary Algorithms", Cluster Computing, Springer, pp.2-14, Feb 2018.