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STATE ESTIMATION FOR LOAD ALLOCATION IN DISTRIBUTION POWER SYSTEMS

R. Sharifian [1]   E. Jafari [1]   M. Rahimi [2]   P. Ghaebi Panah [3]

1. Department of Electrical Engineering, Lenjan Branch, Islamic Azad University, Isfahan, Iran, sharifian@iauln.ac.ir, jafari@iauln.ac.ir
2. Electrical Engineering Department, National Iranian Oil Company, Isfahan, Iran, mrahimi60@yahoo.com
3. Electrical Engineering Department, Ragheb Isfahani Higher Education Institute, Isfahan, Iran, payam.ghaebi@yahoo.com

Abstract- Considering the large number of customers, local online monitoring is not conceivable. Alternatively, customers' load could be estimated using some measurements in the main station and also on important points of power grid. Therefore, the customers' load allocation is a consequential part in automated distribution power systems. In this paper, the load allocation is developed using average demand of each customer and also the classification curve of customers. The mentioned approach could yield a reliable estimation for each load. Application of this method to two real power systems, comparing estimations with the real measured values ascertains a satisfactory performance.

Keywords: Distribution Power System Automation, Load Allocation, State Estimation.

I. INTRODUCTION

A significant part of automated distribution power systems is dedicated to the online monitoring and control of distribution feeders in order to analyze and manage of voltage, reactive power, and reconstruction. A vital duty in distributed management system is to estimate system states properly.

If the presumed values are relatively correct, the operator could calculate power losses carefully as well as reactive power and voltage optimization and also line overload prevention. Obviously, an exact modeling has a key role to make a satisfactory state estimation. Unfortunately, there is not enough available information in practice when estimation is developing. Hence, some statistic and curve analysis are needed to provide requirements [1, 2].

Therefore, some pseudo measurements are required to estimate the demanded load and to check the system observability. Generally, only customers' transformer rate was used for load estimation formerly; the nominal KVA solution determines each client's portion using its nominal power consumption [3].

In the monthly KWh solution the client's power and its role in the simultaneous peak is considered in proportion to the level of consumption [4]. But nowadays, other elements, e.g. new load demands, type of customer, weather condition, and daily load curve of subscribers should be taken into account [5-9].

II. LOAD ALLOCATION

Basic needs of an estimator include load modeling and individual load allocation which are essential because of limitations in measurement devices of distribution system. A radial network is illustrated in Figure 1 to explain the procedure of load allocation which consists of three online real power measuring devices; P_{m1}, P_{m2} and P_{m3}.

An area of effect is defined for each measuring devices. The area is the distance between this device and adjacent ones. The measurement values should be corrected with regard to adjacent measurements. For instance, if P'_{mi} is the corrected value of area i (i=1, 2, 3), the following relations are derived as $P'_{m1} = P_{m1} - P_{m2} - P_{m3}$; $P'_{m2} = P_{m2}$ and $P'_{m3} = P_{m3}$.

As mentioned formerly, traditional systems solely use transformer's rate for load modeling. Hence, a simple equation is employed for power estimation on each bus as follows:

$$P_i = P_m \left(\frac{TC_i}{\sum_{i=1}^{N} TC_i} \right) \quad (1)$$

where P_i is the demanded active power in node i; P_m is the measured active power in node m; TC_i is the transformer's rate in node i; N is the number of transformers in the area of study.

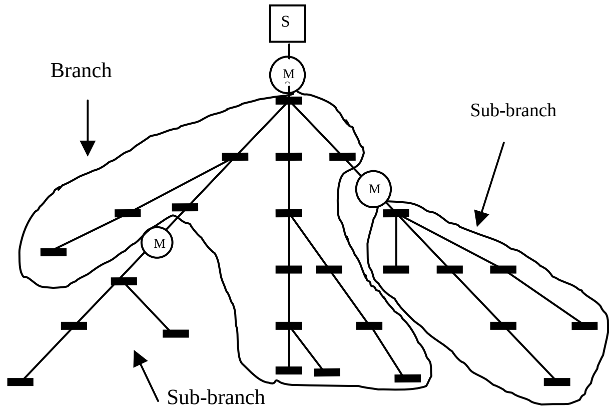

Figure 1. A typical radial distribution power system

As an expanded model, using customers' daily demand, the active power of each node could be estimated as follows:

$$P_i = P_m\left(\frac{ADC_i}{\sum_{i=1}^{N} ADC_i}\right) \tag{2}$$

where ADC_i is the average daily demand in node *i*.

As a matter of fact, categorizing different loads as residential, commercial, and industrial, better estimations of active power on each node may be obtained. Hereafter, the Load Model Factor (LMF) is required which is extracted formerly from the load curve of different classes of loads on the under study bus [10-13].

