Establishment and Optimization of Distribution Network Operation Mode Considering Operation and Grid Risk

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Abstract: Traditional establishment and optimization method of distribution network operation mode doesn't take risk factors into consideration. In order to make the distribution network operate in the optimal operation mode, this paper proposes an establishment and optimization method of distribution network operation mode considering operation and grid risk. The proposed optimization model is a multi-objective nonlinear optimization model, which brings operation risk and grid risk of distribution network into the operation mode optimization. Besides, the proposed multi-objective optimization model is simplified as a single objective optimization model using weights. The calculation results of a numerical example proves the validity of the proposed optimization method of distribution network operation mode. In addition, it can meet users' demand for operation risk and grid risk.

Key words: distribution network; operation mode; operation risk; grid risk

0 Introduction

The normal operation mode of the power system refers to the maintenance mode normally planned and the mode in which the thermal and hydropower power generators behave according to the load curve and seasonal variation, the maximum and minimum load and the maximum and minimum starting mode, as well as the pump storage operation conditions which may turn out to be the long-term operation mode. For the distribution network, the normal operation mode usually meet the following requirements: to fully meet the needs of users for electricity; overload and over-voltage problems of all equipment in the distribution network do not arise, with all transmission lines' power being within the limits; owning reactive power reserve that complies with a standard; relay protection and safety automation devices are configured properly and set correctly; the distribution network runs economically; the distribution network has a reasonable structure, owning high reliability, stability and anti-accident ability; communication and information transmission runs well.

In order to make the operation mode of the distribution network meet the normal requirements, it is very important to pay attention to the operation of the distribution network. In literature [1], the operation mode of the distribution network and the development trend are analyzed. In literature [2], the operation mode and scheduling of a specific distribution network have been studied with emphasis on power quality and reliability of power supply. Literature [3] has established the operation mode evaluation model based on the economic dimension, and evaluated the operation mode of the distribution network based on the engineering practice, which provides a reference for the dispatching of the distribution network. Domestic operation of the distribution network is generally "closed-loop design, open-loop operation". The reliability problem of the open-loop operation has drawn concern from experts and scholars, so in recent years there have been many research on distribution network closed-loop operation [4-8]. The purpose of these studies is to make the distribution network run in the most reliable way, but sometimes ignoring the operating economy.

In order to make the operation of the distribution network reach the overall optimum of reliability, safety and economy, it is usually necessary to involve the optimization problem of the operation mode in the distribution network into consideration. Literature [9] used the analytic hierarchy process to evaluate the advantages and disadvantages of the distribution network operation mode, and used the genetic algorithm to realize the optimization of the distribution network operation mode. Literature [10-11] applied the analytic hierarchy process to multi-objective optimization of distribution network operation. In literature [12], the intelligent operation optimization method applied to intelligent distribution network is studied. In literature [13], a self-healing control hierarchical optimization model of intelligent distribution network operation mode was established. The above-mentioned literatures only consider the safety, reliability and economy in the optimization of the operation mode of the distribution network, while do not consider some risk factors that may exist in the distribution network, so the optimized distribution network may not be able to satisfy risk assessment requirements.

In this paper, based on the study of the traditional optimization methods of the distribution network operation mode, a method to optimize the operation mode of the distribution network considering the operation and grid risk is proposed. On this basis, the normal operation mode is established. The proposed optimization model of distribution network operation mode considering the operation and grid risk is essentially a multi-objective nonlinear optimization model, in which the objective function includes the traditional technical and economic objectives, and also takes two sub-goals on operational risk and grid risk into account, which is based on the consideration of the line and transformer load rate as well as reducing the impact of the expected accident to the minimum, which makes the operation mode optimization more comprehensive, while multiple sub goals are combined into an integrated target with the use of the weighted sum method, therefore simplifying the solution process. The calculation results of the example show that the proposed optimization method of distribution network operation can correctly optimize the operation mode of the distribution network while satisfying users' requirements for operational risk and grid risk.

