Linear State Estimation of Power Grid Based on State Decoupling

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Abstract: Aiming at the relative decoupling of active and reactive power in power grid, a linear phase estimation model based on active voltage measurement for voltage phase estimation and a linear voltage estimation model for voltage amplitude estimation using voltage amplitude measurement and zero injection measurement are proposed. The performance test of the node system shows that the algorithm has a faster calculation speed, can effectively save memory, and has high efficiency.

1. Introduction

Power system state estimation is one of the core functions of the power system dispatching center energy management system (EMS). The safe and economic operation of modern power grids depends on energy management systems (EMS), And the many functions of the energy management system can be divided into two parts: online applications that analyze real-time changes in the power grid and offline applications that analyze typical power flow sections. Power system state estimation can be said to be the advanced software of most online applications. Basic: If the power system state estimation results are not accurate, any subsequent analysis and calculation will not be able to obtain accurate results.The measurement of power systems is divided into two types: telemetry and remote signaling.

As a basic service module of the energy management system (EMS), power system state estimation is the basis of almost all advanced applications of EMS. At present, the most widely used is the weighted least squares (WLS) criterion. (Refers to measurement points where the absolute value of the difference between the measured value and the true value is greater than 3 standard deviations), this method has the advantages of optimal consistency, unbiasedness, and good convergence performance. The methods to solve such problems can be summarized as the detection and identification of bad data, which can be divided into two categories: 1. Manual detection and identification before applying the WLS estimation criteria for state estimation or application of bad data detection criteria; 2. The state estimation criterion that can identify bad measurement points at the same time is the robust estimator, such as the residual search method, non-quadratic criterion method, and estimation identification method. Although the robust estimator has a certain robustness, it has a large amount of calculation. Disadvantages. State estimation is also called filtering, which uses the real-time measurement system redundancy to improve data accuracy, automatically eliminates error information caused by random interference, and estimates or predicts the operating state of the system (or rails).The research on state estimation of power systems also starts with Kalman filtering. According to the characteristics of power systems, that is, the main object of state estimation is high-dimensional space (network) problems on a certain time section, and several commonly used estimation criteria have been formed. : Weighted least squares (WLS) criterion, non-quadratic criterion, weighted minimum absolute value (WLAV) criterion, least median squared (LMS) criterion, and least truncated squares (LTS) criterion. Many power systems actually use the WLS estimation criterion, which has the advantages of simple models and good convergence performance. For the measurement of ideal normal distributions, the estimation quality is high. The disadvantage is that the amount of calculation and the amount of memory used are large, which is difficult to use for large-scale applications. Real-time calculation of power systems. Non-quadratic criteria, WLAV, LMS, and LTS criteria are all robust estimators, which are distinguished by their robustness, but they have the disadvantage of large amounts of calculations, which have long been an important obstacle to their development. the reason.

The methods used in state estimation belong to the estimation theory in statistics. The most commonly used is the least squares estimation, and other methods such as Bayesian estimation of risk criteria, maximum likelihood estimation, and random approximation are also applied. Wiener filtering or Kalman filtering, these methods are only suitable for linear systems, and require sufficient knowledge of the process being estimated. For nonlinear systems or complex estimation problems that do not fully understand the characteristics of dynamic systems, further research is needed. Engineering can use some approximate calculation methods to deal with it.Commonly, there are generalized Kalman filters based on the idea of local linearization, Bayesian or maximal posterior estimators, and adaptive parameters that can automatically modify parameters based on the historical knowledge of the filtering process. Filtering or forecasting technology, etc.

Telemetry is an analog measurement result, including branch power or current, node voltage, etc. Traditional scada systems cannot measure the phase angle of the node voltage. With the development of wams, the measurement of the node voltage phase angle has gradually become possible However, there are still many difficulties in specific implementation, which are not described in detail here.

Therefore, state estimation is necessary. The measurement data is sometimes called "raw data", and the result of state estimation is called "cooked data."It estimates the current operating state of the power system based on various measurement information of the power system.If the power system state estimation result is not accurate, then any subsequent analysis calculation will not be able to get accurate results[1].Many scholars have conducted related research on the state estimation of regional power grids[2-6].In this paper, based on the properties of active and reactive relative decoupling in power grid, a linear phase estimation model for voltage phase estimation using active measurement is proposed, and linear voltage estimation for voltage amplitude estimation using voltage amplitude measurement and zero injection measurement is proposed. The model is then tested for performance in the xx node system.

