Ashu Priya, et al. 2021, 9:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology

An Open Access Journal

Optimal Placement of PMU Considering Effect of Zero Injection Buses for Monitoring Advanced Grid

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Abstract- With the goal of linear static state estimate of electrical grid networks, this study proposes three distinct deterministic algorithms for optimal placement of Phasor Measurement Units (PMU). The first method, called Depth First Search (DFS), finds various solutions with a small number of PMUs, whereas the second method, called Recursive Security N (RSN) is a modified depth first method, and the third one is Integer Linear Programming (ILP). These methods were used to determine the ideal location for all of the buses to be visible. The test has been performed on several IEEE test networks. The outcomes of heuristic based approaches are compared.

Keywords: Phasor Measurement Unit, DFS, RSN, ILP, and Linear Static State Estimation.

I. INTRODUCTION

Now-a-days electrical power network has become very large and complex. And hence the occurrence of any contingency is possible. Therefore, the immediate and precise monitoring of power system is required. To maintain the security and optimal operation of power system we need to know the operating state of power system. The idea of state estimation comes based on this requirement.

The state estimation is basically the finding of operating state of power system using the information provided by the measurement units placed on the system. The main concept of estate estimation is power system observability. If we can observe the voltage and angle at every bus using the measurement units then the power system is said to be observable.

In order to solve the optimal PMUs placement (OPP) problem, large number of algorithms are present in literature. These methods are basically classified into conventional methods, advanced heuristic and modern meta-heuristic methods. Linear programming (LP), Non-linear programming (NLP), Dynamic programming are common optimization methodologies proposed to solve this problem of OPP. Problem like difficulties in obtaining local minima, handling constraints in conventional techniques are overcome by advanced heuristic and modern meta-heuristic optimization methodology. Advanced and modern heuristic techniques are simulated annealing, depth first search, tabu search, minimum spanning tree, immune algorithm, genetic algorithm, differential evaluation, particle swarm optimization or ant colony optimization.

1.Phas or Measurement Units

Phasor measurement units are the synchronized electronic devices that provides the synchronized phasor measurements of current and voltages. By time stamping the current and voltage waveform using a reference signal provided by GPS (Global Positioning System) synchronism is achieved.

2. Formulation of Optimal PMU Placement Problem

A phasor measurement unit measures the voltage and current phasor from the bus where it is installed. Without the PMU it is uncommon to measure direct phase. As shown in figure 1. Anti-aliasing filter filters out the input waveform frequencies above the Nyquist rate. The Phase locked oscillator converts the GPS pulse per second into a sequence of high-speed timing pulses used in the waveform sampling. The Phasor microprocessor performs the Discrete Fourier transform (DFT) phasor calculations. Finally, the 2 time-stamped phasor is uploaded to data concentrator.

Our aim is to observe the network completely with an optimum number of phasor measurement units. For n-bus system in power systems.

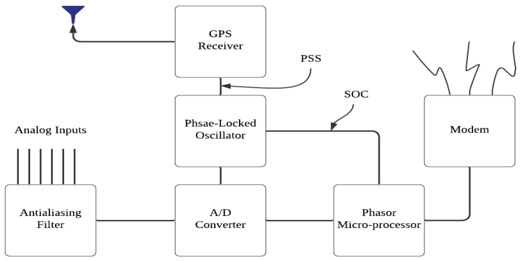

Figure 1: Phasor Measurement Unit

The problem formulation and its solution are given as

$$\min \sum_{i}^{n} w_i x_i$$

Subjected to $f(x) \geq \hat{I}$
where x is binary decision variable vector,
i = bus number,
$x_i = 1$ if a PMU is located at bus I,
$x_i = 0$ Otherwise
w_i is cost of PMU which is installed at ith bus,
$f(x)$ is vector function.
$f(x)$ has zero entry if the corresponding bus voltage is unobservable and $\hat{I}$ is vector having all entries as one. The constraint function is defined by matrix A, which is binary connectivity matrix. The information about connectivity of bus of power network is given by matrix A. Defining the elements of matrix A as,

$$A_{m,n} = \begin{cases} 1, \text{if bus m} = \text{bus n} \\ 1, \text{if bus m and bus n are connected} \\ 0 \text{ otherwise} \end{cases}$$

The constraint equations are for three cases:
1) For PMU measurement only.
2) For PMU measurements and injections (i.e. zero injections), and
3) PMU measurements, injections and flows.

3. Programming Methods for Optimal PMU Placement

Several optimization techniques are available in the literature for optimal PMU placement here in this paper depth first search and recursive security N methods are used for optimal PMU placement. The main objective of this work is to find out the minimal number of PMU placement and to maximize the accuracy of state estimation. The algorithms should take care of a) zero injection buses identification, b) outage of communication line and c) PMU placement phasing.

4.Integer Linear Programming

For the basic ILP, the OPP's mathematical equations are first formulated. After that, utilizing ILP, the effect of a single ZIB is included into the OPP. Finally, we provide the proposed strategy for adding the effect of a set of ZIBs into the OPP model.

II.DEPTH FIRST SEARCH ALGORITHM

It searches for tree of graph data structures. The program starts by selecting arbitrary node as a root node and explores as far as possible to each branch before backtracking. The PMU is placed at the tree branch which is connected as large number of branches as possible. If more than one such roots or nodes are available then randomly on node is chosen. Following the same way PMU were placed till the whole tree becomes observable. If the tree contain all the node of system then it is called observable system.

