Research on a Real-time Dynamic Monitoring System based on PMU

Liu Wei

Electrical Engineering College, Jilin Technology College of Electronic Information, Jilin, China

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Abstract: With the development of real-time dynamic monitoring system, each regional dynamic monitoring system is relatively independent, and has its own photo independent scheduling center. To accommodate this partition management model, state estimation should use a distributed parallel algorithm. Based on the dynamic spread algorithm and the parallel algorithm of lapped distribution, a new dynamic state estimation algorithm for distributed real-time dynamic monitoring system based on phasor measurement unit (PMU) is proposed. The algorithm uses a small number of PMU measurement points to truly realize the parallel computing of each subsystem, avoiding the process of serial waiting by the original algorithm. Combined with the measurement data preprocessing and the comparison of the matrix weighting, the calculation speed is accelerated and the numerical precision and stability are improved. Finally, the simulation results of IEEE 14 nodes are given, and the effectiveness and superiority of the algorithm are verified.

1. Introduction

Dynamic state estimation is particularly important for the safety assessment of the dynamic monitoring system and the prediction of the state to achieve online functions such as economic allocation and preventive control. With the continuous expansion of the scale of real-time dynamic monitoring systems, the structure and operation mode of dynamic monitoring systems are becoming more and more complex, which puts higher requirements on dynamic state estimation.

With the development of dynamic monitoring systems, regional dynamic monitoring interconnects to form larger systems. China will gradually realize nationwide networking. However, the dynamic monitoring of each region is relatively independent, and each has its own independent dispatch center. For such a large system, the overall algorithm is too large to be able to obtain sufficient information to satisfy the system's observability and is no longer applicable. In order to adapt to this partition management mode, dynamic state estimation of dynamic monitoring systems must also adopt distributed parallel algorithms. The districts achieve state estimation relatively independently, which not only speeds up the calculation, improves the accuracy of the data, but also facilitates implementation and management. Therefore, it is of great practical significance to study distributed algorithms for dynamic state estimation.

In the 1980s, some scholars proposed using a hierarchical dynamic state estimation algorithm to conceive a large system consisting of a number of disconnected subsystems and a boundary system. The algorithm has some problems [1]. It gives up the measurement of the tie line power between subsystems when estimating at the first layer, but the measurement configuration on these tie lines is often dense and the precision is high, which will be lost. A lot of information. At the same time, the state values of the boundary bus bars determined by each subsystem are large and difficult to coordinate. Later, some scholars proposed to use the distributed synchronization algorithm to effectively use the measurement information. However, the steps of synchronously detecting the boundary conditions of the boundary bus are caused by the algorithm to exchange data and wait for a long time. These shortcomings limit the application of the algorithm.

To this end, this paper proposes a new distributed dynamic state estimation algorithm based on phasor measurement unit (PMU). The algorithm adopts three measures: configuring a small number of PMUs, introducing a coordination module, and transforming the algorithm using synchronous detection into a distributed parallel algorithm for independent detection; adding a human exponential function to predict the data before state prediction; Several pairs of Jacobian matrices are weighted. The above measures can not only avoid the shortcomings of the above hierarchical dynamic state estimation algorithm and the lap synchronization algorithm, retain its advantages, and truly realize the parallel computing of the algorithm, reducing the amount of data exchange and transmission. Moreover, for the non-uniformity of the reference busbars of each subsystem, a new method of merging the phase angles of each subsystem into the reference nodes of the whole system is proposed, which has certain practical value.

2. Mathematical model of dynamic state estimation

Dynamic state estimation uses Holt's two-parameter exponential smoothing method combined with the conventional extended Kalman filtering (EKF) principle for state prediction and estimation [2].

Assuming that the transient process after disturbance is ignored and the quasi-steady state model describing the dynamic state of the dynamic monitoring system is linearized, it can be expressed as:

$$X_{k+1} = FkX_k + U_k + \omega_k \quad (1)$$

The measurement model of the system can be written as:

$$Z_{k+1} = h\,(X_{k+1}) + V_{k+1} \quad (2)$$

Where: X_k is the n*1 dimensional state vector at time k; Z_k is the m*1 dimensional observation vector at time k; h (X_k) is the m*1 dimensional nonlinear measurement function Number; F_k is the state transition matrix.

The EKF formula can be derived from equations (1) and (2). The forecast step is:

$$a\_k = ax\_k\,(1-a)\hat{x}_k \quad (3)$$

$$b_k = \beta(a_k - a_{k-1}) + (1-\beta)b_{k-1} \quad (4)$$

3. State prediction

At present, the literature on distributed state estimation mostly uses the method of full network prediction and network filtering. In this paper, the distributed algorithm is completely implemented by using the method of network prediction and network filtering. State prediction still uses two-parameter exponential smoothing method in the algorithm, but considering that the algorithm is distributed parallel prediction for each subsystem to achieve the optimal prediction result of the whole system, it is solved by using global uniform optimal parameters.

