STATE ESTIMATION IN ELECTRIC DISTRIBUTION NETWORKS IN PRESENCE OF DISTRIBUTED GENERATION USING THE PMUs

Mahdi Haghifam
Sharif University of Technology, Iran
mahdi.haghifam@sharif.edu

Mahmoud-Reza Haghifam
Tarbiat Modares University, Iran
haghifam@modares.ac.ir

Babak safari chabok
Tarbiat Modares University, Iran
babak.safari@ieee.org

ABSTRACT:

Regarding the high cost of PMU units, optimal placement and minimizing of their numbers are of great importance. Also, this paper proposes a new procedure for determining the optimal placement and less numbers of PMUs in distribution network based on the best state estimation criterion. For DSE solution, combination of Nelder-Mead (NM) simplex search and Ant Colony Optimization (ACO) algorithm have been used. The hybrid method can estimate voltage phasor at each node by minimizing difference between measured and calculated values of state variables and also, it can guarantee observability of distribution system under normal operation conditions. To demonstrate the effectiveness of new procedure, simulation studies are applied on 30-bus radial test feeder. Finally, achievement results for convergence characterestic of DSE solution and estimation error of state variables with regard to the optimal placement and numbers of PMUs in distribution test feeder have been presented.

1. INTRODUCTION

On-line state estimation is becoming one of the key functions in distribution control centers considering deregulation environment and introduction of distributed generators in distribution networks. Distribution state estimation is required to consider error of measurement from actual distribution systems because limited measurement values are obtained from actual distribution systems, in addition to DSE has to create high accuracy estimation with limited measurement. The equipments connected to distribution systems such as, transformers with automatic tap changer have a discrete tap control function and also DG with Output characteristics of induction generators can be described by a nonlinear function expressed by constant impedance, constant current and constant power (ZIP) load which causes nonlinear characteristics of the objective function for DSE. Therefore, target load flow equations may be changed during convergence. Different methods have been developed as an advanced function of distribution control centers which can be divided into categories: statistical and load adjustment SE formulation [1]. A number of efforts have been done as an advance to formulate and solve the DSE problem. Reference [2] has proposed a hybrid particle swarm optimization for DSE including Distributed Generators and also, the nonlinear characteristics of the practical equipments and actual limited measurements in distribution systems have been considered in the proposed method. Reference [3] has presented an approach based on ant colony optimization for DSE including DGs. In that approach, the values of loads and DGs are considered as state variables. Reference [4] has presented a new approach based on honey-bee mating optimization to estimate the state variables in distribution networks including distributed generators. But, it should be noted that accurate observation of network operation states depends on optimal placement and numbers of PMUs in distribution network. Usually, the measurement values are obtained by the Remote Terminal Units (RTUs) located on substations. Recently, by the presence of commutations devices between the measuring equipment, there has been the possibility of synchronization among them. The measuring units use the synchronizing satellite signal of Global Positioning System (GPS), and they measure the positive sequences of voltages and currents. These measurements provide more appropriate estimation of network states [5, 6]. Regarding that the PMUs, in addition to measuring of buses voltages, can measure the currents of lines leading to the bus and the whole network can be observable by outfitting some of network buses to the PMUs. Therefore, by appropriate placement PMUs, all the lines' currents and buses' voltages can be obtained [7]. In [8], the graph theory and Simulated Annealing (SA) have been employed for solving the presented optimization problem of optimal PMUs placement. In [9], for optimizing the number and location of PMUs, the genetic algorithm has been used. In this paper a new procedure for optimizing placement and numbers of PMUs in distribution network in presence of distributed generations, variable loads and voltage regulators has been proposed. The criterion to achieve this goal is the best estimation of state variables by minimum error. Combination of NM and ACO for solving practical DSE is used and also, voltage phasor of buses are considered as state variables, while the difference between measured and calculated values is defined as the objective function.

