

The Expectation Stimulation for No-Measured Loads and Output of Winds in Distribution Networks

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Abstract. The future measurement systems will be multiple and incomplete collect for measurements. The proposed method could not fully utilize real-time measurements. The estimation precision of non-measured loads will be lower. The distribution analysis and calculation precision will be lower too. So this paper establishes the no-measured loads estimation model with all real-time measures. The proposed algorithm is developed based on Monte Carlo simulation technique. The power flow is carried out for simulated multi-group no-measured loads values. Then power results that are more approach real-time measures are marked. The marked simulated multi-group no-measured loads values are used to calculation expectations of no-measured loads. The no-measured wind outputs are accurately estimation by branch power direction judgment. The compared results of different algorithm verify the accuracy and practicability of the proposed algorithm.

1. Introduction

With the improvement of the automation level of distribution network in China, there are not only measuring devices at the root node of the feeder, but also other measuring devices of the feeder segment and distribution transformer will be increased, and more and more measuring devices in real time are collected. However, due to the limitation of funds, there will still be a large number of adaptors and feeders do not have measuring devices. So, it is of great significance to make full use of the existing multi-collection, multi-measurement distribution network measurement information and non-measurement node power information to improve the estimation accuracy of non-measurement load.

Now, a lot of work has been done on real-time estimation of non-measured load [1-11]. Among them, the estimation method based on power flow calculation has high representativeness due to its high accuracy. Based on the load pseudo measurement of each load predicted, the power of each load node is gradually corrected by using the matching power flow technology to realize the effective estimation of the power of load nodes, and the measurement information of branches is not used [6]. According to the power information in the literature [7-9], the first-end coefficient method was adopted to preliminarily estimate the pseudo-measurement of non-measured load, which was more accurate than the literature [6]. However, the characteristics of the matching power flow algorithm itself determined that the method could not use the branch current and power collected in real time, and reduced the estimation accuracy. Literature [10,11] proposed the non-measurement load estimation of distribution



network based on load current, and made use of the real-time measurement data of voltage, branch power flow and current at root nodes to improve the accuracy of estimation, but failed to make effective use of the real-time measurement data of voltage at other nodes except root nodes.

The above algorithms do not make full use of the characteristics of multi-acquisition, multi-measurement of power distribution network. In order to improve the estimated accuracy, a non-measurement load pseudo-measurement high precision is proposed to make full use of all measurement and power information of the distribution network.

2. Mathematical model

The smaller error between the power, current and node voltages calculated by the pseudo-measured tidal current and the actual time value is, the greater the probability of estimating the pseudo-measured value to be close to the real value. The target function as followed:

$$\min_x J(\mathbf{x}) = \sum_{i=1}^n |z_i - h_i(\mathbf{x}, \mathbf{y})| \quad (1)$$

Where, z_i is the i -th real-time measurement, \mathbf{x} is the pseudo measurement vector of non-measurement load; n is the number of real-time measurement. $h_i(\mathbf{x}, \mathbf{y})$ is the corresponding value of power flow calculation and real-time measurement. \mathbf{y} is the state variable of the tidal formula.

Formula (1) satisfies the following constraints of the tidal current formula:

$$h_i(\mathbf{x}, \mathbf{y}) = 0, i = 1, 2 \dots n_h \quad (2)$$

Where, n_h is the number of constraint formulas.

Formula (1) also satisfies the following inequality constraints:

$$g_i(\mathbf{x}, \mathbf{y}) \leq 0, i = 1, 2 \dots n_g \quad (3)$$

Where, n_g is the number of formula constraint, including node voltage constraint, branch current and current constraint, blower output constraint.

According to formula (1) to (3), the key is to find a set of pseudo-measurement of non-measured load and the output of the blower. Combined with the load with real-time measurement, the constraint conditions (2) and (3) are met to minimize the objective function (1). It needs to be pointed out that the model does not guarantee that the obtained non-measured load pseudo-measurement is the closest to the real value, only that the probability of approaching the true value is high.

If the model is solved with the traditional optimization method^[12], according to formula (1), the model needs to express all real-time measurement in the form of explicit function, but it is impossible to realize the nonlinear tidal formula, so a new solution must be found.

