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A LITERATURE REVIEW ON OPTIMUM METER PLACEMENT ALGORITHMS FOR DISTRIBUTION STATE ESTIMATION

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ABSTRACT
The paper presents a comprehensive literature review on meter placement for monitoring power distribution system. Different algorithms used for solving optimum meter placement problem for distribution system state estimation are discussed in detail. Number of works done in this area and percentage of algorithm utilized are compared graphically. The performance accuracy graph is plotted for different meter placement algorithms. The authors suggest the scope of areas for pursuing the research in state estimation meter placement.

KEY WORDS
Distribution System, Distributed Generation, Genetic Algorithm, Meter Placement and State Estimation

1. Introduction

State Estimation is becoming increasingly important in modern energy management of distribution systems. Especially, with world-wide deregulation of the power industry, distribution system state estimation has gained an even greater importance as a real-time monitoring tool. In regard to new possibilities associated with open access and the operation of distribution networks, the patterns of power flow in a deregulated distribution system have become less predictable compared to the integrated systems of the past. In order to achieve a more secure and economic operation of such a complicated system, it is vital for utility operators to be properly informed of the operating condition or state of the system. The state of the distribution system is described by a collection of voltage vectors for a given network topology and parameters. The set of measurements used for state estimation are collected through the Supervisory Control and Data Acquisition (SCADA) system. To gain more time and accurate information in making control decisions such as economic dispatch, stability assessment, and other related functions, the system operator inputs the previous estimate of the system state and measurements transmitted through SCADA into the distribution system state estimator. The location and types of measurements should allow the state variable of the entire network to be calculated uniquely as well as providing enough redundancy to detect and eliminate bad data in the observable part of the network. The problem of choosing meters and their locations for optimal monitoring of a power system is referred to as the meter placement problem. In choosing the types and locations of new measurements, there may be several different concerns, such as maintaining a desired accuracy level for the state estimates obtained, maintaining an observable network when one or more measurements are lost, maintaining an observable network when one or more network branches are disconnected, being able to detect and identify bad data in one or more measurements, minimizing the cost of meters and RTUs.

Prof.Schweppe, the leading researcher of the power systems engineering group at MIT, was the first to propose and develop the idea of state estimation [1] for power systems monitoring and control. The authors in their previous paper [2] discussed the comparative survey on power system state estimation meter placement. This paper seems to be the extension of previous paper, to provide complete literature review on distribution system state estimation meter placement. Various approaches on meter placement are discussed in detail. Some algorithms are tested with IEEE 13 node distribution system to identify cost effective meter location. In the discussion area, authors made a comparative study of number of paper published with respect to number of years and concluded for future scope in the research. The performance accuracy of work is calculated and compared for power system meter placement and distribution system meter placement.

2. Meter Placement Algorithms

2.1 Rule based meter placement scheme

This paper [3] identifies the data requirements for real-time monitoring and control of distribution systems. A rule based meter placement method is proposed to obtain an accurate estimation of data needed for feeder automation functions. The main goal of meter placement is determining the number, place, and type of meters that needs to be placed on a given feeder such that the SE with these measurements will have the desired performance. The cost considerations usually limit the number of meters that can be placed on distribution feeders; usually below the minimum needed for state estimation. To overcome this observability problem, forecasted load data needs to be added as pseudo-measurements. Therefore, the main goal of meter placement in distribution systems becomes supplementing the forecasted load data with real-time measurements such that the SE with these measurements will satisfy the performance requirements. Based on different observations, a simple set of rules are developed for meter placement which can be outlined as follows.

Rule 1: Put meters at all the main switch and fuse locations that need to be monitored. These measurements will provide data especially for feeder switching and switch monitoring functions. One of these measurements must be at the substation end and be of power, the other measurements can be of current type.

Rule *2:* Put additional meters along the feeder line sections such that the total loads in the zones defined by the meters are similar in magnitude. These measurements can be of current type.

Rule 3 Put meters on normally open tie switches that are used for feeder switching. These meters can also be of current type. Voltage measurements at both ends of these tie switches are also desirable for monitoring and control of volt/var control devices from the substation and/or dispatch center..

