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Research on Risk Assessment Method of Distribution Network Operation

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Abstract

Assessing the operational risk of the grid can effectively understand the weak links in the grid for the sake of ensuring the safe and stable operation of the grid. Based on the risk theory and combined with the particularity of the distribution network, it is necessary to analyze the operational risk and establish the calculation model of operational risk. The existing risk assessment characteristics are illustrated, and the risk assessment algorithm applicable to the distribution network is selected. The algorithm is applied to the risk index of scheduling decision taken the typical feeder distribution system as an example to prove the practicability and manipulability.

Keywords

Distribution network, risk, algorithm evaluation, example.

1. Introduction

As China's power system grows in size, the grid structure is increasingly complex. There are three main stages in the safety assessment of power systems in China: traditional deterministic assessment methods, probabilistic assessment methods, and risk assessment methods. The deterministic assessment method refers to the safety assessment of the grid in the given parameters, topology, operation mode, etc. The selection of the accident set is arbitrary, and the operating conditions and the possibility of accidents are not considered comprehensive. The probabilistic evaluation method can calculate the change interval of nodes and systems based on the previous component failure and fix statistics to evaluate the reliability of the system. This method is more comprehensive and objective and makes up for the deterministic evaluation method. Insufficiently, it does not distinguish the consequences of different accidents and the severity very well.

Based on the characteristics of the distribution network, this paper studies the risk assessment method of it. Meanwhile, it adopts the state enumeration method to select the system state and gives quantitative risk indicators, which provides a decision-making basis for the dispatching operation of the grid.

2. Risk Theory

The risk theory mainly studies the possibility of disasters that can cause harm and the severity. General safety engineers and designers check the use of equipment through a risk assessment that systematically evaluates equipment performance and selects safety measures that are reasonable and scientific. Risk quantification can be expressed by the following formula:

$$R\left(C/X_t\right)=\sum_i P\left(E/X_t\right)\times S(C/E) \quad (1)$$

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In this formula, X_t indicates the operating state before the failure occurred; C is the consequences for uncertain accidents; $R(C/X_t)$ is the risk index value; i is the component collection of accident set that is expected; E means the uncertain accidents; $P(E/X_t)$ expresses the probability that E occurs under the Xt; $S(C/E)$ is the severity of the C under E condition.

3. Risk Assessment Algorithm

3.1 Existing Risk Assessment Algorithms

For simple systems, the risk assessment algorithms are network method, fault tree analysis method, and state-space method which are commonly used. Generally, the comparatively large-scale risk assessment adopts two kinds of methods which are state enumeration method and Monte Carlo simulation method.

3.1.1 State Enumeration Method

This algorithm is based on the component fault parameters of the power f the power system to establish a mathematical model. The formula is as follows:

$$P(s)=\prod_{i=1}^{N_f} Q_i \prod_{i=1}^{N-N_f} P_i \quad (2)$$

P(s) is the system probability under the *s* state; P_i is the working probability of the *i*th element; Q_i is the failure probability; *N* means the number of components of the system; N_f is the number of failed components under the *s* state; $N-N_f$ is the number of working elements.

The state enumeration method uses strict mathematical methods so that the calculation result has high accuracy and credibility, and it is suitable for a system with fewer components or low failure rate components. However, with the number of components in the system continually increasing, the number of systems can increase, and a large amount of computation is incurred when performing inspections. Therefore, related techniques can be utilized in applications to reduce the amount of computation.

3.1.2 Monte Carlo Simulation Method

This method is also called random sampling. It mainly applies statistics and probability as a theoretical basis. It simulates the real system function through the method of random generation to reveal the law of system operation. Its essence is to utilize the experiments and simulations of random variables to settle the approximation of physical, mathematical, and engineering problems.

The Monte Carlo simulation is a statistical experiment method that is intuitive , which can predict some unpredictable accidents so that the size of the system does not affect the sampling times. It is also convenient to handle the control strategy in operation. The shortcoming of this method is that the calculation time has a great relationship with precision. To ensure the accuracy of the risk index, it takes a long calculation time.

3.2 Risk Assessment Algorithm for Distribution Network

In the planning scheme of the power grid, the simulation results of the actual power market often do not require excessive accuracy, but only the statistical results are required. At the same time, the planning department needs to plan the operation mode for several months or even several years. The complexity and scale of statistics and calculations are very large, so the Monte Carlo simulation method is more suitable for research.

For scheduling applications, the time of risk assessment is short for decision making. Generally, it is used to predict grid security for a few minutes or hours and to make decisions with strong timeliness, relatively small state and space. Therefore, this paper applies the state enumeration method to carry out the operational risk assessment of the distribution network.

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3.3 Algorithm Flow

The process of risk assessment of the distribution network by the state enumeration method is shown in Figure 1.