3. Solution method based on Monte Carlo Simulation ^[13]

3.1 Preliminary estimate of non-measured load

Real-time measurement nodes obtain data by every 5, 10 or 15 minutes, which is inconsistent with the time scale of power data and reduces the calculation accuracy of a single power flow. So, according to the method in literature [9], this paper deduces the initial value of real-time pseudo-measurement data of non-measurement load based on the electricity quantity per hour given by non-measurement load.

The active load coefficient K_p and the reactive load coefficient K_q are as follows:

$$\begin{cases} K_p^k = \frac{P_{root}^k}{A_p^h} \\ K_q^k = \frac{Q_{root}^k}{A_q^h} \end{cases} \quad (4)$$

Where, P_{root}, Q_{root} is the active and reactive power output by the root node at time k . The A_p^h, A_q^h are respectively one hour of active and reactive power. Assuming that the active and reactive power of non-measured load i per hour are respectively $A_{i,p}^h, A_{i,q}^h$, then the active and reactive power values at k moments are:

$$\begin{cases} P_i^k = K_p^k A_{i,p}^h \\ Q_i^k = K_q^k A_{i,q}^h \end{cases} \quad (5)$$

3.2 Expected value algorithm for pseudo-measure of non-measured load

If the pseudo-measurement of the measured load is subject to a normal distribution, the estimated value in section 3.1 is taken as the mean value, under the condition of given variance, Monte Carlo simulation generates a set of pseudo-measurement of all non-measured loads at one time, and then combines with the load with real-time measurement, the forward extrapolation back to the thrust flow calculation. If formulas (2) and (3) are satisfied, a target value can be obtained according to formulas (1). The smaller the target value is, the probability of the pseudo-quantity measurement approaching the real value is greater. The objective function in this paper is less than the expected value of the multi-group Monte Carlo simulation results of a given value.

If each load pseudo-measurement is calculated according to formulas (1) to (3), it is obvious that the calculation amount is too large for online application. According to the characteristics of the radial distribution network, branch $j-k$ out of power will equal the sum of end node k downstream load power, blower output and network loss. In the case of unknown network loss, there is the following inequality relation:

$$z_i^k(p, q) > \sum_{i=1}^{n_{x_i}} x_i^k(p, q) + \sum_{i=1}^{n_{y_i}} y_i^k(p, q) + \sum_{i=1}^{n_{G_i}} G_i^k(p, q) \quad (6)$$

Where, $z_i(p, q)$ is active or reactive power real-time measurement in the end of the branch $j-k$ node k downstream; $x_i^k(p, q)$ is the load active or reactive pseudo-measurement simulated by Monte Carlo simulation in the downstream of node k , and n_{x_i} is its number. $y_i^k(p, q)$ is active power or reactive power measured by real-time of downstream load of node k , and n_{y_i} is its number. $G_i^k(p, q)$ is active or reactive power of downstream blower of node k , n_{G_i} is its number.

According to the above formula, the load pseudo measurement data of each group of Monte Carlo simulation can be checked to eliminate multiple groups of false measurement that do not meet the requirements. It is unnecessary to calculate the power flow one by one and judge whether the constraint conditions are met, thus improving the calculation efficiency.

The following is the flow chart of estimating the expected value of the pseudo-measured load:

