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COMPLETE MANAGEMENT OF SMART DISTRIBUTION SYSTEM

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ABSTRACT

Phasor measurement units measure the current and voltage phasors of the connected nodes (buses) at the installation point. Thus by choosing proper number of PMUs the system can be made completely supervised. A PMU costs very high, so it is important to supervise the power system network with minimum units. To monitor the entire power system distribution network with minimized number of PMUs in smart grid, this paper proposes a linear algorithm. For dynamic analysis and state estimation, fault diagnosis, time rate of power flow and behavior of system under various circumstances for these events, data must be highly synchronized in time, so that real time inspection and operation of the system can be made available for decision making in smart grid.

KEYWORDS: Smart grid, PMU, GPS, Power system.

I. INTRODUCTION

Recent changes in distribution network [13, 24] formed a highly complex network. Without appropriate control strategies, the system losses, power quality [31-36] and service problem along with customer dissatisfaction has increased [14-23, 25 and 26]. Presently, open loop supervisory system is used to supervise the power system elements to collect the data at different points to generate control and protection commands. Computer aided software with steady state security function, is used to generate the control action by the system operators. The main fact behind this is SCADA measurement systems [1] which are designed for capturing the semi-steady state conditions of operation thus limiting to monitor only the transient conditions in the system. With the development of Phasor Measurement Units (PMUs), very fast transient events can be easily located at very high rate of sampling [2]. Thus, a closed loop control action can be generated which can automatically control the system behavior by monitoring it. This will control the system in very quick manner than a real time control can do, to facilitate voltage and power stability [27, 29, and 30] by initiating corrective action in case of mal-operation and emergency situations. Voltage and current phasors [3], i.e., magnitude and angle of the measured quantity, are measured at the bus where PMU is installed. PMUs are widely used in Smart Grid structure for state estimation, control action generation and for analysis of transient events etc. So, to measure the voltage and current at every bus to exploit PMU abilities, PMU may be installed at every node in the system to observe the state of the system. But the cost of PMU is very high, so, by choosing such solution in very huge and complex system, a very high expenditure occurs. Therefore, alternative ways are required to select adequate units for system observation, keeping cost as a fact of installation [4]. The cost of PMU is function of design characteristics as well as number of communication ports [28] used to record and transmit data from one point to the other point. So, selection of PMUs which are adequate for supervisory system to make distribution system completely observable [5] as well as keeping the lowest possible installation cost, is required. In literature, rigorous studies have been done to estimate the optimal units required for system supervision, in last years. Generally, numerical based and topological based methods have been used by the researchers.

In topological based methods, graph theory is used for calculation while in numerical based technique measurement, Jacobi matrices are numerically factorized. For a large system, numerical calculation requires tremendous efforts as they involve high dimension matrices and causes complex computational calculations [6].

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Modeling the system buses as vertices and line by edges, the problem can be formulated like a domination problem. This problem can be solved by topological observation theory. For a system to be considered as observable, the rules are listed below [7]:

Rule1: A bus with PMU installed and buses connected to it are observable as voltage and currents of the attached buses forming a node, can be calculated by Ohm's law with the measured values of PMU.

Rule 2: A bus connected to zero power injection bus (where net injected power from any other generator or load is zero) and other connected buses are observable.

Rule3: When all observable buses are connected to zero injection then zero injection bus is also observable as its parameters can be calculated by Kirchhoff's and Ohm's laws.

If initial guess for PMU placement is good enough then quick solutions for the transients are achievable. The algorithm developed here is tested over a variety of distribution networks and proven to have excellent solution and very efficient. For a power system network having k vertices of at least degree of 3, the required number of PMUs can be mathematically calculated as follows [8]:

$$\alpha p(T) \geq (k+2)/3 \qquad (1)$$

$$\alpha p(T) \leq n/3 \qquad (2)$$

where, n is considered as the number of vertices in the distribution network.

Equations (1) and (2) give the maximum and minimum number of PMUs required for the complete observability of distribution network. The values calculated here may or may have not considered the tree topology of the network [9]. The results obtained by the proposed algorithm generate the required number of PMUs that are sufficient for the system supervisory. An algorithm to calculate the number dominant set "S" was suggested by Haynes et al. [8] and a complete set G, i.e., power system was divided into number of parts (equal to S) such that every subset produces a "spider". Different topological based algorithms were developed by different authors including tabu search algorithm, linear integer programming, genetic algorithm and artificial intelligent techniques etc. But, these algorithms are highly complex and time consuming and require dedicated hardware and software tools. We are most interested to find the most appropriate location to install a PMU so as to bring a coordination to initiate the protection step required for a situation. Considering the upper and lower limits [10], the algorithm proposed in this paper is especially effective for small scale distribution system

II. THE PROPOSED ALGORITHM

Power system node-incidence matrix formulation

The topological information of the power system interconnected buses can be utilized to formulate a group known as node incidence matrix. From a node incidence matrix, it is easy to see the pattern of interconnections.

