Simulation Analysis of Voltage Transient Stability Margins in Distribution Networks Under Large-Scale Distributed Power Supply Access Conditions

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Abstract In the traditional distribution network voltage transient stability margin analysis under the conditions of large-scale distributed power supply access, the processing of the analysis index is not refined enough, resulting in large errors in the analysis results. In this regard, a simulation analysis of the voltage transient stability margin of the distribution network under the conditions of large-scale distributed power supply access is proposed. Extraction of key features. Determine the characteristic parameters of the distributed power supply. Calculation of different index units and orders of magnitude and standardisation of the margin analysis index. Output of margin simulation results. The experiments show that the method has a lower error value than traditional methods in both active and reactive margin analysis and is of high application value.

Keywords Distribution networks · Voltage transient stability margins · Distributed power supplies · Power access · Margin analysis

1 Introduction

The transient stability margin of the distribution network voltage is the allowable voltage fluctuation range of the distribution network [1]. When reactive power is disturbed, the voltage transient stability margin of the distribution network changes. In the construction of a distribution network structure, access to a scaled-up distributed power supply has more advantages than in a traditional distribution network. In this project, access to medium- or low-voltage distributed power sources is usually chosen [2]. Yield analysis can contribute to the quality of practical applications that account for scaled distributed power distribution networks [3]. The access to large-scale distributed power supplies makes the connection between the various areas of the distribution network even closer. In this respect, the distribution network

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under the conditions of access to a scaled distributed power supply is significantly different from the distribution network under the traditional model, changing the performance of the relay protection devices [4]. Based on this change, the voltage transient stability margin of the distribution network under the conditions of scaled distributed power supply access is analysed to test the operational performance of the distribution network.

2 Extraction of Key Characteristics of Distribution Network Voltage Transient Stability

The process of extracting key features of voltage transient stability in distribution networks using principal component analysis in this article is shown in Fig. 1 [5, 6].

After processing all the data information according to the above criteria, the covariance matrix of the standardised data information is created. Set the standardised covariance matrix as R and the calculation process as formula (1):

$$R = \frac{z_i \cdot z_j}{n-1} \cdot xp \tag{1}$$

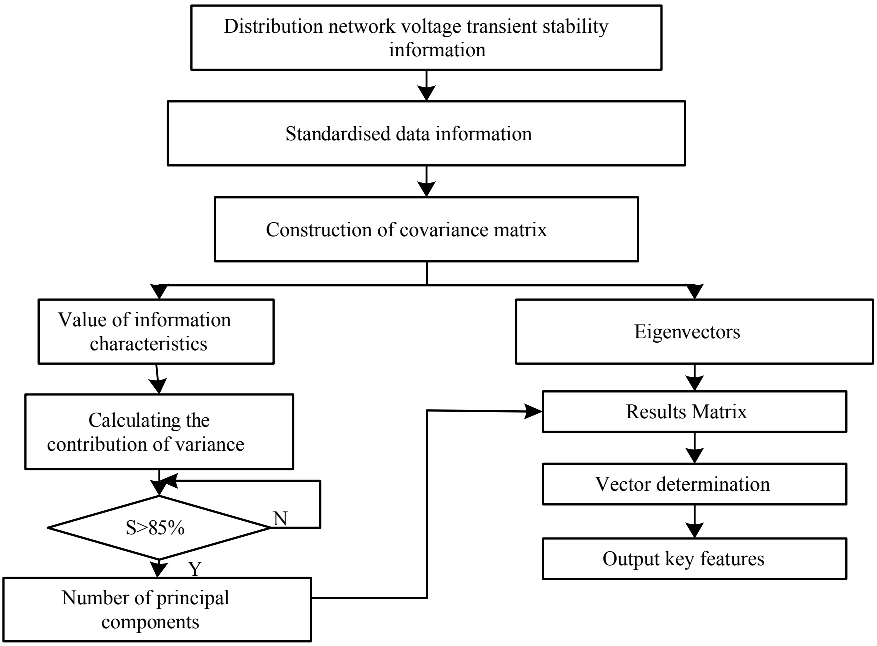

Fig. 1 Distribution network voltage transient stability key features SAR process

In Eq. (1), z_i is the random vector of standardised data information. z_j is the dimension of the standardised data information. n is the amount of distribution network voltage transient stability information. x is the index of the original data information. P is the covariance operation parameter of voltage data. Based on the calculation results of the above equation, the eigenvalues of the covariance matrix correlation coefficients are then calculated. The calculation process is Formula (2):

$$\left|R - \lambda I_p\right| = 0 \tag{2}$$

In Eq. (2), λ is the correlation coefficient of the covariance matrix. I_p is the number of results of the covariance matrix calculation. The eigenvalues are derived from the calculation of Eq. (2). The principal components of the voltage transient stability information of the distribution network are determined from the eigenvalues. The principal components of each information are judged. Assuming the contribution of the principal component as S, the calculation process is shown in formula (3):