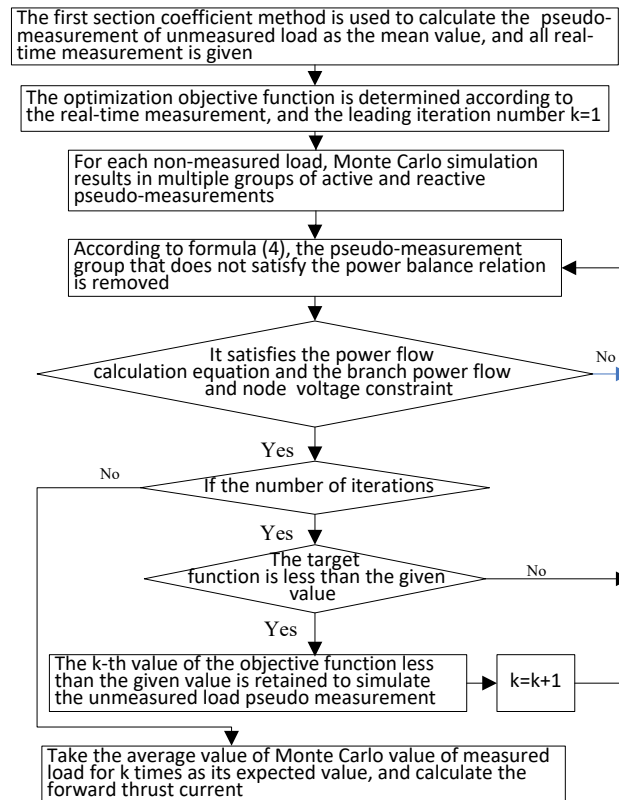


Figure 1. The flow chart of expectation value estimation of non-measured measurements based on Monte Carlo simulation method.

3.3 Real-time measurement data identification

For the data collected in real time, the residual ratio between the real time measurement to be identified and the calculated expected value is calculated according to the following formula:

$$\varepsilon(x_i) = \frac{|x_{i,real} - x_{i,E}|}{x_{i,real}} \quad (7)$$

Where, $x_{i,real}$ is real-time measurement, $x_{i,E}$ is the expected value of a real-time measurement.

The flow chart of identification of real measurements is as follows:

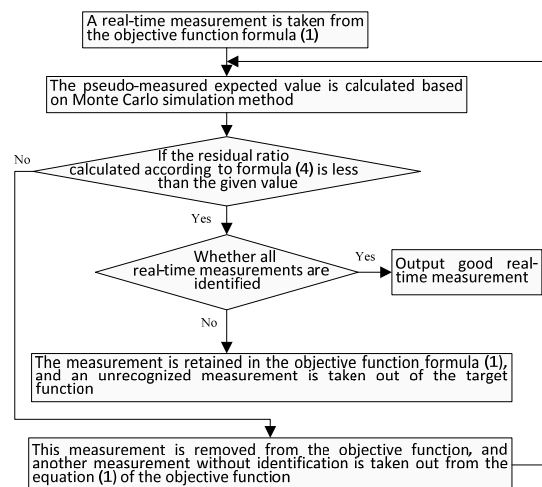


Figure 2. The flow chart of identification of real measurements

3.4 The flow of the algorithm

The flowchart of expected value estimation of unmeasured load is as follows:

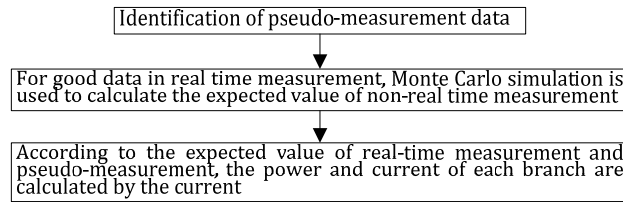


Figure 3. The general flow chart

3.5 Estimation of the pseudo-measured expected value of the unmeasured load containing the blower

In the distribution network without measuring devices, the active power output of the blower can be predicted according to the numerical weather forecast. When the blower is PQ node, the reactive power output can be calculated according to the given power factor. When the blower is PV node, the initial reactive power output of the PV type blower is determined by the initial reactive power value method based on the improved principle of reactive power allocation in literature [14].

But after joining blower on the downstream side of the branch, branch power or current direction could flow back, for the real-time measurement of branch power and current with only numerical size but no direction, even if the output and the measurement of the group of monte carlo simulation blower load pseudo measurement according to the formula (1) the target is very small, but very possible power and current direction and the actual direction inconsistent, seriously affect the estimate precision of the pseudo measurement.