Normally in large distribution system, the node incidence matrix "A" is highly sparse matrix, since interconnections between the buses are very less. If we consider IEEE 18-bus system, the incidence matrix is given as:

= [0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 0 0 0
0 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0
0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0
0 0 0 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 1 0 0 1 1 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0
0 0 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0]

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Figure:

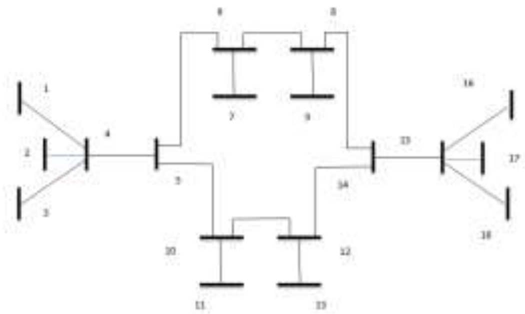

Figure 1. IEEE 18-Bus power system.

The node incidence matrix "A" is formulated depending upon a very simple rule:
For example, if any node "i" is connected to other node "j", then in incidence matrix, the value of element A_{ij} = 1, where $i \neq j$ and zero otherwise.

The number of nodes (buses) connected to each other is the degree of that node. Here, in IEEE-18 bus architecture, there are 8 nodes having degree 3 or more. So, it gives the value of k=8 and n=18 and hence, the number of PMUs required will lie between 3 and 6, i.e., a solution obtained from equations (1) and (2). By using the proposed linear algorithm, the minimum PMUs required for complete observability of the distribution network is to be calculated. Trying all possible combinations of the nodes according to the observation rules stated above, a final set is not achieved until the complete distribution network will be observable. Each set (measurement), ranging from 3 to 6, is called for valedictory. After selecting 3 units and checking the observability, if solution does not converge then 4 units will be selected. The process is repeated up to 6 units, until the final solution is not obtained. One set of PMU units for which the solution is investigated is called as a measurement. A total of 70 measurements are carried out to get the final set required for IEEE 18-bus system supervision. For getting the solution for the observability problem, it is not necessary to run the complete set of 70 measurements. To get the S-set, the number of measurements can be any value from 1 to 70 and there can be multiple solutions for the same number of PMUs, i.e., the same number of PMUs can be located at different bus locations for complete observability of the distribution network.

Process to calculate the number of PMUs required for a distribution network

1. After reading the incidence matrix "A", let G is the total number of buses present in the system.
2. By equation (1) and (2), calculate the maximum and minimum unit requirements of dominating set "S".
3. The observability of the system is checked by creating loops, considering minimum units first and then going toward maximum limit by increasing one unit at a time:
    i. A combination of nodes (buses) equal to the PMUs is generated say, {2, 6, 9}. PMUs, installed on these nodes, are observed. Create an array say "O", to store these nodes.
    ii. Now, the number of adjacent nodes to these three nodes is filtered out.
    iii. These nodes are saved in "O" array.
4. Next step is to find the nodes that are not available in array and that is quite easy by inspecting the array "O".
    i. Pick an arbitrary node say, j and by rule 4, the observability of the node is confirmed. If node is observable then add it to array "O" and check for the next node.
    ii. If all nodes those were not initially present in the array "O", have been checked then comparison of the whole array "O" with the complete set G is done to confirm the observability of the whole distribution system.
5. If O=G, then the whole network is observable and the selected set is a solution of the observability problem, otherwise, generate next combination of the nodes and repeat steps from 1 to 5.
6. If for the dominating set "S", the observability condition is not satisfied then increase the number of units selected in previous case, by one toward the maximum units required.
7. The number of measurement is equal to the total number of combinations tried for the solution to converge. Give the number of measurement as output.

III. RESULTS

The observability of the IEEE-14, 18 and 30 bus structures is verified by the proposed linear algorithm. The algorithm implementation is done in MATLAB. Table 1 summarizes the obtained results. A comparison of the available techniques is done with the proposed algorithm [6] [8]. It is clear from the table that the solutions obtained by the proposed algorithm are better and at the same time, the proposed algorithm is comparatively much simpler than the others.

Tables:

Table 1. Comparison of Results with different Algorithm

IEEE-BUS STRUCTURE	TECHNIQUE	PMUS REQUIRED
IEEE-14	Proposed Algorithm	3
	Dual search	3
	Graphic Theoretic Procedure	5
IEEE-18	Proposed Algorithm	4
IEEE-24	Proposed Algorithm	6
IEEE-30	Proposed Algorithm	7
	Graphic Theoretic Procedure	11
	Genetic Algorithm	7

IV. CONCLUSION

The proposed algorithm is proved to be very advantageous on account of mathematically proven graph theorems as well as the maximum and minimum limits to verify the system observability. The proposed algorithm reduces the computational efforts required to have solution for distribution system observability problem. Solution obtained from the proposed algorithm guarantees the least number of PMUs required as compared to the techniques proposed in [9] and [11]. The proposed algorithm is much simpler as compared to many other intelligent techniques available in literature. The results correspond that the proposed algorithm provides quick and better solutions as compared to numerical and topological based algorithms for full scale supervision of the distribution network [12]. For further study, we can try to find such solutions which give lesser capital investment for the PMU placement as the number of communication port, environmental concerns, technological issues and life cycle also contributes to the cost/unit of a PMU in the system.

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