The rest of paper is organized as follows: DSE optimization problem is formulated in Section 2. In Section 3, DGs modeling is illustrated as a PQ or PV node for entering in the forward/backward power flow study. The Nelder Mead's Simplex Search (NM) and Ant Colony Optimization (ACO) Hybrid Algorithm, which is suggested by this paper for optimizing placement and numbers of PMUs in distribution network has been performed in Section 4. The effectiveness of the proposed hybrid method has been demonstrated by simulation study on the 30-bus radial test feeder in Section 5. Finally, the conclusion of paper will discuss in the Section 6.

2. MATHEMATICAL FORMULATION OF DISTRIBUTION STATE ESTIMATION

The distribution state estimation problem as an optimization problem consists of objective function and constraints. The objective function is the summation of difference between the measured and calculated values. The equality and inequality constraints are defined in DSE to create the real time safe and secure operating conditions for devices which are connected to the distribution network. Mathematical formulation of DSE with regard to variable loads and distributed generations as state variables in this paper can be implemented, as following expressions (1), (2), (3), (4), (5), (6), (7), and (8).

$$\text{Min} \sum_{i=1}^{MD} Wi\,(Zi - hi(x))^2 \tag{1}$$

$$P_{DGi\text{-}min} \leq P_{DGi} \leq P_{DGi\text{-}max} \qquad DGi = 1, 2, \ldots, n_{DG} \tag{2}$$

$$P_{VLoadi\text{-}min} \leq P_{VLoadi} \leq P_{VLoadi\text{-}max} \qquad VLoadi = 1, 2, \ldots, n_{VL} \tag{3}$$

$$V_{bi\text{-}min} \leq V_{bi} \leq V_{bi\text{-}max} \qquad bi = 1, 2, \ldots, n_b \tag{4}$$

$$0 \leq Q_{ci} \leq Q_{ci\text{-}max} \qquad Ci = 1, 2, \ldots, n_C \tag{5}$$

$$Tap_{i\text{-}min} \leq Tap_i \leq Tap_{i\text{-}max} \qquad Tap_i = 1, 2, \ldots, n_t \tag{6}$$

$$\left| P_{lineij} \right| \leq P_{lineij\text{-}max} \tag{7}$$

$$X = [\,V_{b1}, V_{b2}, V_{b3}, \ldots, V_{bn}\,] \tag{8}$$

3. DISTRIBUTED GENERATIONS (DGs)

Distributed generations are the electric energy resources often exist near the load centers in form of synchronous generators which are connected to the medium and low voltage of distribution network. Therefore, they can influence on reliability and power quality from the customers' point of view. Generally, distributed generations depend on type of filed or exciter operation can be modeled as a PV or PQ model in the forward and backward distribution load flow study. In this paper forward and backward method is applied for three phase power flow study. It is assumed medium voltage section (20KV) of distribution network operates in the balance conditions and also, DGs model are considered as PQ nodes [11-12].

4. THE ACO-NM HYBRID ALGORITHM FOR THE OPTIMAL PLACEMENT AND NUMBERS OF PMUs IN DISTRIBUTION NETWORK

Phasor measurement unit has the capability of measuring the voltage of bus on which it has been installed, and also the currents of all lines connected to that bus. Therefore, PMUs placement on specific buses of distribution system should be selected, so that, possibility of complete network observability provide by employing numbers of PMUs. This paper proposes new procedure to determine the optimal numbers and placement of PMUs. To achieving this goal, the DSE problem solve by ACO-NM hybrid method for different numbers and predefined locations of PMUs, until, the best numbers and optimal location of PMUs with minimum estimation error of state variables can be concluded. The NM method is a powerful local search, while ACO algorithm is a strong global search. The diagram of the ACO-NM hybrid method is shown in figure (1).
Therefore, it makes full use of the strong global search ability of ACO and the powerful local search ability of NM for DSE solution [13]. Steps of DSE solving is as follows: In the first stage, network information including branches impedance, switch status, tap changer position, average output and standard deviation and also power factor of DGs and variable loads should be defined. In the second stage, initial population and trial intensities has been generated for each ant and all of the masters of colonies based on voltage phasor of selected buses which, PMUs installed on buses.