1 Establishment of Normal Distribution Network Operation Mode Considering Operation and Grid Risk

With the increasingly complex structure of the distribution network, the user's demand for power supply reliability and power quality continues to improve. Meantime, the normal operation of distribution network plays an increasingly important role in increasing security and stability of the distribution network and cost-effective operation. Therefore, it is necessary to formulate a scientific and reasonable distribution network normal operation mode.

The traditional way of establishing the normal operation mode of the distribution network usually considers security, reliability and economy, but often neglects the risks which may occur during the operation of the distribution network. In this paper, the risk control under the normal operation mode of the distribution network is also involved, including the operation risk and the grid risk. The method proposed to establish the normal operation mode of the distribution network follows the following principles:

1) To meet the N-1 safety criteria, that is, when failure occurs in a distribution network power line or a substation transformer:

A) Under normal circumstances, power failure does not occur outside the part broken down. Low voltage and overload which is not allowed for the equipment is forbidden;

B) In the case of planned maintenance, when power failure occurred, only part of the power failure is allowed and supply should recover after the restoration of power supply failure.

2) The distribution network should be able to meet the line current requirements shown in Table 1.

Table 1 safe carrying capacity of each wiring mode

wiring mode	safe carrying capacity
two supply-and-one reserve	The maximum load current of the lines shall not exceed 100% of the safe carrying capacity of the line. The standby line shall be operated without load.
three supply-and-one reserve	The maximum load current of the lines shall not exceed 100% of the safe carrying capacity of the line, and the standby line shall be operated without load.
single ring network	The maximum load current shall not be more than 50% of the safe carrying capacity of the line.
double-ring network in the form of switch station	The maximum load current of the line is not more than 75% of the safe carrying capacity of the line under the condition of N-1.
the double-ring network composed of two independent single rings	The maximum load current of the line is not more than 75% of the safe current carrying capacity of the line under the N-1 condition.
single radiation	The maximum load current of the line is not more than 100% of the safe carrying capacity of the line.
Multi-segment n-contact (n ⩽ 3)	The maximum load current of the line is not greater than 67% of the line safe carrying capacity of the line.

3) The power supply distance of distribution lines should meet the requirements of the terminal voltage quality (tolerance of the deviation is -7% ~+7% of the rated 20kV and below three-phase supply voltage).

4) The load distribution of the relevant lines should be basically balanced, and meet the requirements of line current carrying capacity in Table 1; the number of substations or switch stations in a single line should be basically balanced, generally not more than 8.

5) Consideration should be given to the need for automation of the distribution network development. For the lines that have already been converted to the automation of the distribution network, when choosing the contact points in the distribution network, priority will be given to the equipment with the function of "three remote control"; For the lines that have not yet been reformed in the distribution network, the selection of the equipment as contact point should consider whether it is suitable for the automation of distribution network.

6) The reliability of the power supply of important users should be considered. Contact points within the feeder group should give priority to the equipment of the important user and avoid supplying power to a plurality of important users in a single line, generally not more than one user for each line.

7) The best economy should be ensured under the normal operation of the distribution network. Under the normal operation mode of the distribution network, the active power loss of the transformer and the line should be at a relatively low level, that is, to maintain the maximum power supply efficiency and reduce the unnecessary power loss.

8) The operational risks during the normal operation of the distribution network should be minimized. Loads of lines and transformers in the distribution network should be protected against overloading as much as possible. Even in the case of overloading or overloading occurs in the lines or transformers, the number of lines and transformers with heavy load or under overload conditions should be as small as possible.

9) It shall be ensured that the losses caused by the anticipated accidents in the normal operation mode of the distribution network are the minimum. The loss caused to the user after the occurrence of the accident of distribution network should be as little as possible, and the load shedding situation should be avoided.

2 Optimization of Normal Distribution Network Operation Mode Considering Operation and Grid Risk

The distribution network operation includes normal, overhaul and fault as well as their mutual conversion.

