# ELECTRICAL DISTRIBUTION NETWORKS STATE ESTIMATION

**A.A.YAGHOTI, M.PARSA, VAHID J.MAJD**
TEHRAN REGIONAL ELECTRICITY CO. (TREC), TARBIAT MODARES UNIVERSITY (TMU)
IRAN
A-YAGHOTI@TREC.CO.IR PARSA@MODARES.AC.IR PARSA@MODARES.AC.IR

**Abstract**- Many of the past work on distribution state estimation have been focused on the adoption of a transmission state estimation approach, without necessarily accounting for specific requirement distribution networks analysis. On distribution networks, typically, there are very few real-time measurements, and power consumption of each load is very uncertain.
This paper presents an alternative approach to distribution state estimation with limited Real-Time Measurements Points (RTMP). This method includes two steps; in the first step Correlation Coefficient (CC) between power consumption of each LP and RTMP with usage of least squares (LS) is determined. In the second step; with data of RTMP, CC and forward backward load flow modification, excellent state estimation of electrical distribution networks can be determine.
**Keywords**: distribution network state estimation, coloration coefficient, real-time measurement, least squares (LS).

## I. INTRODUCTION

In recent years, the electricity sector is facing several changes and challenges related to new legal and regulatory frameworks, to the explosion of dispersed generation (DG) and larger pressures to increase quality of service. In distribution networks the challenges are perhaps even more evident clearly requiring larger investments on automation and telemeter devices as well as in the installation of more powerful control and monitoring centers. This movement determines the need to develop new methodologies and model to cope with specific characteristics of distribution networks.
The general problem addressed by the research described in this paper is the state estimation problem in electrical distribution networks. The state estimation problem can be described as aiming at finding the values for a set of variables (state variables) that adjust in a more adequate way to a set of network values (measurements) which are available. The state variables are such that all of the network variables can be evaluated from them. The calculation of state variables considers the physical laws directing the operation of electrical distribution networks and is typically done by adopting some criterion.
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. Also distribution management system (DMS) has advanced and includes more sophisticated analysis tools. Combination of these developments provides a platform for development of distribution system state estimation (DSE). Furthermore, development of distributed generation (DG) in distribution networks DSE for stability assessment is important.
Many of the past work on distribution state estimation have been focused on the adoption of a transmission state estimation approach, without necessarily accounting for specific requirement distribution networks analysis [2-4]. Those researches assume that MRTP are much more in of distribution networks, as transmit ions networks, and state estimator has much more in of data for state estimation of distribution networks. In those algorithm usage of WLS method for minimal error between input data and dominant physical laws of systems were reported. On distribution networks, typically, there are very few real-time measurements, and power consumption of each load is very uncertain. Ref. [1] proposes a method for DSE with limited real-time measurement in distribution networks. Ref. [5-6] for the improvement above methods a probabilistic or a fuzzy logic approach is use. In these papers the uncertainty power consumption of each LP in distribution networks is consider.
In the proposal research a solution for the state estimation problem in electrical distribution networks is consider with above difficulties. The research includes two steps: in the first step the estimation of the power consumption of LP is estimate from historical data of power consumption each LP and power transfer of each section that includes RTPM by using of a least squares approach. With this method a good relationship between power consumption, each LP and power transfer of each section that includes RTPM can be determine. RTMP can measure voltage (amplitude and angel), input and output power (active and reactive). With RTMP data and CC, uncertain power consumption at every load point at any time can determine. In the second step, by defining uncertain power consumption LP and RTPM certain data at real-time and backward-forward load flow, excellent state estimation of electrical distribution networks can be obtain. For load flow modification in each iteration we must modify power consumption LP (loss of section and power LP) for equality of power transfer of RTPM nodes and power transfer section of each load flow iteration and fixed voltage of RTPM nodes in each load flow iteration. The propose approach has been investigated on a part of real distribution network

(Tehran Regional Electricity Co.), with real data that has been collected during a month, and the results conforms the proposal method.

## II. DISTRIBUTION STATE ESTIMATION

### a) Importance State Estimation

Optimal operation of electrical distribution networks is included of:

- Economic of distribution power
- Quality of distribution power
- Reliability of distribution power

One of the important tools for optimal operation of distribution networks is system's monitoring and distribution state estimation is fundamental tools for installation system's monitoring. With know variable value of distribution networks can be defined:

- Real time reliability system and reconfiguration network for reliability improvement.
- VAR management in the distribution networks for minimal loss.
- Reconfiguration of network for optimal power flow in the distribution networks.
- Fault management in the distribution networks for reductions of customers' interruption duration.
- Short time load forecasting in distribution networks.
- Time of special services in the distribution networks.
- Energy management and load management in the distribution networks.