Ranking is based on the contribution of a measurement to the accuracy of the quantities that we want to estimate which are called interesting quantities, $yi = fi(x)$ .First measurements are taken out of the available measurement list one at a time and the resulting change in *a(z)* is calculated. The measurement which causes the least change in *a(z)* is then actually eliminated from the measurement set and the elimination process is repeated until all the measurements are eliminated and ranked.

$$a(z) = \sum_{i=1}^{k} \sigma_{yi}^{2}(z)$$

User can use this ranking to reduce the meter selection and to reach a compromise between the performance and the cost; the basic metering scheme will yield the best performance but will cost the most. As one eliminates meters, cost will decrease, but the performance will be sacrificed as the variances will get bigger. After selecting a reduced metering scheme, a SE based simulation can be used to assess the performance of the reduced measurement set. The proposed rule based meter placement method is implemented on a DEC Workstation environment and tested using four different size feeders. The results will be given here for an IEEE test feeder. Test results indicate that even a few meters placed strategically on a radial distribution feeder may provide enough data needed for real-time monitoring of distribution feeders. The computation time and error accuracy is not mentioned in this paper.

2.2 GA Meter Placement

This work [4] presents an optimal meter placement methodology f*or* real-time power distribution system monitoring. The proposed methodology is flexible and enables lo take into account aspects such as different network configurations, use of pseudo measurements, already existent meters and remote terminal units, among others. The Genetic Algorithms technique is employed to achieve a trade-off between investment costs and real-time monitoring capability. The problem of planning adequate metering systems can be seen as an optimization problem, where investment costs should be minimized, while some constraints should be attended to guarantee a good performance of SE. This can be formulated as:

$$Min(C_{meas} + C_{RTU})$$

S.t. performance requirements

Where: C_{meas} - cost of meters that will he installed, C_{RTU} - cost of remote terminal units (RTU) necessary

Based on the aspects discussed in the last sections, a GA methodology is proposed for optimal meter placement in power distribution systems network. The methodology is summarized by the following steps:

1) Initial definitions:
Distribution network configurations of interest for real-time monitoring; costs of the acquisition and installation of RTUs and meters; locations in the network where RTUs are already existent; locations where pseudo measurements will be employed and performance criteria to be observed in the analysis of each configuration of interest.
2) Codification of the chromosome structure based on the knowledge of network locations where it is possible to have RTUs and meters installed.
3) Execution of the optimal solution search procedure using GAS**,** consisting of the following basic steps:
a) Definition of GA control parameters and penalties associated with the performance requirements
b) Generation of the initial population.
c) Evaluation of each chromosome in the current population.
d) If a pre-defined maximum number of new population generations are reached, the best chromosome in the current population is chosen as the optimal solution and the algorithm continues in step (d). Otherwise, the algorithm goes to step (e).
e) Generation of a new population by performing genetic operations on the current population of individuals. The new population becomes the current population. Go to step (c).
4) If the investment cost associated with the optimal solution (metering system) is acceptable, the problem has been solved. Otherwise, go to step (5).
5) Reformulate some initial definitions aiming to obtain an optimal solution of lower cost.

The following strategies may be adopted, Redefinition of topological scenarios of interest, Revision of the performance requirement that should be attended in each topological scenario; use of more pseudo measurements; Go to step (2)

The proposed methodology is flexible and enables to take into account important aspects for distribution systems, such as need of monitoring different network configurations, use of pseudo-measurements, already existent meters and remote terminal unit's etc. It is also possible to specify which constraints will be considered for each topology scenario. This can reduce the cost of the designed metering system, by reducing system monitoring reliability for some network configurations. This strategy may be useful under financial constraints. Test results with the IEEE 14 bus system show that the proposed methodology is capable of obtaining optimal metering systems that attend constraints such as network observability and absence of critical measurements. The error accuracy and variance is not mentioned in this paper for proposed approach.

2.3 Reverse Branch Current Meter Placement Impact

This paper [5] proposes a branch-current-based three-phase state estimation algorithm for distribution systems and meter placement impact on system. With the development of automation in distribution systems, distribution supervisory control and data acquisition (SCADA) and many automated meter reading (AMR) systems have been installed on distribution systems. Distribution management systems (DMS) have advanced and included more sophisticated analysis tools. The combination of these developments is providing a platform for the development of distribution system state estimation (DSE). This method chooses the magnitude and phase angle of the branch current as the state variables. Because of the limited number of real-time measurements in the distribution system, the state estimator can not acquire enough real-time measurements for convergence; so pseudo-measurements are necessary for distribution system state estimator. The load estimated at every node from the AMR systems is used as a pseudo-measurement for the state estimator. In addition to this new strategy for DSE, another issue is meter placement. This work includes the type of measurement as well as the location of the measurement.

The DSE algorithm is implemented in the following steps:

1) Initialization

Initialization of the current magnitude and phase angle has a great impact on the convergence speed of the algorithm. In this implementation, a two step approach is used: a) Use a backward approach to get the initial value of current. b) Use a forward approach to get the initial value of voltage.