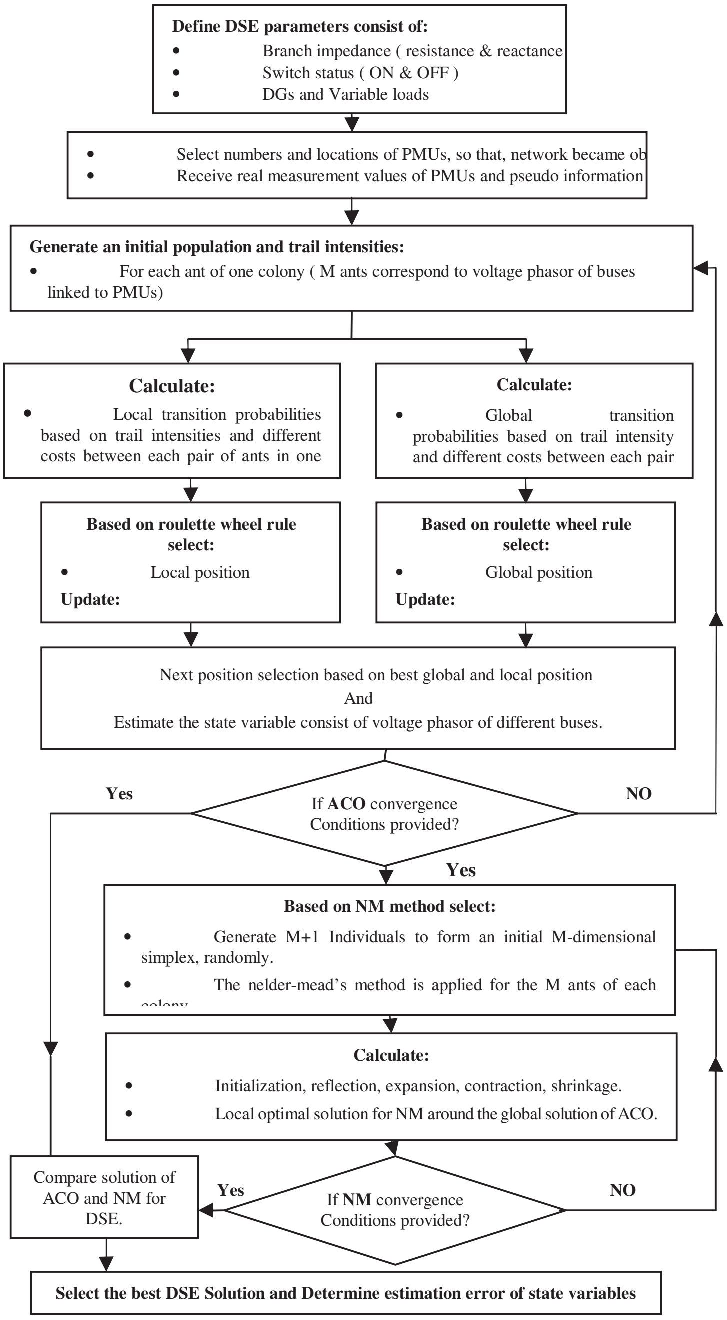

Figure.1: Flowchart of the ACO-NM hybrid approach for DSE

It is assumed that trail intensities between each pair of Masters are the similar. In the third stage, there are two parallel processes to determine the next position of each ant of colony. Therefore, all of the ants at each colony should be moved together along the specified direction which is determined by combination the best next local and global positions. The direction of movement for each ant of colony and Trail intensities updating which are implemented by ant colony global search similar to the reference [14]. If convergence conditions for solving DSE problem by ACO method is satisfied, the output of this stage send to the next stage of hybrid algorithm as input data for starting NM local search and if not, the process must be repeated from step 3. Strong local search around the solution of DSE by ACO method for improving the final solution is implemented by NM method. Finally, if convergence conditions for solving of DSE by NM method is provided, comparison between solutions of two aforementioned methods will determine the best solution of DSE and if not, the process must be repeated from step 5. Installation status of PMUs devices in distribution network is selected as a best configuration, if the solution of DSE by ACO-NM hybrid method cause to minimum estimation error for state variables.