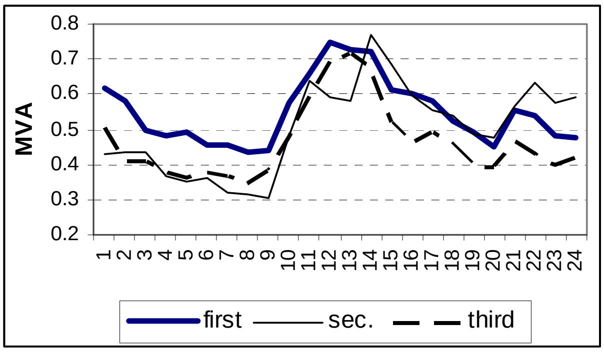
Therefore, state estimation in distribution networks is of great for optimal operation of this network.

### b) Difficulties of State Estimation

With the usage of RTMP variables value of system can be measure and send to control centre. This data is base for state estimation in distribution networks. In distribution networks, typically, there are very few real-time measurements. This problem is unsuitable of state estimation in this network. Usage of historical data and mathematical method, for example PCA (principal component analysis) [7], can help us for limited RTMP placement in distribution networks.

Another problem for state estimation in distribution networks is load uncertainty in this network. Figure (1) shows load profile for one load point for continuous three days.

With usage of minimal error method or least squares, and data processing (classification of historical data), a suitable model load estimation with historical data at each LP can be define.




**Figure(1): load profile**

## III. LOAD ESTIMATION ALGORITHM

The problem is generating coherent load set for distribution networks. This happens because usually the few real time measurements available at a SCADA system installed in a control centre are the power, current or voltage values at then sending end of feeder coming from a medium voltage network and substation. Therefore to add more information to turn the network observable consists of running a load estimation algorithm. In this part of paper the proposal algorithm for load estimation in distribution networks describes.

For uncertain power of each LP estimate from has historical data of power consumption of each LP and power transfer of each section that includes RTPM and usage of least squares error a good relationship between power consumption of each LP and power transfer of each section that includes RTPM can be find. For each load level of historical data from LP load and RTMP load the following equation (1) can be define.

$$S_{i,j}^{L} = \alpha_{i,1}^{j}.S_{1,j}^{M} + \alpha_{i,2}^{j}.S_{j,2}^{M} + ... + \alpha_{i,n}^{j}.S_{j,n}^{M} + \beta_i^j \, , \qquad (1)$$

Where:

$S^j_{l,I}$ : load power at i$^{th}$ LP in j$^{th}$ interval

$S^j_{m,k}$ : power of RTMP k$^{th}$ in j$^{th}$ interval

$\alpha^j_{I,k}$ : correlation coefficient between load power at i$^{th}$ LP and power of RTMP k$^{th}$ in j$^{th}$ interval.

If M number of RTMP are installed in the network and have N data of historical data of LP load power and N historical data of RTMP at j$^{th}$ load level of system can be write following equation (2).

$$\begin{pmatrix} S_{i,1} \\ S_{i,2} \\ ... \\ S_{i,N} \end{pmatrix}^{HL,j} = \begin{pmatrix} S_{1,1} & .... & S_{M,1} & 1 \\ S_{1,2} & .... & S_{M,2} & 1 \\ & ..... & & \\ S_{1,N} & ... & S_{M,N} & 1 \end{pmatrix}^{HM,j} * \begin{pmatrix} \alpha_{i,1} \\ .... \\ \alpha_{i,n} \\ \beta \end{pmatrix}^{j} \qquad (2)$$

Where:

HL: vector (N*1) of historical load of LP

HM: matrix (N, M+1) of historical measurement data

$\alpha$ : Parameters of estimated model

Equation (2) includes N equation with (M+1) unknown parameters where N>> (M+!). Using, matrix notation, can be rewrite the preceding equation (2) in a concise form:

$$S_i^{HL,j} = A.\theta + e \tag{3}$$
$$e = S_i^{HL,j} - A.\theta$$

Where θ is parameter vector of load model for each LP. For defining a good solution for equation (2) least squares estimation (LSE) method can be used. To identify the unknown parameters θ equation (4) with historical data can be used.

$$\theta = (A^T A)^{-1} A^T .S_i^{HL,j} \tag{4}$$

With solution of equation (4) parameters of the model with minimal error can be obtained. Figure (2) shows model of the describe algorithm.