2) Calculate the updates of the system state using (2).

$$\Delta x^n = \left[H^T(x^n) R^{-1} H(x^n) \right]^{-1} X \; H^T(x^n) R^{-1} \left[Z - h(x^n) \right] \quad (2)$$

3) Update the branch current using equation: 3 and using the forward approach to calculate the node voltage.

$$x^{n+1} = x^n + \Delta x^n \quad (3)$$

4) If Δx^n is smaller than a convergence tolerance, then stop. Otherwise, if the number of iteration is smaller than the pre-set maximum iteration number, go to step 2). If it is not, it does not converge.

The proposed three-phase distribution system state estimator was implemented using Microsoft Visual C++. The input data of the test system was stored in a Microsoft Access database. Three feeders are tested. These three test cases are based on IEEE 13 Node, 34 Node and 123 Node Test Feeder radial distribution systems. For all three test cases, the maximum error for the real-time measurements is 5% and 3% respectively, and for the pseudo-measurements (load) is 50% and 20% respectively. Testing also used the combinations of 50%-5% and 20%-3%. For all the test cases, the weight of pseudo-measurement was chosen as 0.01, and the weight of real measurements was 0.1.From the test cases, some rules of meter placement for this proposed distribution system state estimation algorithm can be found:

1) The results of the branch power measurement are the best. The current magnitude measurement comes the second. They are much better than the voltage magnitude measurement.

2) Branch power and current magnitude measurements can get better results when they are installed near the source and in the main feeder which has many downstream nodes, while the voltage magnitude measurement can get better results when it is installed far from the source.

3) When meters are placed at different locations, the results are better.

The proposed distribution system state estimation algorithm provides satisfactory results and accomplished the desired outcomes. This work has provided a foundation related to DSE that can be extended in many areas. Future work can be broken down into three areas: more detailed models, more topologies, and testing on an actual system that has both AMR and other real measurements.

2.4 ANN Selection Meter Placement

This paper [6] proposes to reduce the number of sensors and RTUs required, artificial neural networks (ANN) can be used effectively, without compromising the accuracy of bus voltage estimation. One such scheme for bus voltage estimation for radial distribution feeders is presented. It is shown that instead of using a single ANN, if multiple ANNs are used, accuracy of the estimation increases considerably. However, the estimation accuracy depends on the locations of meters placed and the number of ANNs used. To determine the location of meters and the number of ANNs required for a given estimation accuracy, simple rule based algorithms are proposed in this article.

2.4.1 Meter Placement

Rule 1: Measurement triplet should always be taken from the substation.

Rule 2: Measurements triplets should be taken from the beginning of each bigger lateral.

Rule 3: If two or more laterals are short in length and located quite close to each other, there is no need to take measurement from the beginning of each of these laterals. Instead, take only one measurement triplet from the incoming feeder section which supplies power to these laterals.

Rule 4: For any short lateral which is not in close proximity with any other short lateral, no new measurement triplet is generally required. The measurement triplets already chosen according to above three rules are sufficient for satisfactory bus voltage prediction in most cases.

2.4.2 Selection of ANN

Rule 1: For each of the measurement triplet taken following the rules for meter placement, one single ANN should be used.

Rule 2: If the training time for any single ANN chosen according to Rule 1 is unacceptably high, then instead of this single ANN, choose two ANNs. The task assigned to the earlier single ANN should be distributed equally to these new two ANNs.

Rule 3: For any short lateral which is not in close proximity with any other short lateral, a separate ANN should be used utilizing the appropriate measurement triplet (from a point upstream from this lateral) chosen according to the rules for meter placement.

Heuristic rules have been formulated for meter placement and selection of ANNs and several test conducted on IEEE 30 and 68 nodes radial distribution feeders to validate these rules. The main conclusions of this work are (1) Instead of using a single, large ANN architecture, multiple small ANN architecture can be used for improving the accuracy of bus voltage magnitude estimation. (2) Number of measurements required by the ANN technique is quite less than the number of measurements required by the state estimation technique for bus voltage estimation. Thus, the ANN technique has the potential of reducing the capital cost and maintenance requirements. (3) The accuracy of the proposed scheme is also quite acceptable in the presence of the noisy field measurements.

