Disaster Prevention Network Planning Method Based on Disaster Map

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***Abstract*—This paper mainly studies the problem of network planning in distribution network planning. Based on the research on distribution network planning problems, this paper proposes a distribution network planning method based on disaster map, solving the problem of introducing intermediate nodes into the planning and optimizing in feasible areas which was not considered in the previous research. Firstly, this paper establishes a mathematical model of distribution network planning considering the disaster risk of the area where the network is located, then checks the disaster prevention construction cost of the network on disaster map, finally solves the problem by using the simulated annealing algorithm, and it generates the optimal network structure and determines the constraint conditions. Finally, verifies the performance and effectiveness of the algorithm by an example analysis. The method proposed in this paper breaks through the bottleneck of searching the optimal solution within the limited point set by the traditional distribution network planning method, which makes the distribution network planning method more flexible and expands the selection of intermediate nodes. It also increases the probability of searching for a global optimal solution and provides a new idea for the distribution network planning.**

***Index Terms*—Distribution network planning, disaster map, Steiner tree, simulated annealing algorithm**

I. Introduction

THE distribution network is at the end of the power system and supplies power directly to the user. Making the distribution network safer and more economical is an important task in the planning and operation of the distribution network. At the same time, distribution network planning is also an important part of the overall power system planning [1]. Distribution network planning, including substation site selection, grid planning, feeder route selection, feeder model selection and user actual demand matching, is a comprehensive problem. It is mathematically a complex discrete, non-linear, multi-objective combinatorial optimization problem [2]. This paper mainly discusses the problem of network planning in distribution networks.

For the problem of network planning, there are now many researches. Literature [3] takes the power outage cost of the grid as the objective function, using the improved genetic algorithm to solve the problem. Literature [4] comprehensively considers the economics and reliability of the distribution network, carrying out multi-objective planning on the grid of the distribution network with the objective function of investment cost, running cost and network loss cost as the objective function. Literature [5] considered the construction cost and network loss of the power grid, using the ant algorithm to plan the distribution network. The above literature uses different cost as the objective function and uses different intelligent optimization algorithms to solve the problem, achieves good results. In terms of distribution network differentiation planning, the literature [6-7] proposed that windproof design standards and line spans should be formulated differently according to the typhoon defense range in which the distribution lines are located, but only the disaster-resisting measures are given qualitatively. The planning method of the disaster-resistant distribution network is not quantitatively proposed. The literature [8-9] has developed corresponding distribution line fortification standards for different types of disasters and disasters, and proposed a disaster-resistant distribution network planning method that is differentiated according to disaster zones. However, it is not in accordance with the principle of

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economy to raise all the lines in the same disaster level area to the corresponding fortification standards.

However, the current distribution network grid planning rarely considers the construction cost of the network and the impact of the disaster risk.

For the area with frequent natural disasters, the impact of natural disasters on the distribution network should be considered in distribution network planning so that the impact of disasters on the distribution network is minimized. This paper mainly studies the problem of network planning in distribution network planning considering disaster risk, draws the disaster map through the historical disaster situation of the area to be planned, and obtains the disaster risk of grid construction in different areas. Then it combines the construction cost of the grid and the disaster risk, introduces intermediate nodes in the planning, and finds the best in the feasible area, establish the Steiner tree mathematical model of the disaster prevention network planning, and uses the simulated annealing algorithm to solve it.

II. Problem of Disaster Prevention Network Planning

The goal of the distribution network grid planning problem is to make the grid construction cost under the premise of meeting the power supply requirements of important users under the disaster, which is a discrete and non-linear problem.

When conducting disaster prevention planning, the lines in the distribution network should be placed in areas with small disaster risk, so that the distribution network is least affected by disasters. This paper changes the layout of distribution network lines by considering ways to increase intermediate nodes, which makes the lines in the distribution network grid avoid the disaster-hit areas as much as possible, thus achieving the disaster prevention effect. That is, solving the Steiner minimum tree problem of distribution network planning. In this Steiner minimum tree problem, the construction cost of the line is the weight of the side of the Steiner tree. The construction cost and the disaster risk is the weight of the Steiner point.