It can be known from equation (3) that a uniform optimal parameter is used for each system. When β and α, the state prediction value of the boundary bus is also globally optimal. Specific parameter determination can be found in the literature [3-5].

4. State filtering

The accuracy of the measured data affects the accuracy of the dynamic state estimation. Therefore, this paper preprocesse the measured data to minimize the impact of data errors on the algorithm. Referring to the robust algorithm [6], an exponential function is introduced between state prediction and filtering to change the weight of the measured data:

$$W_k = W_s \exp(-Z_s - h\hat{x}) \quad (5)$$

It can be known from equation (5) that the exponential function can modify the weight, so that the weight of the measured value changes with the accuracy of the prediction, which is in line with the principle of weight selection, which can improve the numerical precision and speed up the convergence.

The lapped distribution algorithm proposed in [7-9] requires that each adjacent subsystem must detect the constraints one by one, which is its main disadvantage. To this end, the algorithm is improved in this paper. As mentioned above, the PMU is configured at the lap joint and referenced to the reference bus of the whole network of the system, so that the equality constraint can be transformed into the filter convergence criterion in each subsystem. It is assumed that the second subsystem has a joint with the jth subsystem, that is, both systems satisfy the boundary bus voltage phasor equality constraint, and the following convergence criterion can simplify the algorithm.

$$\max(\theta_k + G_t) < \xi \quad (6)$$

Since the PMU is configured on the boundary bus, the voltage amplitude and phase angle are relatively accurate measurements, which are included in the filter to accelerate convergence and obtain an accurate voltage phasor. Therefore, it is easy to satisfy the above inequality as one of the criteria for convergence. It coordinates the boundary bus between two adjacent subsystems well.

If the compatibility of the data of the equivalent measurement system is not good or the bad data cannot be effectively processed, and the difference between the two system boundary bus values is large, the coordination module works. The working principle is to use the residual weighted estimation method as follows.

$$\mathrm{X} = \frac{r_1 X_1}{r_1+r_2} + \frac{r_2 X_2}{r_1+r_2} \quad (7)$$

Among the measured values used in the real-time dynamic monitoring system state estimation, there are both the first-level measurement error and the first-order calculation error. Under normal circumstances, the amplitude of the voltage collected by the SCADA system is called the first-order error, while the node power and the power flow are two-level error, which will undoubtedly reduce the estimation accuracy and increase the calculation amount. Therefore, according to the distribution type of the measurement points, the following considerations are made: 1 The voltage amplitude measurement value has only one measurement error, and the relative error is small. These quantities should be effectively utilized to improve the accuracy of the state estimation; 2PMU measurement the value accuracy is high, and the method used to calculate the value of the PMU to improve the accuracy of the state estimation has become a research hotspot.

Reference [10] pointed out that the measurement value of PMU is directly included in H, which has little effect on the accuracy of state estimation. Therefore, this paper adopts the method of weighting Jacobian matrix elements to improve data accuracy and speed up the convergence of the algorithm.

5. Test results

This paper uses the IEEE 14-node system for simulation. The network wiring diagram and line parameters are listed in the appendix [11]. The PMU is configured at the reference points 1, 8, and 4, 5 of the subsystem. The system samples 18 times, and the load change of each node adopts the curve shown in the figure below. The true value in the simulation is calculated by the PSASP analysis synthesis program. At the same time, considering that the data of the measurement system is susceptible to Gaussian white noise, the simulation simulates this error. The error is assumed to be a normal distribution with a mean value, where the error standard deviation of the power measurement is taken as a true value of 2%. Similarly, the standard deviation of the voltage measurement error is taken as a true value of 1%. The phase angle was measured to be 0.10%.