2.5 Multiple Load flow Voltage Measurement

This paper [7] presents a heuristic approach to identify potential points for location of voltage measurements for state estimation as part of a proposed distribution management system controller. The developed technique identifies measurement locations to reduce the voltage standard deviation of the bus bars which do not have a measurement. It addresses the problems of classical transmission meter placement methods, which are not directly applicable to distribution systems due to limited measurements, and unobservability of the network. The algorithm uses (4) to calculate the error between voltage magnitudes obtained initially from a load flow using an estimate of maximum demands and results from series of load flows using random changes in the same loads. The standard deviation of the voltage magnitudes resulting from these random variations in the loads for each busbar is calculated using (5).

$$Error\ function = \sum_{m=1}^{M} (V_0^m - V_{rand}^m)^2 \qquad (4)$$

Standard deviation of the voltage magnitude at bus,

$$w = \sqrt{\frac{\sum_{n=1}^{N} (V_{\mathrm{rand(w)}}^n - \mu_{\mathrm{V_{rand(w)}}})^2}{N-1}} \qquad (5)$$

Where

$$\mu_{\mathrm{V_{rand(w)}}} = \frac{\sum_{n=1}^{N} V_{\mathrm{rand}(w)}^n}{N}$$

Initially bus bars measurements are selected on which voltage measurements are assumed. Placing the measurements primarily at the heavily loaded bus bars with a good cover of network topology is likely to lead to minimum movement of the measurements. A load flow is performed to get V_0^m, the voltages at the measurement locations. The loads are then changed randomly within $\pm$20% and a load flow is again performed. The voltage values resulting from the load flow with random changes in the loads at the measurement bus bars are considered to be random voltage values V_{rand}^m. The value of the error function is then calculated as in (4). The largest acceptable value of the error function is set to be the square of the accuracy of the voltage measurement system. If the error is acceptable, voltage measurements representing the load conditions have been found and the voltage magnitudes at all busbars are stored as single set V_{rand}^n. The process is then repeated, changing all the loads randomly to obtain a number of voltage sets. These sets are then used to calculate the voltage standard deviations at each busbar using (5).Measurements is then moved to locations with the largest standard deviations. If a measurement(s) is moved, then the whole process is repeated to obtain voltage sets with measurements at the new locations. If a sufficiently small deviation of voltages at all busbars cannot be obtained with the given number of measurements, additional measurements need to be included.

The algorithm tested on generic distribution system [GDS] network contains overhead line and cable circuits at 11 kV, 33kV and 132kV voltage levels. It has four grid supply points, 281 bus bars and 322 branches and five distributed generators. The measurement location algorithm presented reduces the voltage standard deviations of the unmeasured nodes on the network by considering the uncertainty of the load injections. Since the estimator is required to use a large number of pseudo load injections, augmenting the estimator with voltage measurements from the potential points would reduce the estimated voltage standard deviations. This will in turn reduce the risk of voltage violation due to DMSC control actions. Simulation results have shown an 11% improvement on estimated voltage standard deviations when measurements in the estimator were compared from two different locations of bus bars. Simulation results have shown that, in the cases studied, the estimator took 4 to 5 iterations to converge and was completed in less than a second. This technique does not obtain the global optimal measurement system for the network as is done in transmission systems and neither does it allocate measurements to overcome observability problems but identifies those points on the network with the higher voltage variations.

2.6 Dynamic programming with Monte Carlo statistical approach

This paper [8] proposes an optimization algorithm suitable to choose the optimal number and position of the measurement devices needed to operate management and control issues, such as energy dispatching and protection coordination, in modern electric distribution networks. The paper aims at proposing a novel algorithm for the optimal meter placement in a distribution network, which guarantees the system observability within prefixed levels of accuracy and reliability. The procedure is based on three main steps: a heuristic optimization technique, to find the optimal solution to meters placement; a DSE algorithm; a Monte Carlo approach to take into account the random load variations and to evaluate the propagation of the uncertainty from measured to evaluated data, starting from suitable uncertainty models of each system element.

The applied procedure can be summarized in the following three steps:

1) Characterizing the uncertainty on the measured data: all the relevant information available is used. A suitable probability distribution is then assigned to these uncertainty terms, which can be numerically represented by sets of random variables defined by the software package.

2) Performing a large number of simulated tests: in each test the measured data are corrupted by different contributions, whose values are extracted from the above sets, and the DSE algorithm is applied by using this set of input data.
3) Processing the set of the obtained output values, which could be considered as the probability density function of the measurement result, whose standard deviation represents the standard uncertainty of the result.

In order to validate the proposed approach, the optimization procedure has been applied to real size MV networks, which are parts of the Italian distribution systems and include Distributed Generation plants. For the sake of simplicity; here the results relevant to a small size benchmark network will be discussed. The network, consists of 17 MV/LV nodes supplied by two 132/20 kV/kV primary substations, and 14 edges with overhead conductor, with a total length of 103 km. The annual medium active power delivered to the MV nodes is about 1.6 MW. The proposed technique is extremely flexible, since it can be simply adapted to different monitoring needs. Expected future developments of this research work include the possibility of dealing with meshed networks, the refinement of the uncertainty models of the measurement devices, the introduction of suitable uncertainty terms also for the parameters that characterize the network impedances and, above all, the introduction of suitable changes to guarantee a prefixed degree of redundancy for the measurement system. The same author in their next paper [9] rectify the drawback of paper [8] by allowing evaluation of the propagation of the uncertainty from measured to evaluated data, starting from suitable uncertainty models of each system element.

