Research on Intelligent Planning of Low-Voltage Distribution Network Based on Adaptive Particle Swarm Algorithm

Min Li, Yigang Tao, Juncheng Zhang, Jing Tan, and Ji Qin

Abstract The current conventional distribution network planning method mainly solves the optimal planning scheme by establishing linear objective function, which is better than the lack of construction for typical scenario set leading to poor planning effect. In this regard, an intelligent planning method of low-voltage distribution network based on adaptive particle swarm algorithm is proposed. The typical scenario dataset is obtained by sampling and extracting the data in the low-voltage distribution network operation dataset and reducing the scenario set. On this basis, the optimization function is constructed with the three parameters of operation cost, power network loss and voltage load as the target parameters, and the function is solved by particle swarm algorithm. In the experiments, the planning performance of the proposed method is verified. The experimental results show that the distribution network intelligent planning method constructed by the proposed method has a high equivalent output of the distribution network and has a better planning performance.

Keywords Particle swarm algorithm · Smart distribution network · Planning methods · Equivalent output

1 Introduction

The rational planning of distribution networks is crucial to the stable operation and power quality of distribution networks. Currently, as the level of distribution network construction continues to improve, customer demand for quality of electricity and project demand for cost also adds more difficulty to the planning process [1]. A good planning of the distribution network must be the result of a comprehensive consideration of operation and maintenance costs, power production quality, power load and voltage. The current lack of planning guidance for conventional distribution network construction projects has led to the following problems: uncoordinated planning and

M. Li · Y. Tao (✉) · J. Zhang · J. Tan · J. Qin
Guangxi Power Grid Corp. Ltd, Nanning 530023, Guangxi, China
e-mail: 418481317@qq.com

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construction projects, high planning costs and low-power production quality. Firstly, due to the limitation of investment amount and construction resources, the grid is usually equipped with more construction resources and investment funds for the main grid during the initial planning and construction, which leads to the lack of sufficient financial support during the construction of the distribution grid, thus affecting the construction effect of the distribution grid [2]. At the same time, the lack of reasonable unified planning between the distribution network and the main grid leads to a larger load and lower power output of the distribution network. In addition, the distribution grid is not integrated with the overall planning direction of the city and adjusted during the planning process, resulting in a serious disconnection between the distribution grid project and the surrounding projects, which is not conducive to the surrounding economic development. Due to the lack of effective purification of historical data, the conventional distribution network has a low accuracy of load forecasting, which also affects the electric energy production efficiency of the distribution network and thus cannot meet the electricity demand of customers. To optimize the above problem, firstly, the distribution network project should be coordinated with the main network project and flexibly adjusted according to the overall planning project of the city, so as to plan the distribution network construction project with a better fit with the surrounding projects. In order to improve the overall efficiency of the distribution network planning, we need to combine multi-objective optimization algorithms, select representative objectives as the main objective function and select a high-performance algorithm to solve the objective function iteratively, so as to obtain a more scientific and reasonable planning scheme [3]. In this paper, we first analyze the historical data of the distribution network and construct a typical set of load scenarios by sampling the historical data to provide a reliable data source for the subsequent planning algorithm. By combining with particle swarm algorithm, a multi-objective optimization function with multiple parameters such as planning cost and power quality is constructed and solved to achieve a reasonable planning of the distribution network [4].

2 Low-Voltage Distribution Network Planning Uncertainty Scenario Generation and Analysis

For intelligent planning of low-voltage distribution network, this paper first needs to simulate the uncertainty of the load situation of the generation equipment of low-voltage distribution network, and then generate planning scenarios to provide sufficient datasets for distribution network planning. In the low-voltage distribution network planning work, the so-called scenario refers to the space where the random parameters in the set of uncertainties are located [5]. The analysis of uncertainty scenarios can effectively understand the operation of the LV distribution network, including power parameters, equipment load situation and system operation stability. Therefore, uncertainty scenario generation and analysis are essential for intelligent planning of low-voltage distribution networks. Conventional distribution network scenario analysis methods usually need to process the historical operation data of distribution network for large planning at the same time, and cluster and analyze different types of scenario data to generate multiple planning scenarios. Although the scenario analysis results obtained by conventional methods are comprehensive, the number of analysis results obtained increases the difficulties in subsequent data processing, which is not conducive to the rapid solution of the planning model [6]. Therefore, in this paper, in order to make the planning effect of the distribution network more rational, after using the stratified sampling method to complete the generation of uncertainty scenarios, the scale of the generated scenarios is reduced to obtain more typical uncertainty scenarios, and the specific implementation process is as follows [7].