This paper divides the construction cost of the distribution network into two parts, that is, the construction cost of the line and the cost of the added node, the cost of the added node is also composed of two parts, namely the construction cost of the tower at the node and the disaster risk of where the tower is constructed. Thus, we obtain the mathematical model of disaster prevention grid planning:

Objective function:

$$\min \sum_{k=1}^{m} C_{lk} + \sum_{k=1}^{n} C_{nk} \tag{1}$$

In the formula, C_{lk} is the construction cost of the line, C_{nk} is the construction cost of the tower at the node considering the disaster risk. C_{nk} is related to the disaster risk of the location of the node. In the area with high disaster risk, to achieve the goal of disaster prevention, the line and tower need to be differentiated during construction, which will increase the construction cost. The greater the risk of disaster, the higher the C_{nk} is.

Restrictions:

Node voltage constraint:

$$U_{\min,j} \le U_j \le U_{\max,j} \tag{2}$$

Where $U_{\max,j}$ is the maximum allowable voltage at node j. $U_{\min,j}$ is the minimum allowable voltage at node j.

Load flow constraint:

$$\begin{cases} P_{G,j} - P_{L,j} = U_j \sum_{k\in J} U_k (G_{j,k} \cos\delta_{j,k} + B_{j,k} \sin\delta_{j,k}) \\ Q_{G,j} - Q_{L,j} = U_j \sum_{k\in J} U_k (G_{j,k} \sin\delta_{j,k} + B_{j,k} \cos\delta_{j,k}) \end{cases} \tag{3}$$

Where $P_{G,j}$ and $Q_{G,j}$ are the active power and reactive power injected at node j respectively. $P_{L,j}$ and $Q_{L,j}$ is the active power and reactive power of the load at node j. $G_{j,k}$ and $B_{j,k}$ is the conductance and susceptance.

The construction cost of the tower at the added node is closely related to the disaster risk of the location of the node. The risk of disaster in a region is determined by various factors, such as geographical location, terrain, disaster level, etc., for the planning area of the distribution network. The terrain of different areas within the planned area may vary greatly in climatic conditions. To make the planning of the disaster risk in different areas intuitively to guide the planning, disaster maps may be drawn. Mark the disaster-resistant construction costs in different areas in the map to guide the planning of the distribution network.

III. Drawing of Disaster Map

The main function of the disaster map is to input the coordinates on the map and output the disaster prevention construction cost of the network. When planning the grid structure of the disaster prevention network, people can consult the disaster map and learn the disaster prevention construction cost of different network.

The method of drawing the disaster map is to classify each region according to the characteristics of meteorological disasters according to the grid by ant colony clustering algorithm. This rating reflects the severity of the impact of meteorological disasters if the network is built in the area. The level of disasters in each region directly affects the cost of building the network there; the higher the level of disaster, the higher the cost of building the network.

A. Extraction of Natural Disaster Information from Power Grid

The natural conditions of the location where the power grid is constructed have a great impact on the disaster resistance of the power grid. To characterize this impact, each region is given a natural environment disaster level, “light disaster”, “medium disaster”, “heavy disaster”, “very heavy disaster," the severity of the impact on the grid's resilience is increasing. This grade is a comprehensive index considering various natural conditions such as local geology and meteorology. It needs to be realized by ant colony clustering algorithm.

To realize the ant colony clustering algorithm, it is necessary to analyze the hazard factors of the natural disaster of the grid and combine the suggestions of relevant experts to encode its characteristics. Extract disaster information for each region for the following four natural attributes:

“Geological conditions” refers to the description of the terrain topography and soil conditions of the area against grid disasters. Under the same meteorological conditions, the high-lying power grid is more affected by wind and lightning disasters; where the soil texture is loose, it is more likely to fall. Therefore, geological conditions are very important in the hazard factor, and the description can be “appropriate geological conditions”, “qualified geological conditions”, “unsuitable geological conditions”, etc.