$$S = \left|\frac{\lambda m}{\lambda p}\right|^i \tag{3}$$

In Eq. (3), m is the principal component of the voltage transient stability information of the distribution network. i is the random vector. The calculation result of Eq. (3) is judged to determine whether the contribution of this principal component is greater than 85%. If it is greater than, the sequence of principal components is output. If it is not, return and re-run the above calculation process. The number of principal components of the distribution network voltage transient stability information obtained from the output is imported into the result matrix. The number of outputs is m. Using the result matrix, the eigenvectors corresponding to the m principal components are determined. The number of this feature vector is again m. The results obtained are then output to complete the process of extracting key features for voltage transient stability of the distribution network based on principal component analysis.

3 Determine the Parameters of the Distribution Network Access to Scale Up Distributed Power Characteristics

In this paper, a supervised machine learning method is used for the calculation. The irrelevant feature quantities are first removed. A regularisation vector is added to the supervised machine learning model to find the sparse solution. Let the sparse solution of the key feature be Y, calculated as formula (4):

$$Y = \min\left(n^{-1}\|S - x\|^2 + \lambda \sum_{i=1}^{2} R(|\beta i|)\right) \tag{4}$$

In Eq. (4), βi is the penalty term for the voltage transient stability of the distribution network. The calculation of Eq. (4) enables the coefficients of the key characteristics of the voltage transient stability of the distribution network to be reduced continuously. The strength of the coefficient reduction is controlled by the number of iterations of the calculation. Based on the results of the above equation, the nodal voltage magnitude V_{Li} is calculated through the expression of the dynamic load is Eq. 5:

$$V_{\mathrm{Li}}^2 = Q_i \cdot F_i^2 / L_i \cdot Y \tag{5}$$

In Eq. (5), Q_i is the reactive power of the node, F_i is the active power of the node, and L_i is the apparent power of the node. After the calculation of the above equation, the determination of the voltage amplitude of the node of the characteristic parameter of the scaled distributed power supply connected to the distribution network is completed. The phase angle is then calculated. The calculation of the phase angle requires a calculation process based on the variations at the different nodes. The calculation of the phase angle needs to be calibrated at a specific position in the fluctuation cycle of the voltage transient stability signal. Then the scaling is calculated for each node of the distribution network between the peaks and troughs. The phase angle is set to J and is calculated as formula (6):

$$J = \frac{\sqrt{a^2 + b^2}}{Q_i \cdot F_i} \tag{6}$$

In Eq. (6), a is the phase value of the crest in the voltage transient stabilisation signal waveform. b is the phase value of the trough in the voltage transient stabilisation signal waveform. The process of determining the characteristic parameters of the distribution network connected to a large-scale distributed power supply is completed by calculating the nodal voltage amplitude and phase angle of the distribution network connected to a large-scale distributed power supply.

4 Standardised Distribution Network Voltage Transient Stability Margin Indicators

The indicators for margin development analysis are divided into different types, as shown in the following Table 1.

The margin analysis indicators shown in the table above all have a certain degree of influence on the performance of the voltage transient stability of the distribution network. The margin analysis index system established in this paper contains a total of eight indexes. These eight indicators have different calculation units and orders of magnitude. Therefore, this paper chooses to use the efficacy factor method to calculate these eight indicators. All the above indicators were standardised. The standardisation

Table 1 Distribution network voltage transient stability margin analysis indicator types

Type of indicator	Indicator content
Distributed Indicators	Very small indicators Range-based indicators Intermediate indicators
Load margin indicators	Maximum load supply capacity Actual load demand
Branch margin indicators	Branch currents in the distribution network during operation Number of distributed power connections to the distribution network
Equipment margin indicators	Power to discharge or charge energy storage elements

process was carried out using the polar difference method. The extreme value interval of each indicator was processed into a pattern of [0, 1] to obtain the standard indicator k, which was calculated formula (7):

$$k = s + \frac{w - d_{\min}}{d_{\max} - d_{\min}} \times r \tag{7}$$

In Eq. (7), s is the translation of the indicator. r is the number of power connections. $d_{\max}$ and $d_{\min}$ are the maximum and minimum values of the indicator, respectively. r is the amount of rotation of the indicator. Based on the calculation results of the above equation, the standardisation process of the distribution network voltage transient stability margin indicator is completed.

5 Output Voltage Transient Stability Margin Development Analysis Results

In this paper, wavelet neural network is used to carry out the simulation analysis. Let the number of hidden layer nodes be c. The formula is (8):

$$c = 2 \times h + 1 \tag{8}$$

In Eq. (8), h is the number of neuron nodes. The number of nodes in the hidden layer is determined by means of the above equation to ensure that the wavelet neural network presents a high level of fitting and fault tolerance without over-fitting due to insufficient training speed.