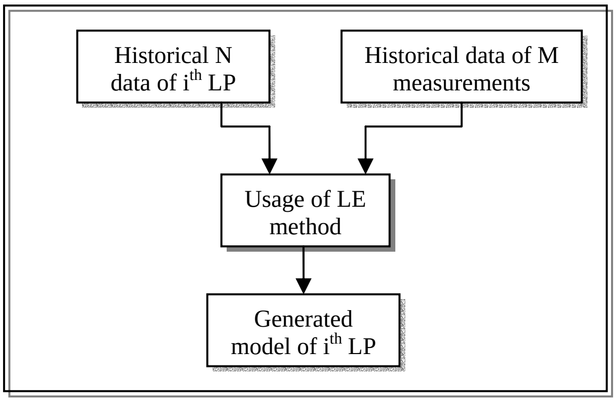



**Figure (2): Model for load estimation**

Table (1) shows some of real data that measuring in two points and values of estimated load of another load point. In this case study contain of 13 historical data for defining parameters of LP.
Figure (3) shows normal distribution of error for this case study. A suitable classification of data defining relationship between classes results to a good estimated model for each LP.

## IV. STATE ESTIMATION ALGORITHM

The objective of state estimation in distribution networks is determination network state variables for any time. For this purpose, the real time measuring some of variable is necessary in the network. Measurement points should be selected such that the network is observable. In a network with N buses, at least N state variable measurements are needed for network observation.
By using the method propose is before part of this paper estimation of load can be obtain. Therefore, by determining the load of each section of the network becomes observable.
RTMP can measure voltage (amplitude and angel), input and output power (active and reactive). Using of power metering for load (active and reactive) estimation

| $\alpha_1$=0.002321 | | $\alpha_2$=0.32932 | | $\gamma = -0.05465$ |
|---|---|---|---|---|
| $S^L = \alpha_1.S^{m1} + \alpha_2.S^{m2} + \gamma$ | | | | |
| **$.S^{m1}$** | **$.S^{m2}$** | **Actual load** | **Estimated load** | **Error%** |
| 3.23 | 1.87 | **0.57** | **0.56871** | 0.23 |
| 2.84 | 1.71 | **0.52** | **0.51511** | 0.94 |
| 2.78 | 1.7 | **0.51** | **0.51167** | 0.33 |
| 3.12 | 1.82 | **0.55** | **0.55199** | 0.36 |
| 3.24 | 1.96 | **0.6** | **0.59837** | 0.27 |
| 3.26 | 2.11 | **0.64** | **0.64781** | 1.22 |
| 2.55 | 1.56 | **0.46** | **0.46503** | 1.09 |
| 2.77 | 1.75 | **0.53** | **0.52812** | 0.35 |
| 2.94 | 1.79 | **0.54** | **0.54169** | 0.31 |
| 3.05 | 1.91 | **0.58** | **0.58146** | 0.25 |
| 2.69 | 1.75 | **0.53** | **0.52793** | 0.39 |
| 2.66 | 1.72 | **0.52** | **0.51798** | 0.39 |
| 3 | 1.83 | **0.55** | **0.555** | 0.91 |
| 2.7 | 1.72 | **0.51** | **0.51807** | 1.58 |

**Table (1): Load estimation for one LP**

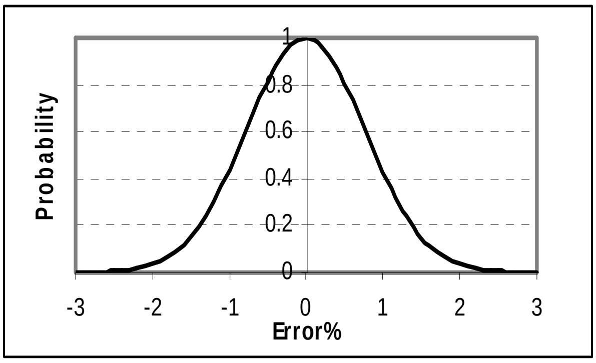



**Figure (3): Normal distribution error%**

and voltage (amplitude and angle) metering for good state estimation. So voltage bus at each RTLP is defined and this bus is PV bus.
Thus, the procedure of the calculation of the expected can be summarized as follows:

- **Step 1. Load estimation:**

  By using propose load estimation algorithm determine the uncertain loads of the distribution networks.

- **Step 2. Backward sweep:**

  If a node has voltage measurement, the node is considered as a PV bus (specific voltage). The voltages of other buses which are feed from PV buses are assumed the same as voltage of PV buses (in the first iteration).