“Windstorm situation” refers to the description of wind disasters affecting grid in the region. Windstorms can cause down-bars, broken wires. The grid lines that have been in strong winds for a long time will wear out, and the probability of failure due to external factors is higher. The description of the windstorm situation can be described as “strong wind zone”, “windy zone”, “breezing zone”, etc. according to the division of its location.

“Thunderstorm situation” refers to the description of thunderstorm disasters affecting grid in the region. Thunderstorms can cause over-voltage on the line, causing the line to trip, or it may burn the grid equipment due to excessive lightning current. The description of the thunderstorm situation can be described as “strong thunder field”, “light thunder zone” and “medium thunder field” according to the local average annual thunderstorm day and lightning density.

“Flood situation” refers to the description of flood disasters affecting grid in the region. Flood disasters mainly affect the geological environment, such as loosening the soil and causing the bar to fall; heavy rain will also aggravate the flashover of the insulator and cause the line to trip. The description of the flood disaster can be based on the highest daily rainfall in the area, and the average daily rainfall is divided into “severe flood-stricken areas”, “medium flood-stricken areas”, and “slightly flood-hit areas”.

The above four kinds of natural disasters should be rationally quantified, and feature distinguishing codes are compiled for each attribute. Taking “geological conditions” as an example, it is divided into “appropriate geological conditions”, “qualified geological conditions”, and “unsuitable geological conditions”, which are coded as “0/1/2”, and the other three attributes are also the same. The attribute value is initially quantified by the above method, and then the clustering process of the historical disaster data can be performed. Here, the weights of the four attributes are same, and in the actual historical disaster clustering, the weight correction can be performed according to the obtained clustering result and the evaluation feedback of the expert feedback to further ensure the quality of the cluster. That is to focus on the professional advice of historical experts in the process of quantification of disaster information, and in the process of clustering, try to achieve rapid and automatic processing, so that the guidance and supervision of experts are more reflected in the general direction.

B. Ant Colony Clustering Algorithm

To improve the poor data aggregation due to data loss, it is necessary to normalize all data. Let the initial value of the ith attribute of the nth disaster be y_{ni} , and become z_{ni} after preprocessing:

$$z_{ni} = \frac{1}{2 - \dfrac{y_{ni} - y_{\min i}}{y_{\max i} - y_{\min i}}} \tag{4}$$

Defining the disaster data chaos $chaos_n$ (n∈[1,k]), the chaos of the nth group is the standard deviation of the sum of the squares of each natural disaster data attribute.

$$chaos_n = \sqrt{\frac{\sum_{i=1}^{t_n} (x_i - avg_n)^2}{t_n}} \tag{5}$$

Where x_i represents the sum of the squares of the attributes of the ith data in the nth group, and the calculation method is:

$$x_i = \sum_{j=1}^{p} z_j^2 \tag{6}$$

In the formula (3), avg_n represents the average value of the nth group xi, and the calculation method is

$$avg_n = \frac{\sum_{i=1}^{t_n} x_i}{t_n} \tag{7}$$

Based on the chaos value of each group, an arbitrage selection method is used to select an array of numbers. Calculate the effect of each data on the degree of confusion in the array, denoted as f. The larger the f-value of the data, the greater the probability that it will be selected.

$$f = (x_i - avg_n)^2 \tag{8}$$

Define $similarity_n$ (n ∈ [1,k]) to indicate the fit of the selected data to each array,

$$similarity_n = \frac{1}{(x_i - avg_n)^2} \tag{9}$$

According to the different similarity values of each group, the arbitrage selection method is used to select an array of input numbers, and the selected data is put into the array.