Considering Figure 2 and Table 1, the effect of using the effect of LMF is sensible. For example, the residential and commercial loads are connected to buses 3 and 4 respectively in Figure 2. Consequently, Figure 3 illustrates daily curves for both residential and commercial loads. These types of curves are produced based on statistical analysis and subscriber history.

For instance, Figure 3 shows LMF for both residential and commercial loads at 4 pm which are 0.75 and 0.85, respectively [1]. In this way, the active power at hour t in node *i* is calculated by the daily load curve of each class and also the corresponding LMF [5].

$$P_{i,j,t} = P_{m,t}\frac{(LMF_{j,t})(ADC_{i,j})}{\sum_{i=1}^{N}\sum_{j=1}^{C}(LMF_{j,t})(ADC_{i,j})} \tag{3}$$

where $P_{m,t}$ is the measured active power in node m and time *t*; C is the number of different load classes connected to the transformer; $LMF_{j,t}$ is the load model factor of class *j* at time *t*.

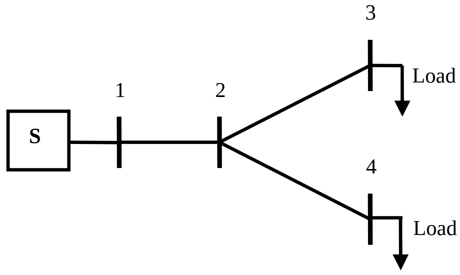

Figure 2. A simple distribution power system

In fact, Equation (3) does not take power loss into account; therefore, it cannot estimate load accurately. Thus Equation (4) is suggested for a better estimation.

$$P_{i,j,t} = (P_{m,t} - P_{loss,m,t})\frac{(LMF_{j,t})(ADC_{i,j})}{\sum_{i=1}^{N}\sum_{j=1}^{C}(LMF_{j,t})(ADC_{i,j})} \tag{4}$$

where $P_{loss,m,t}$ is the power loss in area m at time *t*.

Although the active power loss could be calculated, total loss roughly equals to two percent of demand in the area. Finally, the total demand in node *i* at time *t* is extracted from summation of all demands in different classes. The relative standard deviation of the estimation is obtained using Equations (6) and (7).

$$P_{i,t} = \sum_{j=1}^{C} P_{i,j,t} \tag{5}$$

$$\sigma[P_{i,j,t}] = \frac{\sigma(LMF_{j,t})}{LMF_{j,t}}(P_{i,j,t}) \tag{6}$$

$$\sigma^2[P_{i,t}] = \sum_{j=1}^{C}\sigma^2[P_{i,j,t}] \tag{7}$$

Table 1. Obtained currents with and without *LMF*

Current [A]	Without *LMF*	*LMF* at 8 am	*LMF* at 12 pm	*LMF* at 7 pm
Bus 3	0.465	0.495	0.390	0.501
Bus 4	0.467	0.412	0.543	0.431

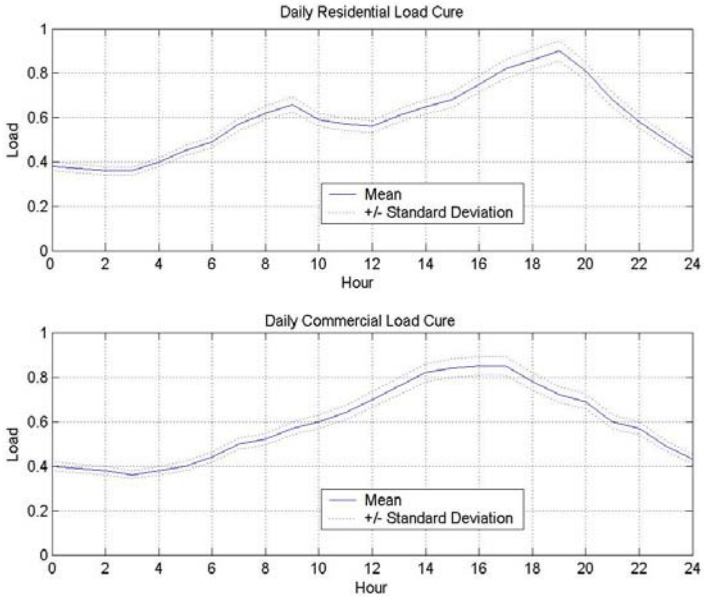

Figure 3. Typical daily load curve

A. Load Modification

Usually, estimation methods use load allocation algorithms; therefore, having estimated voltages of different points the allocated load of subscribers can be modified. Consequently, for the measuring area *k*, allocated load can be modified by minimizing the succeeding relations:

$$\min J(r_P, r_Q) = \sum_{i=1}^{mk} w_{Pi} r^2_{Pi} + w_{Qi} r^2_{Qi}$$

$$P'_{mk} - \sum_{i=1}^{mk} (P_i + r_{Pi}) - P_{loss}(r_P, r_Q) = 0 \qquad (8)$$

$$Q'_{mk} - \sum_{i=1}^{mk} (Q_i + r_{Pi}) - Q_{loss}(r_p, r_Q) = 0$$

where P'_{mk} and Q'_{mk} are the modified values for area *k*; r_P and r_Q are vectors of allocated load demand residuals; $P_{loss}(r_P, r_Q)$ and $Q_{loss}(r_P, r_Q)$ are power losses in system; w_P and w_Q are weighting factors of allocated loads