Distribution network running status being different, the optimization will focus on different points. This paper discusses the optimization of the operating mode of the distribution network under normal operating condition.

2.1 Objective function of the optimization

The multi-objective optimization model is used to construct the optimization model of the distribution network operation mode. The multi-dimensional evaluation indexes considering technical, economic problems and risk are taken as the objective function of the operation optimization. The following five objective functions are considered in this paper.

1) Node voltage deviation

The smaller the voltage amplitude of the distribution network node deviates from the rated voltage amplitude, the better the power quality under the current operating mode of the distribution network, so the objective function is expressed as:

$$\min \quad F_1 = \frac{1}{N_{bus}} |V_i - V_{Ni}| \tag{1}$$

Where, V_i is the voltage amplitude of the i-th node (per unit value); V_{Ni} is the rated voltage (pu) of the i-th node; and N_{bus} is the number of nodes in the distribution network.

2) Line load balancing degree

The closer the ratio of the load current to the rated current for each line in the distribution network, the higher the load balancing degree of the current distribution network. Note that the load rate of the k-th line is β_{Lk}, that is

$$\beta_{Lk} = \frac{|I_{Lk}|}{I_{LNk}} \tag{2}$$

Where: $|I_{Lk}|$ is the current amplitude of the k-th line; I_{LNk} is the the rated current of the k-th line.

When the variance of the sample set consisting of all the load factors of the line is the minimum, the load balance degree of the distribution network is considered to be high enough, so the objective function is expressed as:

$$\min \quad F_2 = \frac{1}{N_L - 1} \sum_{k=1}^{N_L} (\beta_{Lk} - \frac{1}{N_L} \sum_{j=1}^{N_L} \beta_{Lj})^2 \tag{3}$$

Where: N_L is the number of lines; β_{Lk} is the load rate of the k-th line.

3) Distribution network loss

The loss of the distribution network mainly includes the active power loss of the transformer and the line. For the sake of convenience, it can be calculated by the injected active power of nodes minus the active power of all loads, so the objective function is expressed as:

$$\min \quad F_3 = \sum_{i \in \Omega_G} P_{Gi} - \sum_{j \in \Omega_D} P_{Dj} \tag{4}$$

Where: P_{Gi} is the injected active power of the i-th power node; P_{Dj} is the active load of the j-th load node; Ω_G and Ω_D are the set of power nodes and load nodes, respectively.

4) Operational risk

When considering the operational risk of the distribution network, the operation of the lines and transformers should be taken into account. The higher the load rate is, the greater the risk will be. Meantime, number of lines and transformers in heavy load acquire concern, therefore the objective function is expressed as:

$$\min \quad F_4 = \max_i(\beta_{Li}) + \max_j(\beta_{Tj}) + \frac{n_{LO}}{N_L} + \frac{n_{TO}}{N_T} \tag{5}$$

Where: n_{LO} is he number of lines of which the load rate are more than 80%; n_{TO} is the number of transformers of which the load rate are more than 80%.

5) Grid risk

In addition to operational risks, the risks under different operating modes of the distribution network should also include the potential risks associated with the grid structure. The grid risk can be calculated by setting the expected incident, which is in the way of multiplying the probability of occurrence of the expected incident by the consequences value to calculate the final value of the risk, so the target function is expressed as:

$$\min \quad F_5 = \sum_{k\in\Omega_F}(C_{FE}^{(k)} + C_{FC}^{(k)})p_F^{(k)} \tag{6}$$