Since the selection of arrays, data, and arrays of numbers is random, there are many possibilities for each run. To ensure the convergence of the algorithm, $fitness_n$ is used to indicate the quality of each sorting method.

$$fitness_n = \frac{1}{t_n \times chaos_n} \tag{10}$$

Where t_n is the size of the nth group after sorting, and $chaos_n$ is the chaotic value of this group after sorting.

Looping (5) to (10), when each selected data is always put back into the original array, that is, the clustering results no longer changes, each group of data can be divided into two according to the size order of each group of cluster centers. " Light disaster, medium disaster, heavy disasters, and extra heavy disasters."

C. Disaster Level and Disaster Prevention Construction Cost

The level of disasters in each region directly affects the cost of building a grid there; the higher the level of disaster, the higher the cost of building the network. According to the clustering results, for each type of center vector, the required disaster prevention construction schemes corresponding to “light disaster, medium disaster, heavy disaster, and extra heavy disaster” are determined, such as minimum span, arrester clearance, and tower material. Calculate the cost multiple relationship of four grades to build a grid of the same scale, with a light disaster of 1, a disaster cost coefficient of α, a heavy disaster cost coefficient of β, and a special disaster cost coefficient of γ; when conducting disaster-resistant grid planning, the cost must be multiplied by the corresponding factor in the disaster level of the construction site.

IV. Disaster Prevention Network Planning Method Based on Steiner Tree

A. Disaster Prevention Network Model Based on Disaster Map

For the disaster prevention distribution network planning problem, the method of adding intermediate nodes can be used. The cost of the added nodes includes two parts, the construction cost of the tower and the disaster risk of the area where the tower is constructed. The disaster risk of the tower at the node can be classified into the construction cost of the tower by using the weight coefficient. According to the foregoing, for the disaster-hit area, to achieve the goal of disaster prevention, the construction cost of the line and tower during construction is higher. By consulting the disaster map, the construction cost parameters of the tower at different locations can be obtained as a variable in network planning, and the mathematical model of the disaster prevention network planning model based on the disaster map is obtained:

$$\min \sum_{i=1}^{m} C_{li} + \sum_{k=1}^{n} K_i C_{ni}^{'} \tag{11}$$

Where C_{li} is the construction cost of the line, $C_{ni}^{'}$ is the construction cost of the tower, and K_i is the disaster cost coefficient of the tower construction, which is related to the disaster level in the area where it is located. The calculation method is shown in Section B. Then the Steiner minimum tree model can be used to implement disaster prevention grid planning.

B. Method for Solving Steiner Minimum Tree

In this paper, the minimum spanning tree-based heuristic algorithm, simulated annealing algorithm, is used to solve the Steiner minimum tree problem of the disaster prevention network planning. the calculation amount of the simulated annealing algorithm is small when solving the Steiner minimum tree problem [26], furthermore, the simulated annealing algorithm can effectively jump out of the category of the local optimal solution, and has a faster running speed, which is suitable for the actual needs of the project. Therefore, this paper proposes a solution method for Steiner's minimum tree problem to meet the needs of practical engineering planning of distribution network.

In the planning problem described in this paper, the original point set contains the load point set and the substation site set, among which there are n nodes. The specific steps of solving the simulated annealing algorithm are as follows:

Step 1: preprocessing of the original point set, that is, according to the nature of the Steiner minimum tree, the intermediate node to be sought is in the convex hull formed by the original point set, so the coordinate position of the original point set determines a rectangular area $\max\_x \times \max\_y$ ($\max\_x$, $\max\_y$,respectively Length and width), delineating the feasible area of the Steiner point search. Then divide the above area into $n\_x \times n\_y$ grids:

$$n\_x = \max\_x \times \text{degree} + 1 \tag{12}$$

$$n\_y = max\_y \times degree + 1 \quad (13)$$

Where degree is the mesh subdivision multiple, taking any positive integer, all nodes are placed on the vertices of the mesh.