Discriminating branch j - k power or current direction of uncertainty computation formula is as follows:

$$\begin{cases} \left| \sum_{i \in I_G} P_{Gi,ave} - \sum_{i \in I_w} P_{Li,ave} - \sum_{i \in I_r} P_{Li,real} \right| < \varepsilon \\ \left| \sum_{i \in I_G} Q_{Gi,ave} - \sum_{i \in I_w} Q_{Li,ave} - \sum_{i \in I_r} Q_{Li,real} \right| < \varepsilon \end{cases} \quad (8)$$

Where, $P_{Gi,ave}$, $Q_{Gi,ave}$, $P_{Li,ave}$, $Q_{Li,ave}$ and $P_{Li,real}$, $Q_{Li,real}$ are respectively the i -th blower's predicted output, the mean value and real - time measurement of pseudo - measure load; I_G , I_w and I_r are respectively are all the blower, the pseudo measurement load measurement and real-time measuring load collection of the branch j - k downstream.

If active and reactive power of the branch j - k to meet formula (8), that the blower output and load of the downstream branch were similar and power direction of branch j - k is uncertain. In formula (1), remove the power and electrical measurement of the branch, and then based on the algorithm of section 3.3 to get each unmeasured load, power direction of the j - k branch is obtained by power flow calculation, put it in the formula (1), and then by adopting the method of section 3.3, which can realize with the measurement of the blower load of pseudo measurement gauge.

4. Examples and analysis

Taking the 11-node system shown in figure 4 as an example to test the algorithm, the rated voltage of line and transformer is 10 kV, and the average voltage of bus is 10.5 kV.

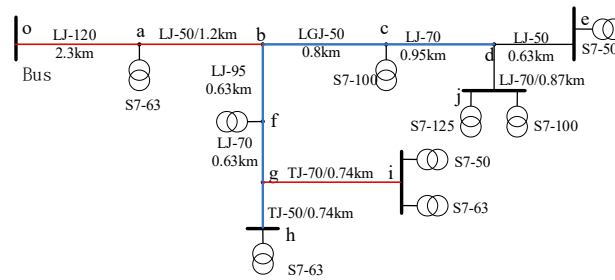


Figure 4. The diagram of 11 node distribution network

Assuming that the power value and current amplitude at the first end of the branch $o-a$ and $b-c$ are known, the measurement values of active and reactive power in the branch $o-a$ section are $P_{o-a} = 558.462\text{ kW}$, $Q_{o-a} = 257.42\text{ kvar}$ and current amplitude is $I_{o-a} = 5.94\text{ A}$; The measured values of active and reactive power in the $b-c$ branch of the branch are $P_{b-c} = 303.209\text{ kW}$, $Q_{b-c} = 189.173\text{ kvar}$, and current amplitude measurement is $I_{b-c} = 3.21\text{ A}$, and voltage amplitude measurement of node b is 10.4 kV . Compared with the existing literature, the measured value of branch $b-c$ segment and the measured value of node b voltage amplitude are increased.

4.1 Unmeasured load estimation without blower

The load pseudometry was simulated 1000 times by Monte Carlo simulation, according to the formula (4), at the same time satisfy the branch $o-a$ and $b-c$ power inequalities of pseudo measurement simulation results a total of 131 sets, reduced the number of load flow calculation, algorithm to calculate time of 1.31 seconds, meets the demand of online calculation, algorithm firstly for a given real-time measurement data are identified, identification results are shown in table 1:

Table 1. The Results of identification of bad measurements
(per unit kvar)

Measurement	True value	Measurement Value	Identification value	Residual error ratio
reactive power of branch o-a	0.222	0.257	0.218	0.179
reactive power of branch b-c	0.119	0.189	0.121	0.562

According to table 1, the residual error ratio is so large, which can be judged as bad data. The algorithm in this paper has a good ability to identify bad data.

Table 2 shows the comparison of the calculation results with the interior point method and the non-measured load estimation results based on load current.

Table 2. The results comparison
(Active power per unit kW, Reactive power per unit kvar)

Node	True value	Desired value	Based on load current [12]	flow matching [17]
Pa	50	50.5	51.84	53.1
Qa	20	19.85	19.832	20.6

Pc	79	81	81.468	81.3
Qc	32	31.3	31.906	31
Pe	40	40.4	39.788	39.4
Qe	16	16.271	16.277	15
Pf	64	64.1	64.734	64.8
Qf	25	24.7	24.457	24.6
Ph	50	50.6	48.680	49
Qh	20	19.8	20.147	20.2
Pi	90	88.9	88.705	90.3
Qi	36	35.8	36.5	37
Pj	179	180.1	176.7	177
Qj	72	72.1	71.729	72.4

Figure 5 shows the change curve of relative error of different calculation methods.