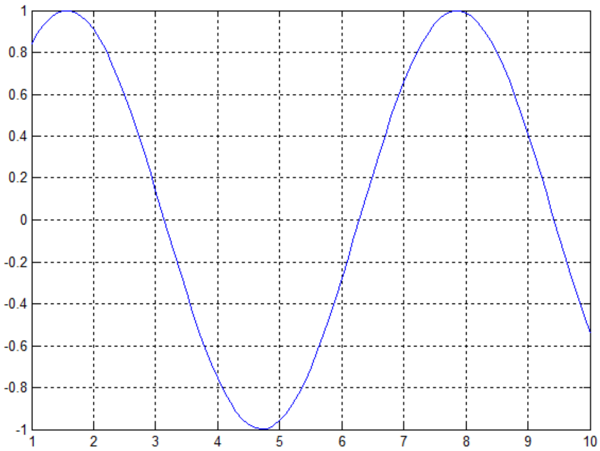

Figure 1 load curve

In order to verify the effectiveness of the PMU-based distributed dynamic state estimation algorithm, it is easy to understand its performance, and the following indicators are used for the prediction and filtering results respectively:

Table 1 Node partition table

Region	Number of nodes	Boundary node	Number of branches	Measurement	Redundancy
A1	6	3	8	26	2.2
A2	12	3	12	48	2.1
Whole network	16		20	69	2.4

In this paper, the proposed algorithm is implemented on MATLAB 6. 5 platform. The feasibility and effectiveness of the proposed algorithm are verified by simulation of IEEE I4 node system.

The improved algorithm reduces the amount of data exchanged between adjacent systems. Before the improvement, after each filter iteration, it is necessary to detect whether the boundary monitoring is equal, that is, the data needs to be continuously transmitted and exchanged in the iterative process; and the improved algorithm only exchanges data when the node voltage and the PMU error are greater than Δ. Obviously, the amount of data exchange is reduced. The selected sampling point is 7, and the exchange amount before the improvement (the number of exchanges X iterations) is 4*I0, and the improved exchange amount is 0. The reduction in the amount of data exchange not only improves the computational speed of the algorithm to a certain extent (see Table 2), but also makes the algorithm easy to implement in an interconnected system.

Table 2 Comparison of calculation time between improved algorithm and global algorithm

algorithm	Number of nodes	Partition time/s	Total time/s
Integral	14	62.5	62.5
Before improvement	5/11	44.1/46.1	44.1
After improvement	5/11	5.46/23.1	23.1

Table 2 lists the comparison of the average and maximum values of the absolute error of the estimated value of the real-time dynamic monitoring phasor of the above three algorithms for all nodes. Among them, the distributed algorithm considers the case of the 5-node system 1 and the 11-node system 2, respectively.

It can be seen from Table 2 that for the overall situation of each sampling point or 18 samplings, the average error of the whole algorithm is small, but it is not applicable to large systems; after using the distributed algorithm, under the premise that the data precision is basically unchanged To maximize the superiority of the algorithm.

In order to further analyse the influence of the phase angle measurement of the two interval boundary nodes on the estimated power flow, the different errors of the phase angle measurement are further simulated.

Table 3 lists the simulation results for the 1 zone (5 nodes) when the phase angle measurement takes different errors. The data in the table are the sum of the maximum error and error of the estimated values of the 10 state variables obtained from 18 samples (the average error is too small to compare). The standard deviation of the phase angle measurement error is taken as 0.100, 0.500 and 500 of the true value, respectively. It can be seen from Table 4 that when the measurement error is below 5%, the influence on the accuracy of the estimation value is not large, and the accuracy of the estimated power flow satisfies the requirements. When the error excessively affects its convergence, the measurement error has exceeded the specified value. In practical applications, corresponding measures can be taken to pre-process the measured data to avoid the occurrence of excessively large measured values.

Table 3 Effect of measurement misdetection on state estimation

Standard deviation	Maximum error	18 total errors
0.1	0.03029	0.5093
0.5	0.0303	0.5095
1	0.03031	0.5097
5	0.03032	0.5099

Figure 2 shows the filtered values of the voltage amplitude and phase angle of node 5 in System 1 and System 2, respectively, using a PMU-based distributed dynamic state estimation algorithm. It can be seen from Fig. 2 that after the convergence criterion determination and coordination module processing, the values are quite close, the error is small, and the accuracy requirement is met.

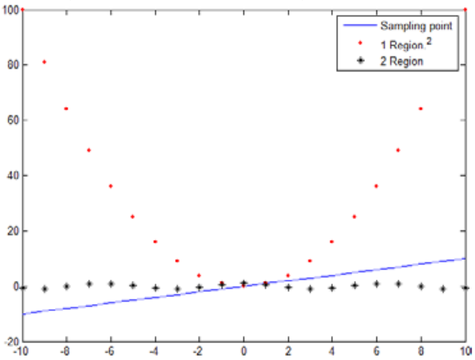

Fig. 2 Results after treatment in different regions

6. Conclusion

The comparison of the above theoretical analysis and simulation shows that the improved algorithm is simple and effective, and has the following advantages:

1) Using the lapped method to achieve network partitioning, can make full use of the tie line power measurement between subsystems, effectively utilizing high precision The information overcomes the shortcomings of the hierarchical partitioning method that loses a large amount of measurement information.