Step 2: initializing the construction cost matrix of the tower at the intermediate node, and the construction cost of the tower is related to the disaster risk of the location of the node.

Step 3: using the simulated annealing algorithm to solve the Steiner minimum tree problem, firstly, calculating the minimum spanning tree from the original point set, obtaining the initial distribution network structure, the objective function value is calculated, and the memory variable of the objective function value is updated. Then, the iteration of the simulated annealing algorithm is started, and the following operations are performed on the existing m intermediate nodes at different temperatures until the equilibrium state at this temperature is reached, and then the temperature is slowly lowered.

The specific operation options are as follows:

1. Add r new s-points ($r+m \leqslant n-2$), get $m \leftarrow m+r$;
2. Delete r existing s-points ($m-r \geqslant 0$), get $m \leftarrow m-r$;
3. Move m s-points one by one to any "allowed" position in each neighborhood;

Constructing a complete graph from n+m points, the side length is the weight between the two points; calculate the objective function value (new_result) at this time, and let ΔW = new_result - last_result. According to the requirements of the constraints of the distribution network planning, judging whether the network structure satisfies the constraint. If it is not satisfied, the new solution is rejected; if it is satisfied, and if $\Delta W<0$, the new solution is accepted; otherwise, the new solution is accepted according to the probability. Where random [0,1] refers to a random number between [0,1].

Step 4: Calculating the objective function value for the last feasible solution, obtaining the total cost of adopting the network plan, and recording the cost and its corresponding distribution network layout plan as the optimal solution for this planning problem. Outputting the layout of the distribution network frame with the lowest total output cost, the localization adjustment for the location selection of the distribution network node can be adjusted according to the actual geographical location and the construction requirements of the intermediate nodes.

V. Case Studies

The distribution network planning algorithm based on the simulated annealing algorithm to solve the Steiner minimum tree problem is programmed and implemented. The original grid in lecture [26] has 20 load nodes and one substation node, which is shown in Figure 1. In Figure 2, the minimum spanning tree is first calculated for the complete graph of the load node and the substation node, and then the optimal network structure without increasing the intermediate node is obtained, which is used as the benchmark comparison group for the analysis of the example. Table I gives the coordinates and load requirements for each load point, and Table II shows the location of the substation to be built. The disaster cost coefficient of different regions in the region where the grid is located is calculated by the second section algorithm: the light disaster cost coefficient is 1, the medium disaster cost coefficient is 2.5, the heavy disaster cost coefficient is 4.2, the extra heavy disaster cost

TABLE I
COORDINATES AND LOAD REQUIREMENTS OF EACH LOAD POINT

Node number	Coordinates	Load demand/kVA
L10	(1.2,6)	530
L11	(5,3)	630
L12	(6,4)	320
L13	(5.5,5)	630
L14	(6,8)	510
L15	(9,5)	650
L16	(12,4)	120
L17	(1,4)	230
L18	(3.5,4)	450
L19	(5,4.5)	580
L20	(8,4)	280
L21	(9.5,3.5)	820
L22	(8,2)	710
L23	(5.5,3)	560
L24	(3,3)	250
L25	(6,2)	0

TABLE II
LOCATION OF SUBSTATION TO BE BUILT

Node number	Coordinates
P1	(5,0)

TABLE III
COST WEIGHTING OF INTERMEDIATE NODES IN DIFFERENT REGIONS

Coordinates of lower left corner of the Rectangular area	Coordinates of upper right corner of the Rectangular area	Weight of cost
(2,0.5)	(7,2)	2.5
(2,2)	(7,4)	6.1
(7,0.5)	(10,4)	4.2
Other area		1.0

TABLE IV
DETAILS OF THE FEEDER

Numbers of loops	Conductor resistivity	Line impedance	construction cost
3	31.5Ω·mm²/km	0.0525Ω/km	500,000 yuan/km