Where: $C_{FE}^{(k)}$ is the power loss rate after the k-th expected accident happen; $C_{FC}^{(k)}$ is the loss rate of the time and users after the k-th expected accident happen; $p_F^{(k)}$ is the probability of occurrence of the k-th expected accident, where only the single line failure situation is considered here; Ω_F is the set of the expected accident. The power loss rate, the loss rate of the time and users, and the probability of occurrence of the expected accident are calculated using the following equations (7) to (9):

$$C_{FE}^{(k)} = \frac{\sum_{i=1}^{N_{FC}^{(k)}}(S_{FL}^{i}\gamma_{FL}^{i})}{\sum_{j=1}^{N_{SC}}(S_{SL}^{j}\gamma_{SL}^{j})}T_{FL}^{(k)} \tag{7}$$

$$C_{FC}^{(k)} = \frac{\sum_{i=1}^{N_{FC}^{(k)}}\gamma_{FL}^{i}}{\sum_{j=1}^{N_{SC}}\gamma_{SL}^{j}}T_{FL}^{(k)} \tag{8}$$

$$p_F^{(k)} = p_{Fk}\prod_{i\neq k}(1-p_{Fi}) \tag{9}$$

Where: $N_{FC}^{(k)}$ is the total number of users suffer from loss after the k-th accident happen; N_{SC} is the total number of users in the system; S_{FL}^{i} is the capacity of the i-th losing-power user; S_{SL}^{j} is the capacity of the j-th user in the system; γ_{FL}^{i} is the level factor of the i-th user whose line is cut; γ_{SL}^{j} is the level factor of the j-th user, whose value is between 0 and 1, and more important the user is, the greater the level factor is; $T_{FL}^{(k)}$ is the failure restoring time for the k-th expected accident; p_{Fk} is the probability of the power failure in k-th line.

2.2 Optimization constraints

1) Power flow balance constraints

$$\begin{cases} P_i - V_i\sum_{j=1}^{n}V_j[G_{ij}\cos(\delta_i-\delta_j)+B_{ij}\sin(\delta_i-\delta_j)]=0 \\ Q_i - V_i\sum_{j=1}^{n}V_j[G_{ij}\sin(\delta_i-\delta_j)-B_{ij}\cos(\delta_i-\delta_j)]=0 \\ P_i = P_{Gi}-P_{Di}, Q_i = Q_{Ri}-Q_{Di} \end{cases} \tag{10}$$

Where: P_{Di} and Q_{Di} are the active power load and reactive power load of node i; P_{Gi} is the injected active power of node i, P_{Gi}=0 when node i is not the source node; Q_{Ri} is the reactive power compensation capacity for node i; G_{ij} and B_{ij} are transfer conductance and susceptance, respectively, between node i and node j; V_i and V_j are the voltage magnitude for node i and node j; δ_i and δ_j are the voltage phase angle for node i and node j.

2) Voltage amplitude constraints

$$V_{i\min} \le V_i \le V_{i\max} \tag{11}$$

Where: V_i is the voltage magnitude (pu) of the i-th node; $V_{i\max}$ and $V_{i\min}$, respectively, are the upper and lower limit of the voltage amplitude of the i-th node (pu).

3) Line flow constraints

$$|I_{Lk}| \le I_{Lk\max} \tag{12}$$

Where: $|I_{Lk}|$ is the current amplitude on the k-th line;

$I_{Lk\max}$ is the maximum carrying capacity of the k-th line.

4) Transformer capacity constraints

$$\left|I_{Tk}\right| \le I_{Tk\max} \tag{13}$$

Where: $\left|I_{Tk}\right|$ is the current which passes through the k-th transformer; $I_{Tk\max}$ is the upper current amplitude which is allowed for passing through the k-th transformer.

5) Reactive power compensation capacity constraints

$$Q_{Ri\min} \le Q_{Ri} \le Q_{Ri\max}, i \in \Omega_Q \tag{14}$$

Where: Q_{Ri} is the reactive power compensation value of node i, $Q_{Ri}=0$ when node i has no reactive compensation device; $Q_{Ri\min}$ and $Q_{Ri\max}$ is the lower limit and upper limit of reactive power compensation capacity respectively for node i; Ω_Q and is the set of nodes owning reactive power compensation device.

6) Network structure constraints

Before and after the optimization, the radial distribution structure of the distribution network remains unchanged, and there is no isolated island.