The process of scenario generation is also the process of generating a distribution network operation dataset. To obtain a comprehensive and high-quality distribution network operation dataset, the selection of the sampling method is particularly important. By selecting a suitable sampling method, the continuous mathematical model can be effectively discrete to obtain more accurate model calculation results [8]. Therefore, this paper samples Latin hypercubic sampling method to randomly sample the historical operating data of low-voltage distribution network to generate uncertainty scenarios. Since most of the data in the LV distribution network operation dataset are time series data, the use of positive-order sampling method may lead to periodic regular changes in the sampling results. Therefore, to improve the sampling effect of historical operating data of LV distribution network random variables, this paper chooses to use the inverse permutation sampling method to sample them. Firstly, the original dataset of low-voltage distribution network is standardized, and the fluctuation range of the elements in the dataset is adjusted to the interval of 0–1, and then the scale is divided in the interval, and the elements in the interval are equally divided into N equal parts by setting the size of the division scale to obtain N divided subintervals. By using stratified sampling, sampling is performed inside each division subinterval, assuming that the sampling value is l_i, and the corresponding inverse transform value is $x_i = F^{-1}(l_i)$. By using the above sampling method, we can obtain N operating data of power equipment in the low-voltage distribution network, and by substituting this data into the power equation, we can calculate the power output corresponding to different power equipment, thus generating different load output scenarios [9].

Since the power equipment load scenes generated by the above method are large, it is significant to reduce the generated scenes in order to improve the operation efficiency of the subsequent algorithm. In this paper, we adopt the backward reduction method to reduce the above generated power equipment load scenes, and the specific implementation process is as follows.

Firstly, the distribution probability corresponding to each scenario i in the set of N distribution network power equipment load-out scenarios is P_i, then the distance between any two random scenarios can be calculated as shown in the following formula.

$$d(K_{i,j}, K_{t,j}) = \left(\left(K_{i,j} - K_{t,j}\right)^2\right)^{1/2} \tag{1}$$

where $K_{i,j}$ and $K_{t,j}$ represent the coordinates of two random scenes in the scene set, respectively. Then, the minimum value of the distance between any two random scenes can be used as the cut scene, from which the cut target expression can be obtained as follows.

$$p_{ki} = \min d\left((K_{i,j}, K_{t,j}), i \neq j\right) \cdot P_i \tag{2}$$

Assuming that the minimum value corresponding to the cut scenario is p_{km}, the scenario probability can be updated as shown in the following expression.

$$p_{tj} = p_{ki} + p_{km} \tag{3}$$

According to the above scenario update expression, the typical scenarios are eliminated from the total scenarios to obtain a new set of scenarios, thus completing the scenario reduction process. The generation of load scenes for low-voltage distribution network can be completed by the above steps, and the reduction of scenes can be completed by the backward reduction method to obtain the typical load scenes dataset at [10].

3 Construction of Intelligent Planning Objective Function for Low-Voltage Distribution Network Based on Adaptive Particle Swarm Algorithm

For the typical load scenario generated above, this paper constructs a multi-objective optimization function with the three objectives of distribution network operation cost, network power loss and voltage stability margin, and constrains it with the capacity of distribution network power equipment and voltage and current parameters as constraints [11]. After the objective function is constructed, it is solved by particle swarm algorithm to obtain intelligent planning results. The process of constructing the objective function is shown below.