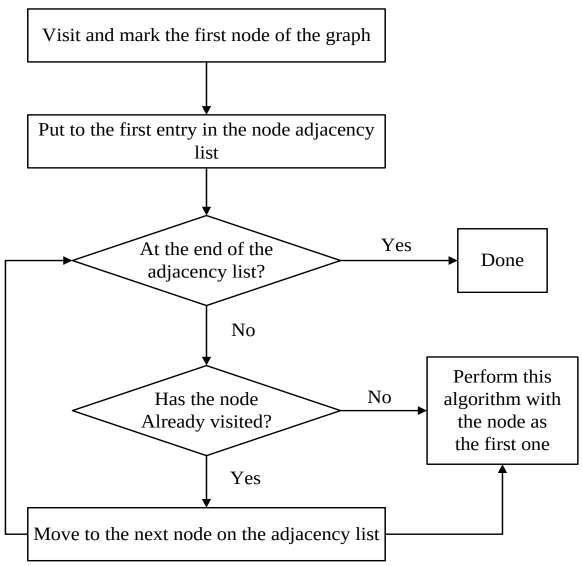

Figure 1: Flow chart of depth first search algorithm.

III.RECURSIVE SECURITY N ALGORITHM

The spanning tree search technique, which includes many solution structures, is the foundation of the recursive security algorithm. To achieve a better result, recursive security algorithm use a verity of starting places. By maximizing the system's observability, the PMU placement site for all buses was decreased using the power system analysis toolbox's recursive spanning tree approach. RSN algorithm is reliable and it is proved by applying this algorithm in IEEE 14, 30, 57, 118, 39 Bus system.

IV.RESULTS AND DISCUSSION

In this paper the code has been written on MATLAB environment for various bus test system. IEEE 14 bus, IEEE 30 bus, IEEE 39 bus, IEEE 118 bus and IEEE 57 bus test systems were used for the optimal placement of PMU. The DFS and RSN algorithms were used for the optimal placement of PMU and the results were compared.

For different bus system number of PMUs required, placement of PMUs and the time required to run the program are given in table 1 and table 2 with depth first search algorithm and recursive security N algorithm respectively.

Table -1: Depth First Search Algorithm

S. No.	Bus System	No. of PMUs	Placement of PMUs	Time (sec)
1	IEEE 118 BUS	42	1,5,9,12,13,17,19,21,25,28,30,32,36,37,41,43,46,49,52,57,58,59,62,65,70,72,73,77,80,83,86,89,91,93,95,100,102,105,110,115,116,118	0.096996 sec
2	IEEE 57 BUS	19	1,4,7,9,15,19,21,24,27,30,32,36,38,39,41,46,50,52,54	0.020995 sec
3	IEEE 30 BUS	10	1,5,6,10,11,12,18,24	0.007316 sec
4	IEEE 14 BUS	6	1,4,6,8,10,14	0.001748 sec
5	IEEE 39 BUS	16	2,4,6,8,10,12,16,18,20,22,26,33,36,37,38,39	0.013014 sec

Table -2: Recursive Security N Algorithm

S. No.	Bus System	No. of PMUs	Placement of PMUs	Time (sec)
1	IEEE 118 BUS	36	1,13,12,19,36,5,9,29,115,21,43,37,32,25,59,53,62,58,41,57,72,46,110,105,49,70,118,101,78,80,94,91,82,89,84,86	98.893593 sec
2	IEEE 57 BUS	12	32,30,56,38,51,54,27,13,1,29,19,4	81.018028 sec
3	IEEE 30 BUS	7	3,19,7,12,10,27,24	15.277057 sec
4	IEEE 14 BUS	3	2,9,6	0.480374 sec
5	IEEE 39 BUS	9	20,23,29,16,25,1,19,3,8	70.959585 sec

Table -3: Integer Linear Programming Algorithm

S. No.	Bus System	No. of PMUs	Placement of PMUs	Time (sec)
1	IEEE 118 BUS	29	3,8,11,12,17,21,27,28,31,32,34,40,45,49,52,56,62,65,72,75,77,80,85,86,91,94,101,105,110	0.198400 sec
2	IEEE 57 BUS	19	1,4,7,9,15,19,21,24,27,30,32,36,38,39,41,46,50,52,54	0.020995 sec
3	IEEE 30 BUS	6	6,9,22,25,27,28	0.154700 sec
4	IEEE 14 BUS	3	2,6,9	0.110100 sec
5	IEEE 39 BUS	11	3,,8,10,16,20,23,25,29	0.013014 sec

IV.CONCLUSION

The accurate measurement offered by the phasor measurement unit devices in one handy technique to evaluate the system state. But due to the high cost of this device (PMU) motivates the researchers to find the optimal placement of PMU device. So as to get low cost monitoring system. This paper offers two different optimal algorithms Depth First Search (DFS) and Recursive Security N (RSN). The program has been run on five different bus system. IEEE-14, 30, 39, 57, 118 bus system. In terms of the time taken by algorithm to provide solution DFS is faster than RSN. Whereas, the number of PMU required for placement is lesser in RSN than DFS.

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