TABLE V
OBJECTIVE FUNCTION VALUE OF THE GRID PLANNING BEFORE AND AFTER CONSIDERING THE INTERMEDIATE NODE (UNIT: 10,000 YUAN)

Traditional method	Method in this paper	Optimization ratio
3667.76	4591.33	20.11%

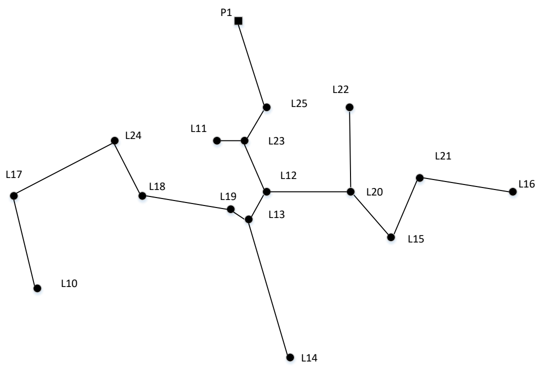

Fig. 1. Result of network planning using traditional method

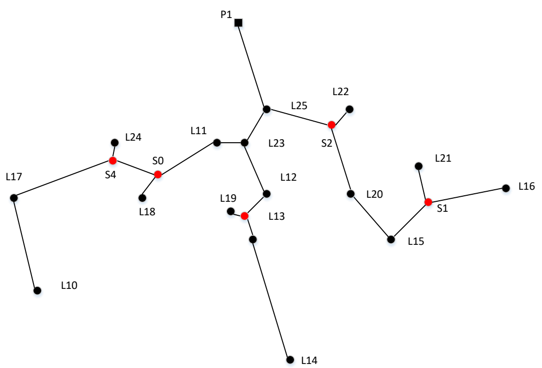

Fig. 2. Result of network planning using the method in this paper

coefficient is 6.1. The location and disaster cost coefficient of each area are shown in Table III. The method of this paper is based on Java language programming. The computer CPU model used is Intel Core i5-4258U and the memory is 8G.

The basic parameters of the distribution network are as follows: rated voltage is 10kV, power factor is 0.95, and annual investment recovery factor is 0.155. The feeder adopts LGJQ-2×300 split conductor, and the details of feeder are shown in Table IV. The construction cost of a substation is 1 million yuan, and the construction cost of the intermediate node is 0.5 million yuan. The actual construction cost is equal to the fundamental construction cost multiplied by the weighting factor of the construction site. In this paper, the plane rectangular coordinate system is established with the actual distance of 5km corresponding to the unit coordinates.

The new distribution network obtained through program optimization is shown in Figure 2. The blue dot represents the newly added intermediate node, which is the Steiner point. The objective function values before and after optimization are shown in Table V. We can be find that the algorithm described in this paper solves the Steiner tree faster, and the total number of iterations is less, also, the increase of the intermediate nodes can make the objective function value of the distribution network planning smaller and the total cost is better. The method can effectively reduce the overall cost.

VI. CONCLUSION

This paper proposes a distribution network planning method based on disaster map, which introduces intermediate nodes to solve the problem. The network structure can adapt to the requirements of the radial operation of the distribution network, and consider constraints such as power supply load, power flow constraints, and feeder current carrying capacity. The proposed method makes the lines in the distribution network grid avoid the disaster-hit areas by adding intermediate nodes, which enhance the disaster prevention performance of the distribution network and makes the distribution network planning method more flexible, and the selection range of the intermediate nodes is expanded, which increases the probability of searching for the global optimal solution and can more effectively realize the optimization planning of the distribution network. The example shows that the distribution network structure based on this method can effectively reduce the total cost of grid construction, making the grid layout of the distribution network more economical. For the planning problem of larger-scale distribution network, follow-up research can consider using a higher computational efficiency algorithm to make the calculation faster.

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