The power source used in low-voltage distribution network is usually distributed power source, and in the process of planning of distribution network, its economic cost and operational efficiency are largely restricted by the condition of distributed power source equipment. Therefore, this paper combines the above analysis and takes the investment cost and operation cost of distributed power supply as the first objective function of intelligent planning of low-voltage distribution network, and the constructed function expression is shown as follows [12].

$$f_{\text{cost}} = \left[\frac{r(1+r)^n}{\big((1+r)^n - 1\big)c_1} + c_2 \right] p_g \tag{4}$$

where p_g represents the electrical capacity of the distributed power supply, n represents the service life of the distributed power supply equipment, c_1 represents the total investment cost of the power supply equipment, c_2 represents the operation and maintenance cost of the power supply equipment in a unit cycle and r represents the cost–benefit conversion rate. Active network loss refers to the value of network power loss due to the operation of the connected power supply in the planning process of low-voltage distribution network. Therefore, in order to improve the overall planning effect of the distribution network, in addition to the operation cost and maintenance cost, it is also necessary to consider the effect of operating power loss.

$$f_{P\text{loss}} = \sum_{k=1}^{k} |i_k|^2 r_k \tag{5}$$

P_{loss} represents the operating power network loss value of the LV distribution network, l and r_k represent the total number of distribution network branches and the corresponding resistance value and i_k represents the current amplitude of distribution network branches. Since the voltage environment of the LV distribution network is susceptible to unstable fluctuations from distributed power sources, it is necessary to take into account the voltage fluctuation interval in addition to the network loss to ensure the effectiveness of the LV distribution network planning. In this regard, this paper introduces an index to describe the degree of change of voltage fluctuation interval, namely voltage stability margin. The voltage stability margin refers to the acceptable variation interval between the actual voltage value and the desired value of the power node. By reasonably limiting the voltage stability margin, the voltage stability of the low-voltage distribution network and the voltage fluctuation of each load node can be effectively ensured. The resulting objective function expression is constructed as shown below.

$$f_U = \sum \left(\frac{U_{\text{load}} - U_e}{U_e} \right)^2 \tag{6}$$

where U_{load} represents the actual voltage value of a load node in the LV distribution network and U_e represents the desired voltage value of the node. The objective planning function of the LV distribution network can be constructed through the above steps. To ensure that the results solved by this function are in a reasonable range, constraints need to be applied to the above objective function. In this paper, three parameters of distributed power supply capacity and current and voltage are selected as the main constraint objects, and the expression of the constraint function is constructed. The specific expressions are shown below.

$$\begin{cases} P_{\min} \leq \left|P_{gi}\right| \leq P_{\max} \\ |v_i|_{\min} \leq |v_i| \leq |v_i|_{\max} \\ |I_i|_{\min} \leq |I_i| \leq |I_i|_{\max} \end{cases} \tag{7}$$

where P_{gi} represents the useful power output from the distributed power sources in the LV distribution network, $P_{\min}$ and $P_{\max}$ represent the maximum and minimum values of the active load in a branch of the distribution network, respectively. $v_i |v_i|_{\min}$ and $|v_i|_{\max}$ represent the maximum and minimum values of voltage fluctuation at the load node of a branch of the distribution network, respectively. I_i The current amplitude at a load node of a branch of the distribution network, $|I_i|_{\min}$ and $|I_i|_{\max}$ represent the maximum and minimum values of current fluctuation at the load node, respectively.

Through the above steps, the construction of the objective function for low-voltage distribution network planning can be completed, and the objective function is constrained by three parameters: capacity, current and voltage, and the objective planning result can be obtained by solving the objective function with the particle swarm algorithm [13].

4 Particle Swarm Algorithm-Based Objective Function Solving

After completing the construction of the objective function, this paper combines the adaptive particle swarm algorithm to solve the objective function of the distribution network intelligent planning constructed above, and the specific algorithm flow is shown in Fig. 1.