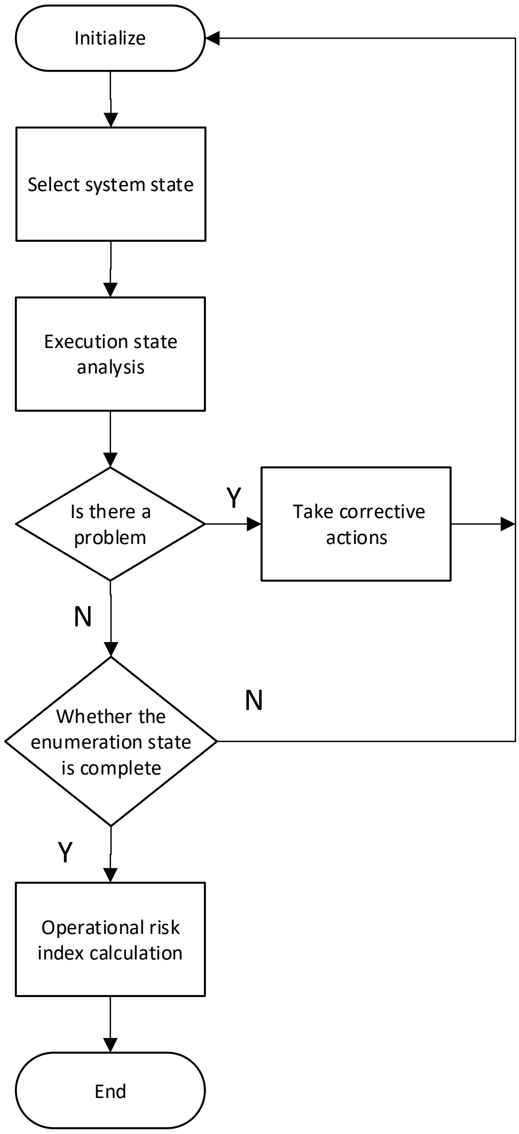

Fig. 1 Assessment process of operation risk of distribution network

4. Analysis of System States

Risk assessment is not only to identify the possibility of an accident but also, more importantly, to identify the serious consequences that may occur after the accident to conduct a safety analysis of the system status. The rapid development of the power grid has led to the installation of a large number of self-injection and relay protection devices in the distribution network. The normal operation of relay protection can quickly remove the fault and effectively ensure the safe and stable operation of the power grid. The self-injection device can make up for the shortage of the power grid when the faulty bus of the power grid is cut off to effectively reduce the operational risk of the power grid. However, both of them will change the operation mode and topology which will result in changes in the operational risk of the power grid. Consequently, this paper also considers various ingredients affecting the change process of the grid in the system state analysis to evaluate the grid operation risk accurately and scientifically.

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5. Risk Assessment Index

5.1 Component Risk Indicators

The risk points that dispatchers pay attention to are mainly load loss, bus decompression, and line overload. Therefore, the risk indicators of components are proposed based on the relevant literature at home and abroad.

risk indicator of bus decompression is Risklov:

$$Risk_{\mathrm{lov}} = \sum_{s\in C} Serv_{\mathrm{lov}}(s)P(s) = \sum_{s\in C} \frac{L_{\mathrm{n}}(s)}{L_0} P(s) \tag{3}$$

In this formula, G is the set of grid load loss states after the bus loses voltage; s means the grid state; $Serv_{lov}(s)$ reflects the severity of the grid load loss caused by the bus voltage loss of grid state s; P(s) is the probability of the grid state s; $L_n(s)$ is the grid load loss only considering bus voltage loss; L_0 is the total grid load.

Risk indicator $Risk_{\mathrm{ol}}$ caused by the line overload:

$$Risk_{\mathrm{ol}} = \sum_{s\in G} \mathrm{Serv}_{\mathrm{ol}}(s)P(s) = \sum_{s\in G} \frac{L_{\mathrm{b}}(s)}{L_0} P(s) \tag{4}$$

In this formula, *G* is the set of grid load loss state after line overload; $\sum_{s\in G} \mathrm{Serv}_{\mathrm{ol}}(s)$ reflects the severity of grid load loss caused by line overload of grid state *s*; $L_{\mathrm{b}}(s)$ is the grid load loss only caused by line overload.

In this formula, G is the set of grid load loss state after line overload; $\mathrm{Serv}_{\mathrm{ol}}$ reflects the severity of grid load loss caused by line overload of grid state s; $L_{\mathrm{b}}(s)$ is the grid load loss only caused by line overload.

5.2 Risk Indicators of System Level

Generally, the vector R= (R1, R2,..., Rn)T is used to represent the single risk indicator vector of the accident set expected by the system safety assessment; n represents the total number of all components in the accident concentration; Ri is the individual risk value of component i. The risk indicators for defining system-level bus voltage loss and line overload are calculated as follows.

$$R_S = \alpha \times \frac{1}{n} \| R \|_1 + \beta \times \| R \|_\infty \tag{5}$$

In this formula,αand βare weight coefficients which satisfy α+β=1; ‖R‖1 and $|R||_\infty$ mean the one and ∞ norm of vector R.

$$\| R \|_1 \sum_{i=1}^{n} | R_i | \tag{6}$$

$$\| R \|_\infty = \max_{1\le i\le n} | R_i | \tag{7}$$

The weight coefficient β takes an appropriately large value in equation (5), which can highlight the impact of serious accidents and avoid or reduce the possible shadowing phenomenon of risk indicators. Equation (6) represents the cumulative effect of all predicted accident risk indicators in the system, and equation (7) represents the impact of the expected accident with the largest risk indicator in the system.