- **Step 3. Forward sweep:**

  The estimated load of network includes both the power consumption and power loss between the feed bus and load bus. Therefore, by determination of power loss in each section the corrected power consumption of each load point can be obtained.

- **Step 4. checking**

The convergence is checked by calculation of power mismatches for all nodes. Repeat steps 2 and 3 if is not converged.

Figure (4) shows the proposed algorithm.

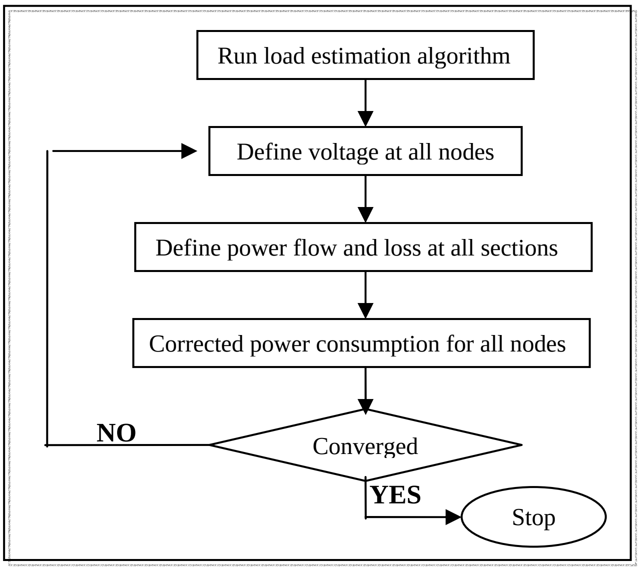



**Figure (4): State estimation algorithm**

## V. ESTIMATOR EVALUATION

The proposed algorithm has been tested on a medium voltage of real distribution networks (Tehran Regional Electricity Co.), with real data collected during a month. This network includes six buses and two RTMP. The first RTMP installed outset of feeder which can measure the power injected to at the feeder. The second RTMP is installed at bus 4 (show the figure 5) which measures the output power and voltage at this node

Load model of each load point are determined (learning) by 15 days load data, then the models are evaluated with 30 days of load data (all of data). Figures 6 and 7 illustrate the estimated and actual daily power consumption profile at buses 3 and 6.

The maximum relative load error (calculated from equation 5) is 3% whereas the maximum load tolerance is 8%.

$$MIRLERR\% = \max_{K}\left(\frac{|S_{LK}^{est} - S_{LK}^{meas}|}{S_{LK}^{meas}}\right)*100 \qquad (5)$$

Where:

$S^{est}_{,LK}$: Estimated power consumption

$S^{mea}_{,LK}$: Actual power consumption

MIRLERR%: Maximum individual relative load error.

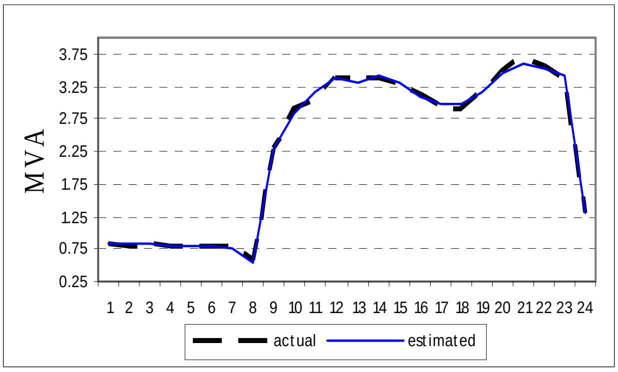



**Figure (6) : Estimated and actual power consumption of bus 3**

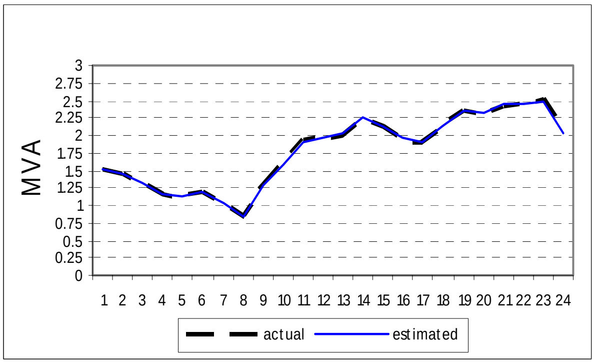



**Figure (7) : Estimated and actual power consumption of bus 6**

Investigation of figures (6, 7) reveals that the estimated load models are suitable for this network and the loads can be allocated with a good accuracy.