2.3 Optimization model and solution

The optimization problem of the distribution network operation is a multi-objective nonlinear programming problem. According to the objective function in Section 2.1 and the constraints in Section 2.2, the complete mathematical model of the distribution network operation model can be obtained as follows:

$$\begin{aligned} &\min \quad \boldsymbol{F}(\boldsymbol{x}) \\ &\text{s.t.} \quad \begin{cases} \boldsymbol{h}(\boldsymbol{x}) = \boldsymbol{0} \\ \boldsymbol{g}(\boldsymbol{x}) \le \boldsymbol{0} \end{cases} \end{aligned} \tag{15}$$

Where: $\boldsymbol{F}(\boldsymbol{x}) = [F_1(\boldsymbol{x}), F_2(\boldsymbol{x}), \cdots, F_5(\boldsymbol{x})]^{\mathrm{T}}$ is the objective function vector; $\boldsymbol{h}(\boldsymbol{x}) = \boldsymbol{0}$ is the equality constraint in Section 2.2; $\boldsymbol{g}(\boldsymbol{x}) \le \boldsymbol{0}$ is the inequality constraint in Section 2.2; and $\boldsymbol{x}$ is the variable vector.

Obviously, the dimensions of each objective function in the mathematic model above are different, so in order to facilitate the solution, we need to turn it into a non-dimensional objective function. First, figure out the optimal result of each sub-target. For example, to solve the i-th sub-problem, whose target function is $F_i(\boldsymbol{x})$, that is, solving the nonlinear programming problem of Eq. (16)

$$\begin{aligned} &\min \quad F_i(\boldsymbol{x}) \\ &\text{s.t.} \quad \begin{cases} \boldsymbol{h}(\boldsymbol{x}) = \boldsymbol{0} \\ \boldsymbol{g}(\boldsymbol{x}) \le \boldsymbol{0} \end{cases} \end{aligned} \tag{16}$$

The minimum value of $F_i(\boldsymbol{x})$ can be obtained by solving the nonlinear programming problem of Eq. (16), which is denoted as $F_i^{\min}$. After obtaining the five optimal results of the five sub-targets, Eq. (15) can be transformed into the following single-objective optimization model by using the analytic hierarchy process (AHP):

$$\begin{aligned} &\min \quad \sum_{i=1}^{5} \omega_i \frac{F_i(\boldsymbol{x})}{F_i^{\min}} \\ &\text{s.t.} \quad \begin{cases} \boldsymbol{h}(\boldsymbol{x}) = \boldsymbol{0} \\ \boldsymbol{g}(\boldsymbol{x}) \le \boldsymbol{0} \end{cases} \end{aligned} \tag{17}$$

Where: ω_i is the weight of the i-th sub-object, and satisfies $\sum_{i=1}^{5}\omega_i=1$, which can be determined by the analytic hierarchy process, or it can be directly assigned according to the demand.

The model is solved by the branch-exchange method based on heuristic search, which is obtained by collecting the basic data of the distribution network, and obtaining the multi-objective optimization mathematical model, that is Eq. (17). The solving steps are as follows:

1) Calculate the power flow under the initial operating mode (open-loop operation), and get the

objective function value of the five sub-targets in the initial running state;
2) Close all the line switches, search all the paths in the network which can constitute the ring network;
3) Randomly select a path to search, and analyze the first sub-problem, that is choosing the minimum voltage deviation as the goal. Disconnect the switches in each path respectively. If no isolated island occurs after some switch is disconnected, further calculate the value of its target function. If there is an isolated island, analyze the situation of the next switch. Finally search of this path is done and we obtain the switches disconnected in the first path while the first target function gets its optimal value.
4) Select another path to search and repeat step 3) to obtain the switches disconnected when the value of the first sub-objective function in the second path is optimal;
5) Repeat steps 3) and 4) until all the paths in the network are searched and obtain the disconnected switch combination when the value of the first sub-objective function is minimum in the network;
6) Repeat steps 3), 4) and 5) for the second sub-goal, that is, looking for the highest load balancing degree of the line, and get the switch combination when the value of the second sub-objective function is minimum in the network;
7) Repeat steps 3), 4), 5) and 6) until all the sub-targets are analyzed and the minimum value of each sub-object and the corresponding disconnected switch combinations are obtained;
8) Recombine the disconnected switch combinations obtained in step 7), and calculate the objective function values in Eq. (17) with the combinations without isolated islands. The disconnected switch combination obtained which is corresponding to the optimal value of the objective function, is the optimal operation mode in technology, economy and risks that satisfying all kinds of constraints.