Considering weighting factors which are positive, the difference between r_P and r_Q in $P_{loss}(r_P, r_Q)$ and $Q_{loss}(r_P, r_Q)$ is neglected. Afterwards, using the following inequality, the above-mentioned relation can be minimized. Similarly, the optimized values of r_P and r_Q are achieved by Equation (10). Accordingly, Equations (11) and (12) are extracted.

$$J(r_P, r_Q) = \sum_{i=1}^{mk} w_{Pi} r^2_{Pi} + w_{Qi} r^2_{Qi}$$

$$J(r_P, r_Q) \ge \frac{\left(\sum_{i=1}^{mk} r_{Pi}\right)^2}{\sum_{i=1}^{mk} \frac{1}{w_{Pi}}} + \frac{\left(\sum_{i=1}^{mk} r_{Qi}\right)^2}{\sum_{i=1}^{mk} \frac{1}{w_{Qi}}} \qquad (9)$$

$$w_{P1} r_{P1} = w_{P2} r_{P2} = ... = w_{Pmk} r_{Pmk}$$
$$w_{Q1} r_{Q1} = w_{Q2} r_{Q2} = ... = w_{Qmk} r_{Qmk} \qquad (10)$$

$$r_{Pi} = \frac{P'_{mk} - \sum_{j=1}^{mk} P_j - P_{loss}}{\left(\sum_{j=1}^{mk} \frac{1}{w_{Pj}}\right) w_{Pi}}$$

$$r_{Qi} = \frac{Q'_{mk} - \sum_{j=1}^{mk} Q_j - Q_{loss}}{\left(\sum_{j=1}^{mk} \frac{1}{w_{Qj}}\right) w_{Qi}} \qquad (11)$$

$$P_i^{(k+1)} = P_i^{(k)} + r_{Pi}{}^k$$
$$Q_i^{(k+1)} = Q_i^{(k)} + r_{Qi}{}^k \qquad (12)$$

B. Load Allocation Algorithm

The algorithm is described as follows:

1. The power system should be sectionalized as a main branch and some sub-branches (Figure 1);
2. The measured active power and also the modified measured value is obtained for each branch;
3. The total loss of area is subtracted from the measured value for each branch;
4. The type of load and demand ought to be calculated using the history and available data for each node;
5. *LMF* is built with regard to the load model and curve adopting Equations (4) and (5) for all nodes of each branch;
6. The standard deviations of estimations are calculated by Equations 6 and 7;
7. Steps 3 to 7 should get repeated until the convergence conditions are met.

III. RESULTS

A. Case 1

The above-mentioned algorithm is implemented on a real power system. The network is composed of 7 distribution substations, 51 feeders, 834 transformers, and nearly 9000 nodes. The *r*/*x* ratio is from 0.43 to 2.3 and average 1.15. A typical power grid is demonstrated in Figure 4. Accordingly, a summary of belonging data are listed in Table 2. Table 3 contains both the measured and estimated values. Obviously, trifling errors confirm merits of proposed algorithm.

B. Case 2

A distribution power system with 21 buses is assumed to evaluate the performance of algorithm (Figure 5). All the loads are single phase and connected to the buses. The line resistance and reactance are 0.231 and 0.080 ohm/km respectively. Providing three measuring devices in the main, seventh, and tenth buses and calculating the measured values using load flow program, both input data for the algorithm and estimated loads are achieved. The measured values for some random nodes are listed in Table 4 versus the associated simulation results. Obviously, as expected, both columns have more or less similar values which could be a confirmation of the proposed solution [14].