Table 2 illustrates the estimated and actual voltage amplitude and the respected at bus 6 (end of feeder) in some of load level on the 11TH day.

The above results confirm accuracy of the estimators.

**Table (2): Voltage data**

| Load level | Voltage actual | Voltage Estimated | Relative Error% |
|---|---|---|---|
| 2 | 0.97498 | 0.97497 | **0.001026** |
| 4 | 0.97624 | 0.97624 | **0** |
| 6 | 0.97728 | 0.97728 | **0** |
| 8 | 0.98229 | 0.98231 | **0.002036** |
| 10 | 0.96996 | 0.96995 | **0.001031** |
| 12 | 0.96308 | 0.9631 | **0.002077** |
| 14 | 0.95714 | 0.95713 | **0.001045** |
| 16 | 0.95296 | 0.95295 | **0.001049** |
| 18 | 0.95475 | 0.95475 | **0** |
| 20 | 0.95168 | 0.95169 | **0.001051** |
| 22 | 0.94996 | 0.94997 | **0.001053** |
| 24 | 0.95129 | 0.95128 | **0.001051** |

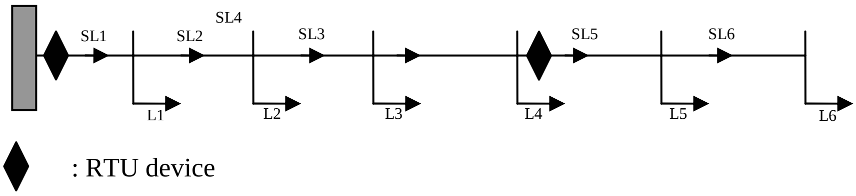



**Figure (5): Real network for estimator evaluation**

Figure 8 illustrates the estimated and actual voltage amplitude profile at bus 6 (end of feeder) for on the 11TH day.

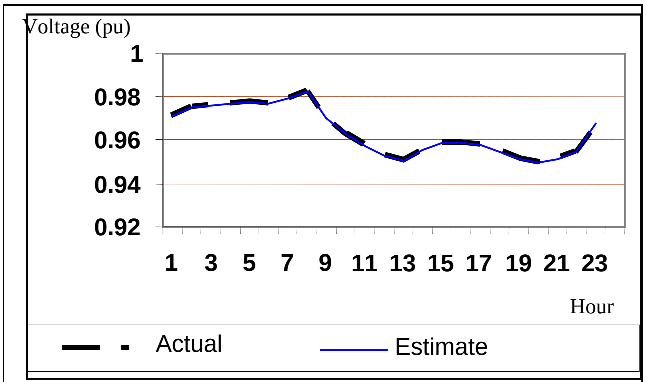



**Figure (8) : Estimated and actual voltage at bus 6**

## VI. CONCLUUSION

State estimation of distribution networks is an important tool for distribution networks monitoring. This paper presented an effective state estimation method for distribution networks. The method uses incorporates specific features of distribution network such as radial topology, non-normal forecast statistical behaviour of load, and low ratio of real-time measurements to number of states. With the usage of proposed method and excellent state estimation of distribution networks can be achieved.

The performance of the proposed approach has been investigated on a part of real distribution network (Tehran Regional Electricity Co.) and the results conform the validity of the method.

## VII. REFERANCES

[1] A.A.YAGHOTI, M.PARSA, 2004,”PLACEMENT LIMITE MEASUREMENT FOR STATE ESTIMATION IN DISTRIBUTION NETWORKS”, 19TH PSC

[2] Jie Wan, 2002, “Nodal Load Estimation for Electrical Distribution Systems”, DREXEL UNIVERSITY

[3] Jie Wan, Karen Nan Miu, 2003, “Weighted Least Squares Methods for Load Estimation in Distribution Networks”, IEEE Tran. On Power systems, Vol. 18 No 4

[4] Final Project Report, 1996,”Power System State Estimation and Optimal Measurement Placement for Distribution Multi-Utility Operation”, Power systems Engineering Research Centre.

[5] Vladimiro Miranda, Jorge Pereira, 2000, “Load Allocation in DMS with a FUZZY State Estimator “, IEEE Tran. On Power systems, Vol. 15 No 2

[6] Atish K. Ghosh, David L. Lubkeman, 1997, ” Distribution Circuit State Estimation Using Probabilistic Approach, IEEE Tran. On Power systems, Vol. 12 No 1.

[7] Isao Higuchi, Shinto Eguchi, 2004, “Robust Principal Component With adaptive Selection for Tuning Parameters”, Journal of Machine Learning Research 5, p.p. 453-471