5. SIMULATION STUDIES

To determine the optimal placement and numbers of PMUs by ACO-NM hybrid algorithm, simulation studies has been done on 30-bus ridial distribution test feeder as shown in figure (2).

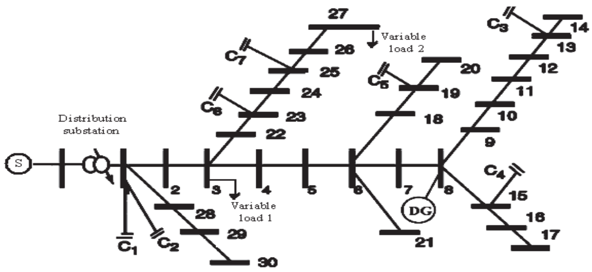

Figure.2 : The one-line diagram of 30-bus radial test feeder

As it can be seen, node 0 is connected to node 1 from one transformer barnch equipped with OLTC. The OLTC has 17 tap positions, which, therefore It can change and control the terminal voltage from − 5% to +5%. The impedance of the transformer between nodes 0 and 1 is 0.0178+j0.3471 per unit and the base apparent power is 52.9MVA. Lower and upper limits of voltage for each bus are 0.95 and 1.05 per unit, respectively. It is assumed the voltage at the primary bus of a substation is 1.0 per unit. In this 30-bus distribution test feeder all of the loads are connected to system without transformers via lines and model type are constant power cexcept loads which are connected to bus 3 and 27. Load level is equal to 0.4725. There is one DGs, which linked to the bus 8. Available DGs' and VLs' information consist of average value of output power, standard deviation and power factor are gathered in table(1). The detailed data of capacitors, active and reactive load demand and the impedances of branches consist of the resistance and reactance of each line in term of ohm per kilometer are gathered from reference [15].

Table.1: Information of DGs and VLs in 30-bus distribution test feeder

State variables	DG1	Variable load1	Variable load2
Average of active power output (kW)	2500	300	250
Standard deviation (%)	15	10	10
Power factor	0.85	0.95	0.95
Location	Bus 8	Bus 3	Bus 27

The proposed model has been implemented on a T7700 ASUS (Intel) with two processor at 2.4GHz and 2GB of RAM memory in the mathlab software. Simulation parameters of ACO-NM hybrid method are presented in the paper appendix. Simulation studies in this section of paper consist of two case study as follow: **Case1** is the base case study indicate to convergance characterestic of ACO-NM hybrid method for solving DSE problem. In **Case2,** changing effects of optimal numbers and placement of PMUs is analyzed by the estimation error of state variables and also propose the best configuration of PMUs placement (numbers and locations) in 30-bus distribution test feeder.

5.1. BASE CASE STUDIES

In order to, distribution system under base case study conditions became observable it is assumed that, the minimum numbers of PMUs are installed on appropriate buses along the feeder, which are less than the number of state variables. Simulation results in figures(3) shows convergence characterestic of ACO-NM hybrid method. Also, it can be understood the proposed ACO-NM hybrid method is very fast and precise to solve DSE problem and estimation errors are in permissible levels.