2. Working Principle

2.1.Work Process

The state ne2rk linear state estimation based on state decoupling is mainly divided into program initialization, measurement data input, state decoupling processing, phase linear state estimation, voltage linear state estimation and estimation result output.The phase linear state estimation and the voltage linear state estimation are the core steps of the estimation procedure.Since the estimation algorithm does not need to be iterated for linear estimation, there is no convergence problem, and the reliability of the algorithm is greatly improved.

2.2.Regional Grid State Decoupling

Due to the normal operation of the regional power grid, the relationship between the active power P and the voltage amplitude V, the reactive power Q and the voltage phase angle θ is weak, so $\partial P/\partial V$ with $\partial Q/\partial \theta$ is approximately zero in the Jacobian matrix.Ignoring this element to separates P-θ from Q-V and implements system state decoupling[7].In addition, the accuracy and reliability of active and voltage measurements in the actual power grid are relatively high, while the accuracy and reliability of reactive power measurement are relatively poor.To this end, this paper uses the characteristics of active and reactive relative decoupling in high-voltage power grids, uses active measurement to estimate voltage phase, and uses voltage measurement and zero injection measurement to estimate voltage amplitude to reduce dependence on grid basic data.

2.3.Linear Phase Estimation

In phase estimation, only the relationship between active power measurement (branch measurement and injection measurement) and node voltage phase is considered. If the change of grid voltage amplitude is ignored, the value of voltage amplitude is taken as 1 .Thus, the state quantity of the phase estimation problem is the voltage phase of each bus, and the quantity is measured as the branch active power flow or node active injection[8].

For the branch part of the regional power grid, the active power flow expression is:

$$P_{ij} = Y_{ij}(\alpha_i - \alpha_j) \tag{1}$$

Where i is the starting node number of the branch; j is the end node number of the branch; P_{ij} :The active power flowing to the end node j for the routing start node i; Y_{ij} :The imaginary part of the j-th column element of the i-th row of the node admittance matrix; α is the node voltage phase.For the active injection measurement of node i, there is:

$$P_i = \sum P_{ij} = \sum Y_{ij}(\alpha_i - \alpha_j) \tag{2}$$

Since the grid structure and parameters are unchanged, the branch admittance is a constant coefficient.It can be known from equation (2) that the measurement equation is a linear expression of the state quantity, so that the phase estimation problem is transformed into a linear weighted least squares estimation problem.The linear weighted least squares estimation problem can be described mathematically as a minimization problem:

$$\min J(x) = [z - h(x)]^T W[z - h(x)] \tag{3}$$

Where x is the state vector, n-dimensional; z is the measurement vector, m-dimensional; h is the measurement equation vector, m-dimensional; W is the measurement weight matrix, m × m-dimensional, generally a positive definite diagonal matrix.

2.4.Linear Voltage Estimation

Assuming the regional grid has n nodes, and its ne2rk structure and ne2rk comp1nt parameters are known, the network equation can be obtained:

$$Y\dot{U} = \dot{I} \tag{4}$$

Where y is an n × n order node admittance matrix; $\dot{U}$:a phase voltameter for the n x 1 dimensional node voltage; $\dot{I}$:a current column vector is injected for the N x 1 dimensional node.For node i, there are:

$$\dot{I}_i = \sum_{j=1}^{N} Y_{ij}\dot{U}_j = \sum_{j=1}^{N}(g_{ij} + jy_{ij})(\cos\alpha_{ij} + j\sin a_{ij})U_j = \sum_{j=1}^{N}(g_{ij}\cos\alpha_{ij} - y_{ij}\sin a_{ij})U_j$$
$$+ j\sum_{j=1}^{N}(y_{ij}\cos\alpha_{ij} + g_{ij}\sin a_{ij})U_j \tag{5}$$

In the formula, $\dot{I}_i$:Injecting current phasor for node i; Y_{ij} :The i-th row and the j-th column of the node admittance atrix; g_{ij} and b_{ij} separately is the real and imaginary parts of Y_{ij} .If node i is zero injected into the node, ie its injected current phasor is 0, then there are:

$$\dot{I}_i = \sum_{j=1}^{N}(g_{ij}\cos\alpha_{ij} - y_{ij}\sin a_{ij})U_j + j\sum_{j=1}^{N}(y_{ij}\cos\alpha_{ij} + g_{ij}\sin a_{ij})U_j = 0 \tag{6}$$

Therefore, there are:

$$\begin{cases} \sum_{j=1}^{N}(g_{ij}\cos\alpha_{ij} - b_{ij}\sin a_{ij})U_j = 0 \\ \sum_{j=1}^{N}(b_{ij}\cos\alpha_{ij} + g_{ij}\sin a_{ij})U_j = 0 \end{cases} \tag{7}$$

It can be seen that for zero injection node i, zero injection measurement can be added:

$$img(\dot{I}_i) = \sum_{j=1}^{N}(y_{ij}\cos a_{ij} + g_{ij}\sin a_{ij})U_j \tag{8}$$

In the formula, img(·) is the imaginary part function.