2.7 RDAC Meter Placement

This paper [10] presents an outline of the measurement and control system for the Drexel University laboratory and then focuses on the capabilities purposely added for the meter placement and network reconfiguration studies.

Several hardware and software instruments have been specifically designed and implemented to allow for meter placement and network reconfiguration studies. The instruments provide measurement and control capabilities for distribution systems of different configurations. The hardware and software instruments have been combined with measurement instruments to form the unique and flexible instrumentation and measurement system of the Reconfigurable Distribution Automation and Control [RDAC] Laboratory at Drexel University. Instrumentation and measurement capabilities of the laboratory include the following: monitoring up to 16 user-selected locations, recording and displaying real-time measured voltage, current, and power waveforms, and remotely operating controllable devices, such as digital relays, to reconfigure the network structure. These characteristics enable event and state estimation. The resulting laboratory can be applied to study meter placement and network reconfiguration and can be utilized for research, as well as for educational purposes. Future work includes the integration of a remote master station, where the recorded data and control signal can be transferred through the Ethernet, allowing for larger system studies and remote laboratory operation.

2.8 Variance Moment GA Meter Placement

The authors [11] have developed an innovative procedure to obtain a quick evaluation of the active network Performances and to detect possible problems in the estimated voltage uncertainty, defining a suitable parameter here denoted as "*variance moment*". The method accounts for network structure and characteristics of consumptions and generations, in accordance with the time-variable probabilistic value of loads demand and generators production respectively. The uncertainties of the active and reactive injections in each node and its distance from the Primary Substation contribute in defining the "variance moment". In the proposed procedure the optimal location of remote voltage measurements is identified by minimizing the higher variance moment in the network. The discrete non-derivable formulation of the measurement siting problem induced the authors to make use of stochastic constrained methods. In particular, a procedure based on a Genetic Algorithm has been developed.

The structure of the proposed procedure is the following:

By using a traditional SE tool, the siting algorithm evaluates the highest uncertainty in the starting scenario. If other N_v* voltage measurement points are available in the network and DSO chooses to use them online, this condition becomes the starting one.

Check the target on the SE accuracy: in case the check condition is satisfied, the algorithm ends; otherwise the algorithm tries to combine the (N_v*+1) installed voltage measures with NADD further ones, starting from N_{ADD} = 1. The location aims to minimize the highest variance moment of the network. To adopt the matrix computation described in the previous chapter, the order of the nodes has to be rearranged to obtain the bus-bars with voltage measures as the 1, 2, …, (N_v*+1+N_{ADD}) nodes.

The algorithm continues increasing N_{ADD} until the target is achieved. Alternatively the process ends when the highest number of installable measurement N_{ADD} max is reached.

The implemented GA aims to minimize the variance moment randomly moving a data set of N_{ADD} voltage measurements. The GA generates a population of N_{ADD} possible measurement locations by defining a set of numbers forming a vector . The number Ni of individuals composing each population is defined. The possible locations composing vector L may vary in the range between 2 and N (number of bus-bars). Solutions outside this range are automatically disregarded. For each combination of N_{ADD} possible locations, the variance moment is evaluated depending on loads and DGs uncertainties on injected power. The highest variance moment obtained in a defined configuration is used as the corresponding fitness value. The location algorithm aims to minimize this fitness function.

The algorithm, applied to several realistic MV radial distribution networks with different characteristics, has demonstrated to be computationally efficient and stable also for different DG penetration levels. A stochastic Genetic Algorithm provides the variance moment minimization by adding voltage measurements in critical nodes, with good performance in stability and speed compared with deterministic trial and error methods.

2.9 Planning PSO Metering Scheme

The author in their paper [12] presents a PSO algorithm for initial planning metering scheme for power distribution system. The main aim of meter placement technique is to establish number, position and type of meters to be placed on a given system to achieve an observable system. The problem of planning adequate metering systems can be seen as an optimization problem, where investment costs should be minimized, while some constraints should be attended to guarantee a good performance of SE. This can be formulated as:

Min (Crtu+ Cm)
s.t. performance requirements

where,
Cm - cost of meters that will he installed
Crtu - cost of remote terminal units (RTU) necessary

For meter placement problem, the binary version of PSO [13] [14] is usually used. However in the present work, the binary PSO algorithm is not used because of the level of randomness present in the algorithm. Due to this randomness it becomes difficult to satisfy the constraint equations most of the times the program is run. So to deal with the difficulty that occurred, the original PSO algorithm used for solving the continuous optimization problems but a few changes are made to the algorithm. Firstly, the range of the particles is restricted to [0,1]. Then the velocity is calculated in the normal procedure, but while updating the position of the particles it is rounded of to either 0 or 1. But the disadvantage using this procedure is that the effectiveness of PSO is lost to some extent with this procedure.