First, the R-WNN parameters of the wavelet neural network are iteratively updated. Then the right-hand side weights of this neural network are adjusted. Let the difference of the right-hand side weight adjustment be $E(n)$, which is calculated formula (9):

$$E(n) = \frac{D(n) - O(n)}{h} \tag{9}$$

In Eq. (9), $D(n)$ is the weight value of the desired output. $O(n)$ is the weight value of the actual output. The update learning rate is then calculated. Let the learning rate be T, and its calculation formula is (10):

$$T = \max\{C_1 * E(n)l\}, \text{else} \tag{10}$$

In Eq. (10), C_1 is the empirical value of the wavelet neural network. l is the learning rate of the scale scaling factor. Based on the calculation results of Eq. (10), the indicators are assigned to the standard indicators under the eight base indicators derived above. In this paper, we use the method based on entropy value method to carry out the weighting of indicators. The information entropy value e corresponding to the standard indicator k is first calculated using the formula (11):

$$e = -T|\ln x \cdot k| \tag{11}$$

Based on the calculation results of Eq. (11), the information utility value of the voltage transient stability margin of the distribution network is obtained. The weighting factor B of the standard indicator for this node is then calculated as formula (12):

$$B = \left(\frac{e}{iG}\right)^m \tag{12}$$

In Eq. (12), G is the information utility value of the voltage stability margin of the distribution network. This completes the assignment of indicators to the standard indicators for voltage stability margins in the distribution network. The result of the indicator weighting is judged, and if it does not meet the expectations, the iterative calculation is started again. If the expected value is met, the neural network cycle is exited, and the results of the distribution network voltage transient stability margin simulation are output. This completes the simulation of the voltage stability margin of the distribution network under the conditions of large-scale distributed power supply access.

6 Experiment

6.1 Experiment Preparation

In order to verify the feasibility of the simulation analysis of the voltage transient stability margin of the distribution network under the conditions of scaled distributed power supply access proposed in this paper, this experiment was designed. The

Table 2 Simulated values of basic distribution network parameters

Project	Parameters
Percentage of node distance from the distribution network	50%
Distribution network impedance factor	1
Number of distributed power sources on the distribution network	23
Distribution network mechanical torque	0.25
Distribution network mechanical characteristic load	2
Distribution network stator reactors	0.295
Rotor reactors for distribution networks	0.12
Initial frequency of the distribution network	50

Simulink software was used to carry out the simulation of this experimental data. In this experiment, the basic simulation parameters are shown in the following Table 2.

In this experiment, five nodes were randomly selected for simulation of the voltage transient stability margins in a distribution network with a large-scale distributed power supply. The nodes of the distribution network analysed by different methods are kept consistent.

6.2 *Analysis of Results*

The simulation and analysis method of voltage transient stability margin of distribution network under the condition of scaled distributed power supply access proposed in this paper is named Method 1. The traditional method of simulating and analysing the voltage transient stability margin of the distribution network under the conditions of scaled distributed power supply access is named Method 2. The results of the experiment were obtained as shown in Tables 3 and 4.

From Tables 3 and 4, it can be seen that the simulation analysis method of voltage transient stability margin of distribution network under the condition of large-scale distributed power supply access proposed in this paper is closer to the real results in the case of active and reactive power. The difference between the analysis results of the proposed method and the real results is 0.001413, while that of the traditional

Table 3 Results of simulation analysis of active margin for different methods

Nodes	Real results	Method 1	Method 2
1	0.410585	0.408466	0.418563
2	0.071025	0.070582	0.072329
3	0.057482	0.058595	0.065284
4	0.235676	0.237307	0.253758
5	0.308761	0.307166	0.314757

Table 4 Results of reactive power margin simulation analysis for different methods

Nodes	Real results	Method 1	Method 2
1	0.188869	0.187166	0.267503
2	0.054361	0.054972	0.056639
3	0.041059	0.041854	0.041891
4	0.118279	0.117638	0.120545
5	0.181479	0.180541	0.185004

method is 0.041162. The average difference between the two methods is 0.0002826 and 0.0082324, respectively. In the analysis of the voltage transient stability margin of the reactive distribution network, the difference between the analysis result of the proposed method and the real result is 0.001876, while the difference of the traditional method is 0.087535. The average difference between the two analysis methods is 0.0003752 and 0.017507, respectively. The results are closer to the real results than those of the traditional method, which can significantly reduce the error of the margin simulation analysis.

7 Conclusion

This paper addresses the problem of large errors in the analysis of the voltage transient stability margins of distribution networks under the conditions of large-scale distributed power supply access. By standardising the margin analysis indexes, the error value of the analysis results is significantly reduced, which is of high practical application value. In future research, it is necessary to solve the unstable balance point in the process of voltage transient stability margin analysis of distribution networks to excise the practical accuracy and further improve the accuracy of the margin simulation analysis results.

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