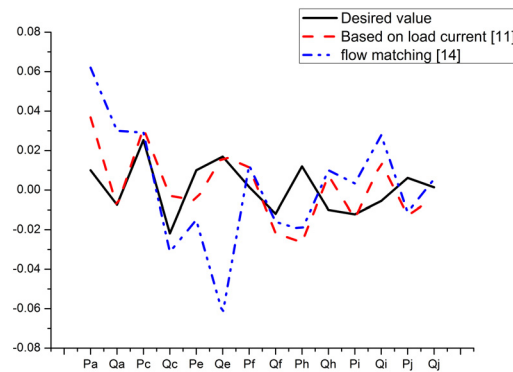


Figure 5. The curve of errors

As can be seen from figure 5, the estimated value of the expected value estimation method at three points of Qc, Pe and Qh is less accurate than that of the other two methods, and the estimated precision of the remaining load points is higher than that of the other two methods.

Table 3 shows the expected value estimation results under different variance conditions.

Table. 3 The expectation values of non-measured measurements under different variance
(Active power per unit kW, Reactive power per unit kvar)

Node	True value	The variance as a percentage of the mean		
		5	2.5	1.25
Pa	50	48.6	50.5	51.3
Qa	20	17.6	19.5	19.2
Pc	79	77.1	81	82
Qc	32	31.3	30.3	31
Pe	40	40.6	40.4	40.3
Qe	16	20.8	16.7	18.4
Pf	64	65.6	64.1	63.7
Qf	25	24.5	24.7	24.5
Ph	50	46.7	50.6	49.5
Qh	20	21.3	19.8	20.1

P _i	90	90.3	88.9	90.2
Q _i	36	34.8	35.8	35.1
P _j	179	177	180.1	178
Q _j	72	73.1	72.1	71.4

It can be seen from table 3 that under the condition that the variance is 2.5% of the mean value, the difference between the calculated result and the true value is the smallest, and the result is taken as the pseudo-quantitative measurement value.

Figure 6 shows the curve diagram of the error mean changing with the simulation times of Monte Carlo.

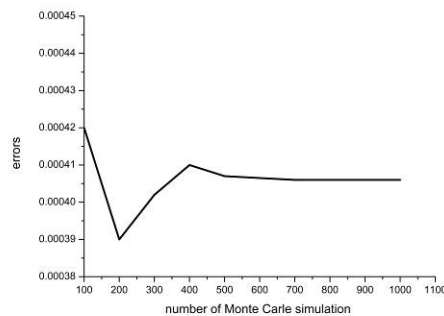


Figure 6. The error change curve with the number of Monte Carlo simulation

As can be seen from figure 6, when The times of Monte Carlo simulation are greater than or equal to 500 times, the error mean change is small, so The Times of simulation are 500.

4.2 Non-measured load estimation of the blower

If one blower (1500kW) is connected in parallel in node c, if the blower does not have a real-time measuring device, the specific parameters are shown in literature [15]. The blower's predicted wind speed is 7.4m/s. According to the wind power curve, the blower's output force is 400kW. If the blower is PQ node and the power factor is 0.9, then the reactive power output of the blower is 193kvar. However, the downstream load of node c is all non-measured load, the mean sum of its active load is 388kW, and the mean value of reactive load is 152kvar. According to formula (5), the downstream active power error of branch *b-c* is 5kW, and the reactive power error is 23kvar. The error of active power is small and the direction of power flow at the first end of branch *b-c* cannot be determined. In this way, only the measurement of branch *o-a* and the voltage amplitude of node b are retained in the objective function formula (1). By using the algorithm in figure 4, the power and current direction of branch *b-c* are all from node b to node c.