Table 1: IEEE system tested result

Test System	Total Cost	Meter Placement Buses	No. of Meters
IEEE 13	8.79	1,4,6,9,10,13	6
IEEE 34	18.8	2,5,7,11,13,17,21,24,26,29,31,33	12
IEEE 37	20.4	1,3,6,10,13,14,19,21,24,28,31,35	12
IEEE 61	35.4	2,5,8,11,14,17,19,21,25,28,31,33,35,37,39,41,44,46,49,52,55,58,60	23
IEEE 123	69.4	1,2,6,8,14,15,20,22,24,28,31,33,37,39,41,43,47,52,56,58,62,65,68,71,74,76,78,82,85,88,90,92,94,95,98,103,105,107,110,114,116,118,119,121	44

Test results with the IEEE and TNEB bus systems shows that the proposed methodology is capable of obtaining optimal metering systems that attend constraints such as network observability and absence of critical measurements. Test results of IEEE system shown in Table 1. The algorithm predicts the cost and location of meters for identification and collection of measurements from the system. The drawbacks in the algorithm are not considering any switch location and more computational time required for large system.

2.10 Bivariate Chebyshev bound Measurement Placement

This paper [15] introduces a technique for meter placement for the purpose of improving the quality of voltage and angle estimates across a network. The proposed technique is based on the sequential improvement of a bivariate probability index governing relative errors in voltage and angle at each bus. The meter placement problem is simplified by transforming it into a probability bound reduction problem, with the help of the two sided- Chebyshev inequality. A straightforward solution technique is proposed for the latter problem, based on the consideration of 2- error ellipses.

Step 1) Run WLS over a set of Monte Carlo simulations and observe the relative errors in voltages and angles in each simulation at all the buses.

Step 2) If in more than 95% of the cases the relative errors(P_i)in the voltages and angles are below their specified thresholds, respectively (i.e., 1% for voltage and 5% for angle), stop; else go to Step 3.

$$P_{\mathrm{i}} = P_{\mathrm{r}} \left\{ \left| \frac{\overset{\circ}{V}{}^{\mathrm{i}} - V_{\mathrm{t}}^{\mathrm{i}}}{V_{\mathrm{t}}^{\mathrm{i}}} \right| \le \in_1 , \left| \frac{\overset{\circ}{\partial}{}^{\mathrm{i}} - \partial_{\mathrm{t}}^{\mathrm{i}}}{\partial_{\mathrm{t}}^{\mathrm{i}}} \right| \le \in_2 \right\}$$

Step 3) If only the relative errors in voltage estimates satisfy the criterion in Step 2, go to Step 6; else Step 4.

Step 4) Take the mean of the state error covariance matrix over all the Monte Carlo simulations and extract the sub-matrices corresponding to the voltage and angle at each bus.

Step 5) At every bus compute the area of the error ellipse from the determinant of sub-matrix and identify the bus with the largest area and place the voltage measurement at this bus. If measurement is already present choose the bus with the next largest area. Go to Step 1.

Step 6) Compute the mean of error covariance matrix corresponding to the real and reactive power flow, in each line.

Step 7) For each line compute the area of the line flow error ellipse and place the flow measurement in the line with the largest area. If the measurement is already present choose the line with the next largest area. Go to Step 1.

The proposed method seeks to find the location with largest area of the 2-error ellipse as a potential location for meter placement. The procedure is sequential and stops when the desired level of accuracy in estimates is achieved. The advantage of the method is that it reduces the errors in both voltage and angles by exploiting the error correlations under a wide range of uncertainty in the pseudo measurements. The technique is simple and easy to implement. The performance evaluation of the technique on 95-bus UKGDS demonstrates the potential for practical implementation despite the fact that it produces feasible but not necessarily optimal solution. The performance of the technique needs further investigation in view of the possible presence of the leverage points in the network.

3. Discussion

State Estimation is essential for monitoring, control and optimization of a power distribution system. Regardless of the different estimation algorithms, the location, types of measurements, cost of meters, and cost of RTUs are always decisive factors for successful state estimation. In this paper the authors discussed, different types of algorithms used for distribution system state estimation meter placement

Comparison of number of papers with years for Distribution system meter placement is represented in figure 1.The Distribution system meter placement work started in the year 1994.Only limited number of algorithms with less number of works are done in this area. Huge scope is in this area for pursuing research work by considering distributed generation.