2) The proposed PMU real-time dynamic monitoring system configuration scheme is feasible and effective for solving the subsystem phase angle merging as a reference node of the whole system.

3) After adopting the improved algorithm, it overcomes the shortcomings of the original lapped distribution algorithm to successively detect the constraint conditions, and avoids the waste of time and the heavy data transmission caused by the processor waiting.

4) The coordination module is used to correct the estimated deviation of the boundary bus node, and no secondary coordination of the whole network is needed.

5) The weighting of the Jacobian matrix elements is adopted, thereby improving the data precision, saving the calculation time, and speeding up the convergence speed of the algorithm.

Of course, in practical applications, the algorithm still has some problems. One of the more prominent key problems is that when the boundary PMU measurement error is large, it will affect the convergence criterion, which in turn affects the accuracy of the estimated flow in the two regions, and even affects its convergence. To this end, it is necessary to study the method to ensure the accuracy of this small number of boundary PMU measurements, to maximize the advantages of the algorithm.

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References

[1] Vanfretti L, Baudette M, Domínguez-García J L, et al. A Phasor Measurement Unit Based Fast Real-time Oscillation Detection Application for Monitoring Wind-farm-to-grid Sub–synchronous Dynamics [J]. Electric Machines & Power Systems, 2015, 44(2):123-134.

[2] Brahma S, Kavasseri R, Cao H, et al. Real Time Identification of Dynamic Events in Power Systems using PMU data, and Potential Applications - Models, Promises, and Challenges [J]. IEEE Transactions on Power Delivery, 2017, PP (99):1-1.

[3] Asprou M, Chakrabarti S, Kyriakides E. A Two-Stage State Estimator for Dynamic Monitoring of Power Systems [J]. IEEE Systems Journal, 2017, 11(99):1-10.

[4] J.-P C, Main G, Webster A, et al. State-matrix-independent dynamic process estimation method in real-time for weakly observable measurement nodes without PMU [J]. Behavioral Sciences & the Law, 2015, 21(2):578-85.

[5] Khazaei J, Fan L, Jiang W, et al. Distributed Prony analysis for real-world PMU data [J]. Electric Power Systems Research, 2016, 133:113-120.

[6] Zhao J, Zhang G, Das K, et al. Power System Real-Time Monitoring by Using PMU-Based Robust State Estimation Method [J]. IEEE Transactions on Smart Grid, 2016, 7(1):300-309.

[7] Dasgupta S, Paramasivam M, Vaidya U, et al. PMU-Based Model-Free Approach for Real-Time Rotor Angle Monitoring [J]. IEEE Transactions on Power Systems, 2015, 30(5):2818-2819.

[8] Sharma A, Srivastava S C, Chakrabarti S. Multi-agent-based dynamic state estimator for multi-area power system [J]. Iet Generation Transmission & Distribution, 2015, 10(1):131-141.

[9] Patil V U, Kapur A R. Internet Based Interactive Society Monitoring System Using Dynamic IP in Real Time ☆ [J]. Procedia Computer Science, 2015, 45:611-619.

[10] Liu Y, Liu Y, Liu J, et al. A MapReduce Based High Performance Neural Network in Enabling Fast Stability Assessment of Power Systems [J]. Mathematical Problems in Engineering, 2017, (2017-02-8), 2017, 2017:1-12.

[11] Tang M, Yao J, Chen Z, et al. [Implementation of Wearable Terminal Used for Dynamic ECG Real-time Monitoring Based on Internet of Things]. [J]. Chinese Journal of Medical Instrumentation, 2018, 42(3):161-171.

[12] Bi T, Liu H, Feng Q, et al. Dynamic Phasor Model-Based Synchrophasor Estimation Algorithm for M-Class PMU [J]. IEEE Transactions on Power Delivery, 2015, 30(3):1162-1171.

[13] Kong X, Dong B, Song X, et al. Dual turn-on fluorescence signal-based controlled release system for real-time monitoring of drug release dynamics in living cells and tumor tissues [J].

Theranostics, 2018, 8(3):800-811.

[14] Farantatos E, Huang R, Cokkinides G J, et al. A Predictive Generator Out-of-Step Protection and Transient Stability Monitoring Scheme Enabled by a Distributed Dynamic State Estimator [J]. IEEE Transactions on Power Delivery, 2016, 31(4):1826-1835.

[15] Vahdatikhaki F, Hammad A. Dynamic equipment workspace generation for improving earthwork safety using real-time location system. [J]. Advanced Engineering Informatics, 2015, 29(3):459-471.