According to the above process, it can be seen that the algorithm used in this paper will first input the original dataset, i.e., the dataset of typical scenarios of distribution network completed by the above reduction, which contains important parameters such as current and voltage of each branch node of the distribution network, and the initial population will be generated by judging the type of this parameter. Then, the initial speed of iteration needs to be set, which is set to 0 in this paper, and the maximum number of iterations of the algorithm is set to 100 [14]. Then, the adaptive degree value of each individual is calculated and the particle position is updated according to the power parameters such as tidal network loss in the original typical scene dataset. The coordinates of each particle in the solution space can be output as an output result, but the direct output of the particle coordinates without poor restrictions easily leads to poor accuracy of the algorithm results, and the obtained planning results lack rationality and cannot provide reliable support for the actual planning of the distribution network. Therefore, in order to ensure that the intelligent planning objective function of the distribution network constructed in this paper can output the most reasonable planning scheme, it is also necessary to restrict the output conditions of the particle coordinate output results. Then, the termination condition needs to be set, and the termination condition is set to be the minimum of the

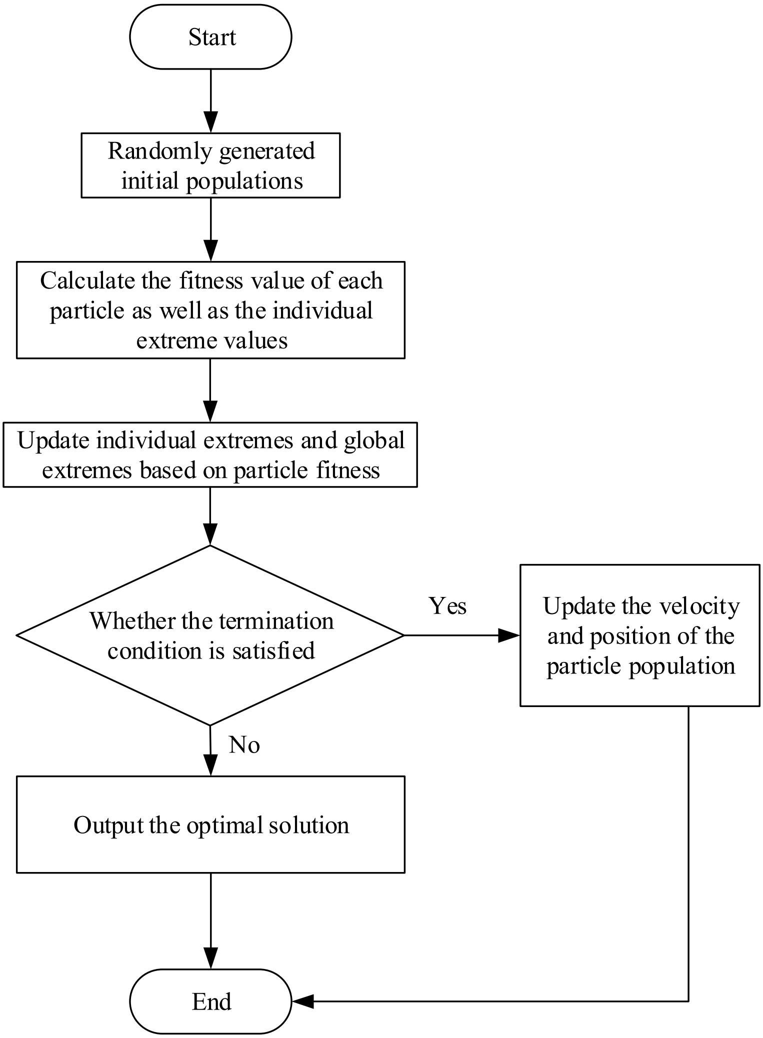

Fig. 1 Algorithm solving process

adaptation value in this paper. By judging whether the updated particle position and particle movement speed satisfy the termination condition, it is determined whether the optimal solution needs to be output. If the updated particle position and moving speed meet the termination condition, the result is the best result and the optimal solution can be output. If the updated value does not meet the termination condition, the above steps need to be repeated to keep updating the particle position until the optimal solution is output [15]. Through the above iterative update process, the accuracy of the optimal solution can be continuously corrected in the process of optimizing the particle velocity and position, so as to obtain the most suitable global optimal solution.