The performance accuracy of the different algorithms used in distribution system meter placement is checked by specific formula. To check the performance accuracy, five different papers are selected from power system meter placement and distribution system meter placement. The percentage absolute error, CPU processing time and other constraints are validated and converted to 0 to 1 accuracy value .For each paper the combined performance accuracy is calculated and compared with two different meter placement. The figure 2 cleared that the performance accuracy of power system meter placement is high when compared with distribution system meter placement. The identified reasons for less accuracy in distribution meter placement are limited real time measurements and large number of pseudo-measurements. The utilization of different algorithms in distribution meter placement is represented by pie chart in figure 3.The representation of different algorithm are Genetic Algorithm (GA) ,Particle Swarm Optimization (PSO) ,Artificial Neural Network (ANN) , Dynamic programming with Monte Carlo (MCDP) , Distribution Load Flow (LF) and Rule Based Meter Placement (RBMP).

The future scopes of the research work in Distribution state estimation meter placement are:
The possibility of dealing with meshed networks, introduction of suitable changes to guarantee a prefixed degree of redundancy for the measurement system, considering the transformer, CB and Tie switch position, Check the feasibility of the algorithm with larger nodal system, More detailed models, more topologies and testing on an actual system that has both AMR and other real measurements.

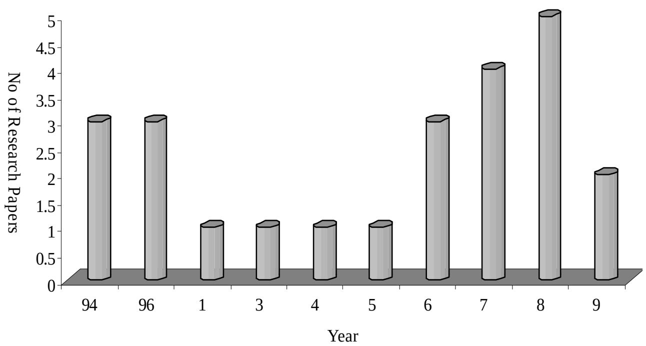

Figure 1: Comparison of number of papers with years for Dist. meter placement

Various authors [16-22] discuss different meter placement scheme in the area of harmonic, voltage sag, PMU, power quality, load estimation and switch placement. More attraction has to be given to this area for future research work

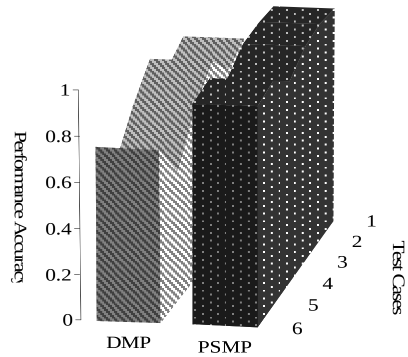

Figure 2: Comparison of Performance accuracy with Power System and Distribution System Meter Placement

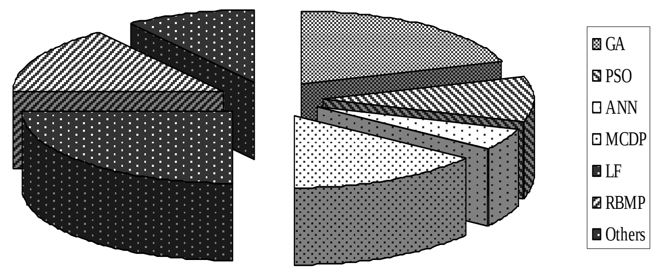

Figure 3: Percentage allocation of Dist. Meter Placement Key features

References

[1] Schweppes F.C., Wildes J.C., Rom D , Power System Static State Estimation .Part I, II, and III , *IEEE Transaction on Power Apparatus and System -89, pp.120-135, 1970*

[2] L. Ramesh, S.P.Chowdhury, S.Chowdhury, P.A.Crossley, Electrical Power System State Estimation Meter Placement—A Comparative Survey Report, T*aylor and Francis Electrical Power Components and Systems, Vol: 36, No: 10, Page 1115-1129.*

[3] M.E.Baran, J.Zhu, A.W.Kelley, Meter placement for real time monitoring of Distribution feeders , *IEEE Transactions on Power systems, Vol.11, No.1, Pp. 332-338, 1996.*

[4] J.C.S.Souza, M.B.C.Filho, E.M.M.Schilling, Planning metering system for power Distribution systems monitoring, *IEEE Bologna PowerTech Conference, Italy, 2003.*