Table 2. Outline of grid

Number of branches	115
Number of nodes	116
Number of switches or fuses	47
Number of transformers	40

Table 3. The estimated and measured values

Active Power	Measured Value [KW]	Estimated Value [KW]	Error [%]
P_1	1330.1	1321.7	0.632
P_2	1069.8	1045.7	2.25
P_3	1014.2	1012.4	0.177
P_4	111.2	112.5	1.170

Table 4. The estimated and measured values

Active Power	Measured Value [KW]	Estimated Value [KW]	Error [%]
P4	0.9898	0.9871	0.268
P6	0.9841	0.9741	1.017
P9	0.9811	0.9760	0.519
P14	0.9873	0.9812	0.621
P18	0.9871	0.9673	2.001
P20	0.9749	0.9717	0.327

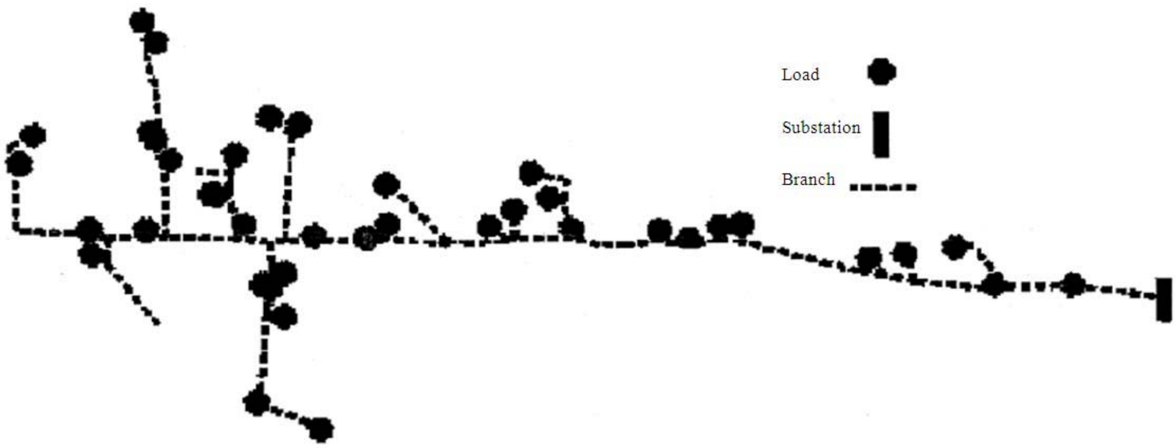

Figure 4. The first under study system

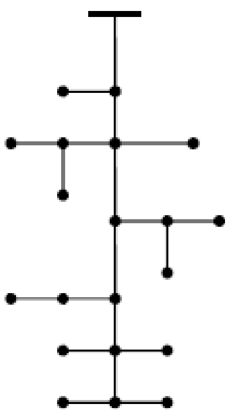

Figure 5. The second under study system

VI. CONCLUSIONS

Generally, if many aspects such as transformers' rate, load type, daily load curve etc. are taken into account, the accuracy of estimation is boosted. In this study, a load allocation approach is developed using the class curves of clients and also the individual average load demand. This method apparently ameliorates the estimation errors. Afterwards, the algorithm performed on a real power grid and estimated values are produced. This approach is in fact based on a measurement in the main substation and some in other different points. Comparison of measured and estimated values verifies the effectiveness of new approach.

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BIOGRAPHIES

Reza Sharifian received the B.Sc. degree from Electrical Engineering Department, Najafabad Branch, Islamic Azad University, Isfahan, Iran, in 2005, and the M.Sc. degree from the University of Isfahan, Isfahan, Iran, in 2009. He is now with the Lenjan Branch, Islamic Azad University, Isfahan, Iran, as a lecturer and also the Head of Electrical Engineering Department. His main research interests include electrical machines and drives, power system stability, renewable energy, artificial intelligence, FACTS devices, nonlinear and robust control.

Ehsan Jafari received the degree in Power Systems from Khomeinishahr Branch, Islamic Azad University of Isfahan, Iran, in 2007, and received the M.Sc. degree in Power Systems from Najafabad Branch, Islamic Azad University, Najafabad, Iran, in 2011. Now, he is Academic Collaborator at the Department of Electrical Engineering, Lenjan Branch, Islamic Azad University, Isfahan, Iran. His interests include FACTS devices and nonlinear control.

Mahdi Rahimi received the B.Sc. degree from the Electrical Engineering Department, Najafabad Branch, Islamic Azad University, Isfahan, Iran, in 2003, and the M.Sc. degree from Electrical Engineering Department, Iran University of Science and Technology, Tehran, Iran in 2005. He is now with the National Iranian Oil Company, Isfahan, Iran.

Payam Ghaebi Panah received the B.Sc. degree from Electrical Engineering Department, Iran University of Science and Technology, Tehran, Iran, in 2007, and the M.S. degree from the University of Isfahan, Iran, in 2010. He is now with the Ragheb Isfahani Higher Education Institute, Isfahan, Iran as a lecturer and also the Head of Electrical Engineering Department. His main research interests include electrical machines and drives, renewable energy, artificial intelligence, FACTS devices, power quality, nonlinear and robust control.