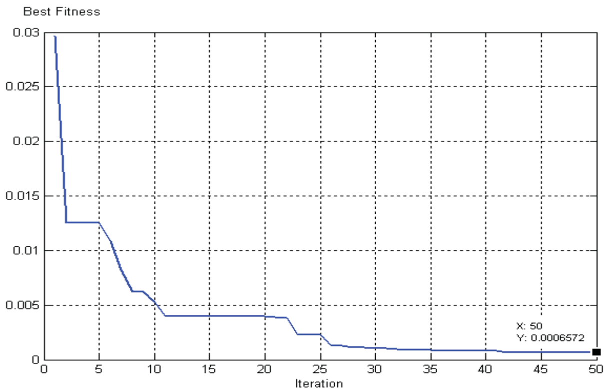

Figure.3: Convergence characterestic of ACO-NM hybrid method (case1)

5.2. IMPACT OF PMUs ON ESTIMATION ERROR

In case2, the effect of increasing in number of PMUs which are fixed onto optimal locations of distribution system has been analyzed onto the estimation error of state variables. For this means the numbers of PMUs increase from 11 to 18 in optimal locations of 30-bus test feeder, while network observability constraint is considered. According to our expectation, it can be concluded from the figure(4), difference between measured and estimated voltage magnitude of bus3 by increasing in numbers of PMUs onto the optimal locations of network will be decrease, significantly, But, with more increase in numbers of PMUs from certain limit the error of voltage magnitude of aforementioned bus will be saturated.

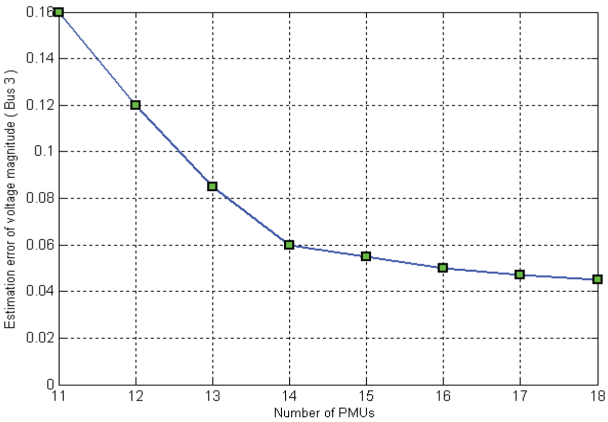

Figure.4: Estimation error of voltage magnitude of bus3 by increasing the numbers of PMUs from11 to18 in distribution network (case2)

Estimation error of voltage magnitude for other buses of 30-bus test system by increasing in numbers of PMUs and the volume of receiving information will follow behaviors similar to the figure (4). Bold characters in table (2) show the optimal placement and numbers of PMUs in test network because, this configuration of PMUs lead to minimum estimation error of state variables and optimal cost of investment for PMUs installation in test system.

Table.2: Optimal numbers and placement of PMUs in 30-bus radial distribution test feeder (case2)

Operating Condition	Numbers of PMUs	Optimal locations of PMUs in network (bus number)
Normal	11	1, 3, 6, 9, 10, 13, 16, 19, 24, 27, 29
	12	1, 3, 6, 9, 10, 13, 14, 16, 19, 24, 27, 29
	13	1, 3, 6, 9, 10, 11, 13, 16, 19, 21, 24, 27, 29
	14	**1, 3, 4, 6, 9, 10, 11, 13, 16, 19, 24, 25, 27, 29**
	15	1, 3, 6, 8, 9, 10, 13, 15, 16, 17, 19, 24, 27, 29, 30
	16	1, 3, 4, 5, 6, 8, 9, 10, 13, 16, 19, 20, 24, 26, 27, 29
	17	1, 2, 3, 6, 7, 8, 9, 10, 13, 16, 19, 21, 24, 25, 26, 27,29
	18	1, 3, 6, 7, 9, 10, 11, 12, 13, 14, 16, 19, 20, 24, 25, 26, 27, 29

8. Conclusion

In this paper an efficient procedure for optimal placement of PMUs have been presented based on minimum estimation error of state variable. Proposed method by utilization the ACO-NM hybrid algorithm for solving DSE problem in presence of DGs can determine the optimal placement and numbers of PMUs in different buses of distribution network under real time system conditions, accurately. Simulation results indicate that new procedure is very precise and more feasible.

T