According to the above analysis,Think of $y_{ij}\cos a_{ij} + g_{ij}\sin a_{ij}$ as a known parameter.In this way, the voltage value can be obtained by solving the linear equations.

In addition, the actual power system is also equipped with more voltage amplitude measurement, and its reliability and accuracy are usually higher.Thus, the voltage estimator can be constructed by using the node voltage amplitude measurement and the zero injection current imaginary measurement to estimate the voltage amplitude of the power grid.Obviously, the voltage estimator constructed by these 2 types of measurements is a linear estimator.

3. Case Analysis

In order to verify the effectiveness of the algorithm, the IEEE30 node test system (shown in Figure 1) was selected for performance testing of the algorithm.

In each test, firstly add 2% Gaussian noise to the power flow calculation result to obtain raw data without bad data, and then test the raw data by changing the sign, zeroing or adding or subtracting the measured value by 20% or more. Bad data, and finally changed the proportion of bad data, and conducted 5 trials.

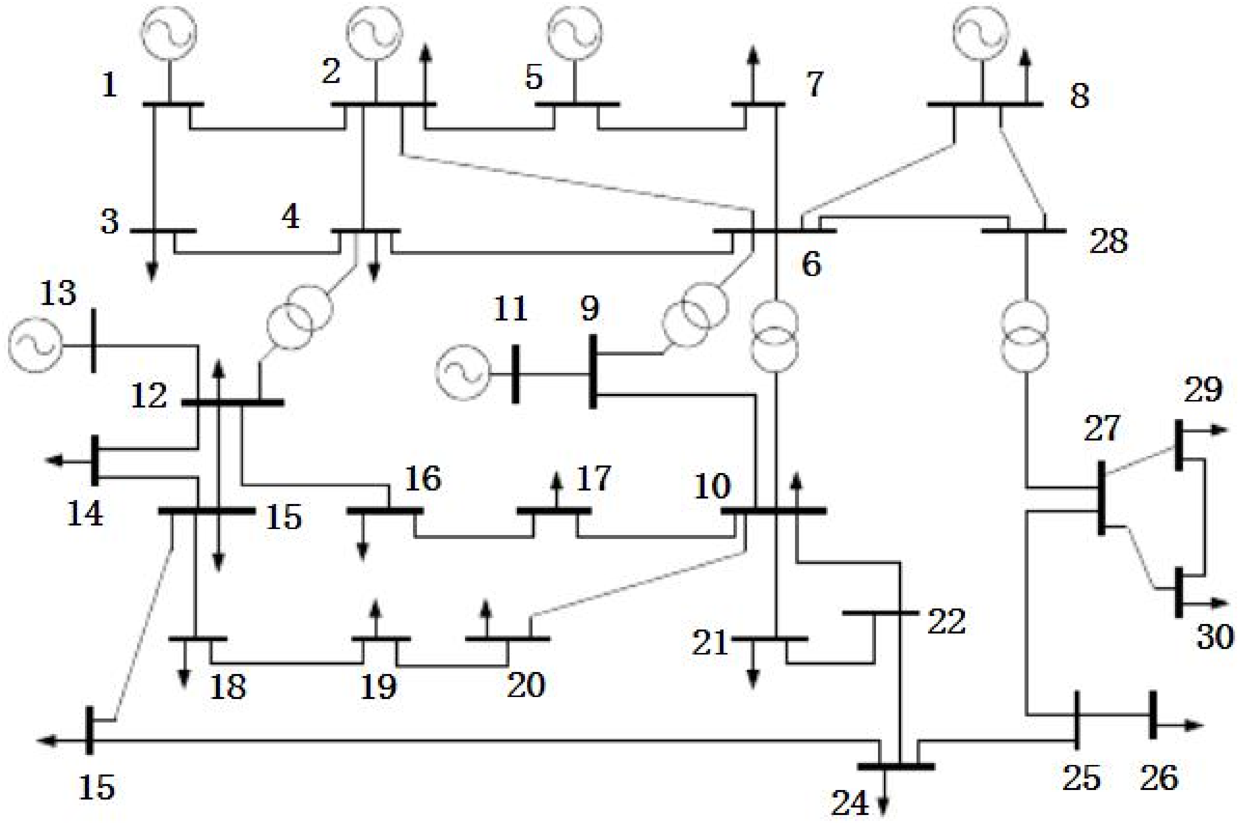

Figure 1: The topology graph of IEEE 30 node power grid.