If the actual wind speed is 7.5m/s, the actual active power output of the blower is 417kW, and the reactive power output is 202kvar, then the expected value output of each load node and blower and the actual output are shown in table 4.

Table 4. The results with wind turbines
(Active power per unit kW, Reactive power per unit kvar)

Node	True value	Expected value estimation	
		The power direction of branch b-c is determined	The power direction of branch b-c is not determined
P_w	417	419	423
Q_w	202	207	211
P_a	50	50.7	51.4

Qa	20	19.45	20.1
Pc	79	78.6	77.9
Qc	32	31	32.1
Pe	40	40.8	41.7
Qe	16	16.57	17.21
Pf	64	64.65	65.4
Qf	25	24.1	23.9
Ph	50	50.9	52
Qh	20	19.4	18.4
Pi	90	90.2	91.2
Qi	36	35.4	34.9
Pj	179	181	182.7
Qj	72	71.5	70.9

It can be seen from table 4 that the estimation accuracy is improved by judging the power and current direction of b - c branch.

5. Conclusion

The uncertainty method of Monte Carlo simulation is applied to the mathematical model of unmeasured load and blower output estimation. Compared with the existing algorithm, the method provided in this paper makes full use of all the real-time measurement data that can be collected. It can improve the estimation accuracy, and is suitable for the modeling of the multi-acquisition and incomplete measurement system of the future distribution network, which is of great practical significance.

References

- [1] R. P. Broadwater, A. H. Khan, H. E. Shaalan, et al. Time vary load analysis to reduce distribution losses through reconfiguration. IEEE Trans. On Power Delivery, **8(1)**: 294-300 (1993).
- [2] R. E. Lee, C. L. Brooks. A method and its application to evaluate automation distribution control. IEEE Trans. On Power Delivery, **3(3)**: 1232-1240 (1988).
- [3] C. S. Chen, M. Y. cho. Determination of critical switches in distribution system. IEEE Trans. On Power Delivery, **7(3)**: 1443-1449 (1992).
- [4] Ding Xinhai, Luo Yifang, Liu Wei et al. A new practical method for calculating line loss of distribution network-improved iteration method. Power System Technology, **4(1)**: 39-42 (2002).
- [5] Wanger T P, Chikani A Y, Hackam R. Feeder reconfiguration for loss reduction: An application of distribution of distribution automation[J]. IEEE Trans. on Power Delivery, **6(4)**: 1922-1931(1991).
- [6] Sun Hongbin, Zhang Boming, Xiang Niande. Distribution matching power flow technology and its application to state estimation for distribution systems. Automation of Electric Power Systems, **22(7)**: 18-22(1998).
- [7] Wen Jianchun, Han Xueshan, Zhang li. Improved method for theoretical line loss calculation of distribution network. Proceedings of the CSU-EPSA, **20(4)**: 72-76(2008).
- [8] Chen Dezhi, Guo Zhizhong. Distribution system theoretical line loss calculation based on load obtaining and matching power flow. Power System Technology, **29(1)**: 80-84(2005).
- [9] Yang Lin, Wang Weidong, Chen Dezhi, et al. A research on theoretical energy losses of medium-voltage distribution networks based on measures. RELAY, **33(3)**: 28-33(2005).
- [10] Li Hui, Yang Minghao. Least-square state estimation of pseudo-measured loads in distribution systems. Power System Technology, **27(7)**: 47-51(2003).
- [11] Li Hui, Yang Minghao. A load-current-based state estimation for distribution systems non-measurement loads. Proceeding of the CSEE, **25(5)**: 33-37(2005).

- [12] Li Wei. *Linear optimization and extension* [M]. Beijing: National Defence Industry Press, (2011).
- [13] Liu Baoding, Zhao Ruiqing. *Uncertain mathematical programming methods*. Beijing: Tsinghua University Press, (2005).
- [14] Yan Limei, Xie Mingxia, Xu Jianjun, et al. Improved power flow calculation of distribution network with DG. *Power System Protection and Control*, **41(5)**: 17-22(2013).
- [15] Shen Hong. *Study on the grid-connected operation model of variable speed and constant frequency wind turbine and its application*. Beijing: China electric power research institute, (2003).