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6. Case Analysis

Figure 2 shows the system diagram of the example, tables 1 and 2 show the attribute descriptions of the system. There is no distributed power source in the system, and the probability, duration of failure and the repair time are all derived from historical statistics.

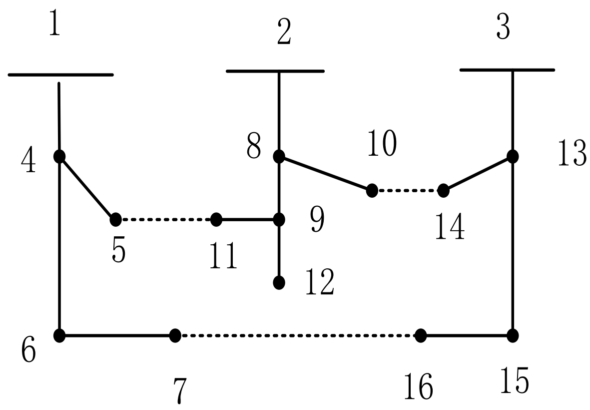

Fig. 2 IEEE 3 feeder distribution system diagram

Tab. 1 Branch attributes

Branch type	Length(km)	Probability of failure /%	branch	Rated current
Cable	1	0.027	4-5,2-8,8-9,9-12,9-11,8-10,13-14,4-6	2.2
Overhead line	1	0.200	The rest of the branch	0.8

Tab. 2 Line data

Line	RES /P.U.	Reactance /p.u.	Active load /MW	reactive load /Mvar	reactive compensation /Mvar
1-4	0.075	0.1	3.0	4.6	
4-5	0.08	0.11	6.0	1.4	1.1
4-6	0.09	0.18	8.0	3.0	1.2
6-7	0.04	0.04	9.0	3.5	
2-8	0.11	0.11	3.2	2.7	
8-9	0.08	0.11	5.4	2.0	1.2
8-10	0.11	0.11	3.0	1.0	
9-11	0.11	0.11	3.0	2.0	0.6
9-12	0.08	0.11	8.0	3.0	3.7
3-13	0.11	0.11	3.0	0.9	
13-14	0.09	0.12	3.0	0.7	1.8
13-15	0.08	0.11	3.0	0.9	
15-16	0.04	0.04	6.3	1.0	1.8
5-11	0.04	0.04			
10-14	0.04	0.04			
7-16	0.09	0.12			

To achieve the purpose of reflecting the safety of the system accurately, firstly, the risk indicators are calculated in the initial operating state of the original system. Then the tie switch is removed in the example and the same state is calculated. This will increase the system risk value. The calculation results are shown in tables 3 and 4.

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Tab. 3 The result of calculation example

The fault branch	Bus loss risk	Line overload risk
1-4	0.024 8	0.032 15
4-6	0.022 7	0.082 2
6-7	0.035	0.023 79
4-5	0.021 2	0.026 9
2-8	0.022 1	0.016 86
8-9	0.021 8	0.011 03
9-12	0.022 7	0.026
9-11	0.020 9	0.027 35
8-10	0.020 9	0.040 94
3-13	0.024 8	0.052 97
13-15	0.024 8	0.018 42
15-16	0.030 5	0.024 1
13-14	0.020 9	0.026
System risk value	0.174 05	0.230 84

Tab. 4 The calculation result after removing part of the contact switch

The fault branch	Bus loss risk	Line overload risk
1-4	0.024 8	0.101 9
4-6	0.022 7	0.023 9
6-7	0.035	0.032 3
4-5	0.021 2	0.023 3
2-8	0.028 1	0.021 8
8-9	0.025 7	0.021 8
9-12	0.022 7	0.022 1
9-11	0.020 9	0.022 7
8-10	0.020 9	0.023
3-13	0.024 8	0.068 3
13-15	0.024 8	0.045 8
15-16	0.030 5	0.036 8
13-14	0.020 9	0.022 4
System risk value	0.176 75	0.251 45

7. Conclusion

With the development of the economy in recent years and the increasing demand for electricity in all walks of life, the scale of the distribution network is expanding and the power supply load is increasing. Therefore, the safe operation of the power grid should be ensured to make the society stable and nation secure. The scientific and quantitative assessment of the risks in the operation of the power grid can maintain effectively the stable operation and take corrective measures for weak links in time. The operation risk assessment method analyzed in this paper combines the characteristics of the distribution network, and the application of the state enumeration method defines the component-level and system-level operation risk indicators of distribution network. The indicators can accurately reflect different network structures and operational risk of the distribution network under the load levels to provide scheduling decisions with effective support.

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