3 Case Study

In this paper, the proposed method of distribution network optimization is described by using the 3-line power distribution system proposed in literature [14], which is shown in Fig. 1, where node 1, node 2 and node 3 are feed-in nodes, the remaining nodes are load nodes. The contact switches of line 5-11, line 10-14 and line 7-16 are open in the initial running state. Without loss of generality, the user level of each load node is randomly obtained between 0-1, and the number of users is randomly obtained between 1 and 10. Assume that the level factors of all users in the same node are the same.

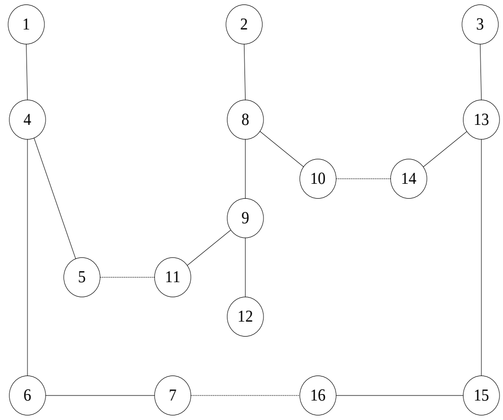

Figure 1 3 feeder distribution system diagram

The failure attribute parameters of each line in Fig. 1 are shown in Table 2, and the other electrical parameters are described in detail in literature [20].

Table 2 Branch failure attributes

Branch type	Failure rate (times / hour)	Average failure duration time (hours)	Branch
cable	0.5×10^{-5}	6.5	4-5,2-8,8-9,9-12
overhead line	0.9×10^{-5}	4.2	other branches

In general, for the middle-voltage and low-voltage distribution network, the user is often more concerned about the anti-risk ability of the entire distribution network, that is, the corresponding operational risk and grid risk of the final optimization result should be as small as possible, and the rest factors including the load balancing, network loss and voltage deviation degree are secondary considerations. Therefore, the weight of each sub-goal chosen in this case is: weight of node voltage deviation degree $\omega_1=0.025$, weight of line load balancing degree $\omega_2=0.15$, weight of distribution network loss $\omega_3=0.025$; weight of operation risk

ω_4=0.4 and weight of grid risk ω_5=0.4 .

In order to show that the optimization method proposed in this paper can optimize the operation mode of the distribution network correctly, the sub-target and the integrated target value are calculated first in the initial operation mode of the distribution system. Then, the optimized operation mode is obtained by solving the optimization model of Eq. (17) and the calculation results of each sub-target and the integrated target value are given. In order to facilitate the analysis of the optimization results, several typical operation modes are selected and compared, as shown in table 3. The operation mode 1 in the table is the initial operation mode, and the operation mode 2 is the optimized mode. The integrated target value is the objective function value in Eq. (17).

Table 3 Comparison of optimization results of operation mode

Operation mode number	1	2	3	4	5	6
Branch separation	5-11,10-14,7-16	9-11, 8-10, 7-16	8-9, 13-14 ,4-6,	9-11,13-14,7-16	8-9, 13-14, 7-16,	9-11,10-14,7-16
Node voltage deviation degree	0.0191	0.0169	0.0243	0.0228	0.0236	0.0165
Line load balancing degree	234.37	211.74	213.29	274.81	322.93	206.19
Distribution network loss	0.0070	0.0061	0.0090	0.0090	0.0084	0.0058
Operational risk	5.868	5.217	5.577	6.308	6.949	5.366
Grid risk	8.840	8.840	8.838	8.840	8.845	8.840
Integrated target value	1.0795	1.0058	1.0583	1.1569	1.2399	1.0115

ween 10-14 aThe main calculation process is as follows:

1) Calculate the power flow under the initial operating mode, obtain the voltage information of different nodes and the tributary current information, and calculate the value of each sub-objective function.