In addition, in order to measure the effectiveness of the estimation Method, the 2 indicators in equations (9) and (9) are used to measure the accuracy of the estimated state variables (the state variables take the voltage and phase angle of the nodes other than the equilibrium node)[9,11]:

$$S_1 = \sum_i \left| x_i^* - x_i \right| \tag{9}$$

$$S_2 = \max \left| x_i^* - x_i \right| \tag{10}$$

In the formula, x_i^* is the estimated value of the i-th state variable; x_i is the true value of the i-th state variable.The performance test results are shown in Table 1.

Among them, the first Method is the traditional weighted least squares state estimation Method; the second Method is the traditional fast decomposition state estimation Method; the third Method is the Method described in this paper.

It can be seen that compared with the 2 traditional state estimation algorithms, the proposed Method has the advantages of no iterative calculation and saves computation time; the performance index S_1 of this Method, Basically,it does not change with the change of the proportion of bad data, and in the traditional Method, the value increases with the increase of the ratio; The change of performance index S_2 was small in all 3 Methods, and the test performance was close.

Table 1: Comparison table of running results of 3 test methods in IEEE 30 node power grid.

Test number	Poor data ratio (%)	Number of iterations			S_1			S_2			Run time / ms		
		Meth-od 1	Meth-od 2	Meth-od 3	Meth-od 1	Meth-od 2	Meth-od 3	Meth-od 1	Meth-od 2	Meth-od 3	Meth-od 1	Meth-od 2	Meth-od 3
1	2.53	3	3	0	2.214	2.763	2.425	0.003	0.002	0.003	462	242	97
2	3.55	3	4	0	3.807	3.264	3.047	0.005	0.004	0.002	503	347	131
3	4.44	4	4	0	4.809	5.025	3.267	0.004	0.005	0.003	498	385	154
4	6.94	4	5	0	5.785	5.471	3.568	0.006	0.005	0.002	527	455	202
5	8.95	5	5	0	6.077	6.004	3.783	0.005	0.004	0.003	604	470	248

4. Conclusion

The test results show that compared with the traditional power system state estimation problem, the phase estimation model and voltage estimation model used in this method are linear estimation models, so there is no need to iterate, there is no convergence problem, and the reliability is greatly improved.Since the calculation scale of the phase estimation model and the voltage estimation model is much smaller than the traditional power system state estimation model and does not require iteration, the algorithm has obvious advantages in execution efficiency.In order to make the effect of this method more ideal, some aspects of the program still need to be further studied. For example, there are still some shortcomings in the identification of bad data under complex grid conditions. It is hoped that relevant personnel engaged in research in this field can conduct more in-depth research in the future. Therefore, the regional grid state estimation operation effect has made greater progress.

References

[1] Yu Erkeng. Estimation of the state of the electric system [M]. Beijing: Water Power Electric Press, 1985.

[2] Yu Qinjie, Wang Xiaoru, You Jiaxun, et al. Two-stage state estimation model based on phasor measurement for equality constraints[J].Power System Technology, 2007, 31(10): 84-87.

[3] Zhang Lei,Guo Yandong,Chen Fangming.Three-phase state estimation of distribution network under different line models[J].Guangdong Electric Power, 2014, 27(4): 96-98.

[4] Zhou Huafeng,Xie Guocai,Hu Yaping, et al. Grid state estimation method based on dynamic partitioning[J].Guangdong Electric Power, 2015, 28(11): 70-75.

[5] Li Qiang, Zhou Jingyang, Yu Erkeng, et al. Linear State Estimation of Power System Based on Phasor Measurement[J]. Automation of Electric Power Systems, 2005, 29(18): 24-28.

[6] Gao Ming, Xu Qingshan, Qi Rui, et al. A practical fast algorithm for state estimation of distribution network[J].Guangdong Electric Power, 2015, 28(2): 101-106.

[7] Li Chao, Wei Zhinong, Ni Ming, et al. A stepwise linear state estimation model considering PMU measurement[J].Power Grid Technology, 2014, 38(6): 1700-1704.

[8] Lagace P J.Power flow methods for improving convergence [C]//38 th Annual Conference of IEEE Industrial Electron-ics.Montreal,Canada, 201 2: 1387-1392.