[5] H.Wang, N.N. Schulz, A Revised Branch Current-Based Distribution System State Estimation Algorithm and Meter Placement Impact , *IEEE Transactions On Power Systems, Vol. 19, No. 1, February 2004 ,PP: 207-213*

[6] B. Das, Rule Based Algorithm for Meter Placement and ANN Based Bus Voltage Estimation in Radial Power Distribution System, *Taylor and Francis, Electrical Power Components and Systems, Feb. 2005, Vol: 33, No: 4, Page 449-462.*

[7] A.Shafiu, N.Jenkins and G.Strbac, Measurement location for state estimation of distribution networks with generation, *IEE Proc. Gener. Transm. distrib., Vol.152, No.2, 2005.*

[8] C.Muscas, F.Pilo, G.Pisano, S.Sulis, Optimal Placement of Measurement Devices in Electrical Distribution Systems, *IEEE Instrumentation and Measurement Technology Conference, Italy 24-27, April 2006, Page: 1873-1878.*

[9] C.Muscas, F.Pilo, G.Pisano, S.Sulis, Optimal Allocation of Multichannel Measurement Devices for Distribution State Estimation, *article has been accepted for inclusion in a future issue of IEEE Transactions on Instrumentation and Measurement, 2008.*

[10] V. Cecchi, X. Yang, K.Miu and C.O. Nwankpa, Instrumentation and Measurement of a Power Distribution System Laboratory for Meter Placement and Network Reconfiguration Studies, *IEEE Transactions on Instrumentation and Measurement, Vol. 56, No. 4, August 2007*

[11] F.Bignucolo, R.Caldon, Optimizing the Voltage Measurements Location for Management of active Distribution Network, *University Power Engineering Conference 2007, Page: 960-964.*

[12] L.Ramesh, S.P.Chowdhury, S.Chowdhury, A.A.Natarajan, Planning optimal intelligent metering for distribution system monitoring and control, *IEEE INDICON 2008, Vol: 1, PP: 218-222*

[13] A. Moradi and M. Fotuhi-Firuzabad, Optimal Switch Placement in Distribution Systems Using Trinary Particle Swarm Optimization Algorithm , *IEEE Transactions on Power Delivery, Vol. 23, No.1, January 2008*

[14] J.Kennedy and R.C.Eberhart, A Discrete Binary Version of the Particle Swarm Algorithm, *Proceeding of the world Multiconference on Systemics, Cybernetics and Informatics (WMSCI), pp.4104-4109, 1997*

[15] R.Singh, B.C.Pal, and R.B. Vinter, Measurement Placement in Distribution System State Estimation, *IEEE Transactions On Power Systems, Vol. 24, No. 2, May 2009.*

[16] J.Wan and K. Miu, Load Estimation in Radial Electric Power Distribution Networks Using Limited Measurements, *Proc.2000 IEEE International Symposium on Circuits and Systems, Geneva, Switzerland, 2000, Vol. 2, pp. 517-520*

[17] H.M.Ranjbar, A.M.Amraee, T.Shirani, Optimal Placement of Phasor Measurement Units: Particle Swarm Optimization Approach, *International Conference on Intelligent Systems Applications to Power Systems, 2007, Volume, Issue, 5-8, Nov.2007, pp.1-6.*

[18] D.J.Won and S.Moon, Optimal Number and Locations of Power Quality Monitors Considering System Topology, *IEEE Transactions On Power Delivery, Vol. 23, No. 1, January 2008.*

[19] B. Xu, A. Abur, Observability analysis and measurement placement for system with PMUs , *IEEE PES Power Systems Conference & Exposition, New York, Oct.10-13, 2004.*

[20] A.Kumar, B.Das, Genetic algorithm based meter placement for static estimation of harmonic sources, *IEEE Transactions on Power delivery, Vol.20, No.2,Pp. 1088-1096, 2005.*

[21] C. Madtharad, S. Premrudeepreechacharn, N.R.Watson, R.S.Udom, An optimal measurement placement method for power system harmonic state estimation, *IEEE Transactions on Power delivery, Vol.20, No.2, Pp. 1514-1521, 2005.*

[22] G.Olguin, F.Vuinovich, M.H.J.Bollen, An optimal monitoring program for obtaining voltage sag system indexes, *IEEE Transactions on Power systems, 2005.*

[23] H.Liu, D.Yu, H.D.Chiang, A heuristic meter placement method for load estimation, *IEEE Transactions on Power systems, Vol.17, No.3, Pp.913-917, 2002.*

[24] J.Peng, Y.Sun, H.F.Wang, Optimal PMU placement for placement for full network observability using tabu search algorithm, *Electrical Power and Energy Systems, Pp.223-231, 2006.*