2) Close all the line switches, search the network and find all the paths that constitute the ring network, namely:

Path 1: 1-> 4-> 5-> 11-> 9-> 8-> 2;

Path 2: 1-> 4-> 6-> 7-> 16-> 15-> 13-> 3;

Path 3: 2-> 8-> 10-> 14-> 13-> 3

Firstly, the path search is performed with the first sub-goal, that is, the minimum deviation of the node voltage, starting from path 1, searching towards node 1 and node 2 from contact switch 5-11. Searching towards node 1 and obtaining the contact switch between 4 and 5, while searching towards node 2 and obtaining the contact switch between 9 and 11, 8 and 9. After calculation, the objective function reaches the minimum value after disconnecting the contact switch between 9 and 11.The same method can be used to get the result of the other two routes. It is to disconnect the switches betnd 7-16. The final result of the switch combinations which can get the minimum degree of deviation of the node are: 9-11, 10-14, 7-16, and the corresponding objective function value is 0.0165.

3) Using the same method, we can get that the switch combinations with the objective function as the minimum load balancing degree are 9-11, 10-14, 7-16, and the corresponding objective function value is 206.19. The switch combinations with the objective function as the minimum loss of the network are 9-11, 10-14, 7-16, and the corresponding objective function is 0.0058; The switch combinations with the objective function as the minimum risk of operation are 9-11, 8-10, 7-16, and the corresponding objective function is 5.217; The switch combinations with the objective function as the minimum risk of the grid are 8-9, 4-6, 13-14, and the corresponding objective function is 8.838.

4) It can be seen from the above calculation results that the disconnected switch combinations are all 9-11, 10-14, 7-16 when the objective functions are the node voltage deviation degree, the line load balance degree and the distribution network loss. The disconnected switch combination is 9-11, 8-10, 7-16 when the objective function is operational risk. The

disconnected switch combination is 4-6, 8-9, 13-14 when the objective function is grid risk. Recombine the combinations above, 18 combination formulas can be obtained. Calculate the corresponding integrated target value respectively, and finally get the disconnected switch combination: 8-9, 4-6, 13-14, that is, the optimal mode of operation.

Using the method described in this paper to optimize the distribution network operation, it can be seen from Table 3, that the optimized operation mode compared with the initial operation mode, in addition to that the risk of the grid remained basically unchanged, the remaining several sub-targets' function values have been optimized to some degree. The integrated target value is much lower than that of the initial operation mode, that is to say, realizing the goal of comprehensive optimization of technology, economy and risk.

In fact, since this paper mainly focuses on the optimization under the normal operation mode of the distribution network, the weights of the operation risk and the grid risk are set relatively large. If considering the optimization of the operation mode under maintenance and failure conditions, the weight of each sub-goal should be appropriate, while still can be solved by using the nonlinear optimization model in Eq. (17). It can be seen from the optimization results of operation mode that the multi-objective optimization method of distribution network, which considers grid loss, load balance, voltage deviation, operation risk and grid risk, is reasonable and effective.

4 Conclusion

In this paper, a method of operation and grid optimization is proposed to consider the operation and grid risks. The operational risks and grid risks are incorporated into the operation mode formulation and optimization. The lower operational risk ensures that the load rate of power lines and transformers in the distribution network are as low as possible. The lower grid risk ensures that the losses to the users after the expected accidents occur in the distribution network are as small as possible. At the same time, the multi-objective optimization problem is transformed into a single-objective optimization problem with the use of the weighted-sum method. Calculation results of the example show that the method can accurately optimize the distribution network operation mode.

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