Through the above steps, the objective function of intelligent planning for low-voltage distribution network can be solved and the optimal planning results can be obtained. By combining the particle swarm algorithm, multiple iterations can be performed to optimize the objective function and the planning results can be more reasonable. By combining this section with the above-mentioned typical scenario set generation and reduction, objective function and constraint construction, the intelligent planning method of low-voltage distribution network based on adaptive particle swarm algorithm is completed.

5 Experiment and Analysis

5.1 Experimental Preparation

To prove that the intelligent planning method of low-voltage distribution network based on adaptive particle swarm algorithm proposed in this paper is better than the conventional intelligent planning method of low-voltage distribution network in terms of practical planning effect, after the design of the theoretical part is completed, an experimental session is constructed to test the practical planning effect of the platform of this paper. In order to ensure the experimental effect, two conventional LV distribution network intelligent planning methods are selected for comparison, namely the grid-based LV distribution network intelligent planning method and the safety boundary-based LV distribution network intelligent planning method.

This experiment uses the historical operational power data of the IEEE-15 distribution network as the experimental raw dataset, which uses distributed power supply as the power supply equipment, with more than 100 power load nodes, of which the nodes to be planned account for more than 60%, which is more suitable to be used as the experimental test set for testing. The data in the original dataset are sampled and reduced by the method in this paper to obtain a typical original data scene collection. This set will be used as the test set as well as the training set for this experiment, and the algorithm will be trained and iterated until the optimal results are output. By analyzing the above typical scenario dataset, four distribution network nodes and 50 electric load nodes are selected as the planning objects of this paper, and the specific planning area is shown in Fig. 2.

The distribution network nodes and electric load nodes in the above region are used as planning objects, and three methods are used to test the planning of the above nodes. In this paper, the number of iterations is set to 100, the initial population size is set to 50, the velocity update parameter is set to 2 and the velocity interval for individual particles is limited to between [− 10, 10] and the position of individual particles is limited to between [0, 1450]. Finally, the actual planning effect of the

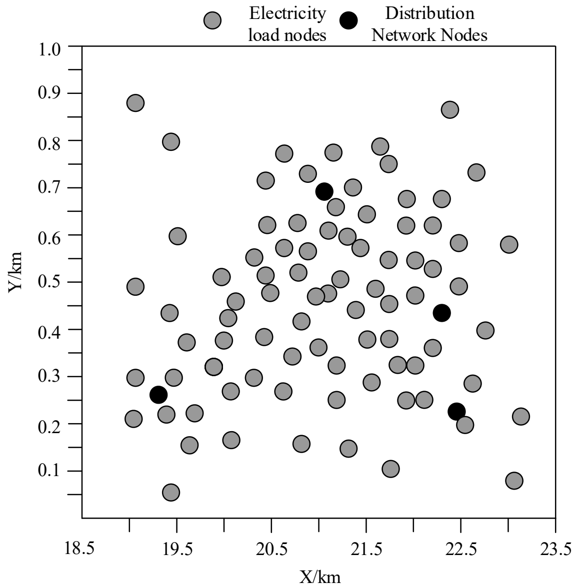

Fig. 2 Schematic diagram of the area to be planned for the low-voltage distribution network

method is determined by comparing the equivalent power output of the distribution network under different planning methods.

5.2 *Analysis of Test Results*

The comparison standard selected for this experiment is the improvement performance of different planning methods for the output situation, and the specific measurement index is the equivalent output size of the distribution network under different planning methods, and the higher the value represents the better the improvement performance of the method for the processing situation, and the specific experimental results are shown in Fig. 3.

It can be seen from the above experimental results that the equivalent output of each distribution network under different planning methods varies with the changing of sampling time. By observing the equivalent output curve, it is obvious that the equivalent output of the distribution network under the three planning methods shows a trend of decreasing and then increasing. The numerical comparison clearly shows that the adaptive particle swarm algorithm-based planning method proposed in this paper has better planning effect, and the equivalent output of the distribution network after planning is significantly higher than the equivalent output of the two conventional methods. It can be proved that the method proposed in this paper is better than the conventional method in terms of planning effect and has better performance in improving the power output of the distribution network.

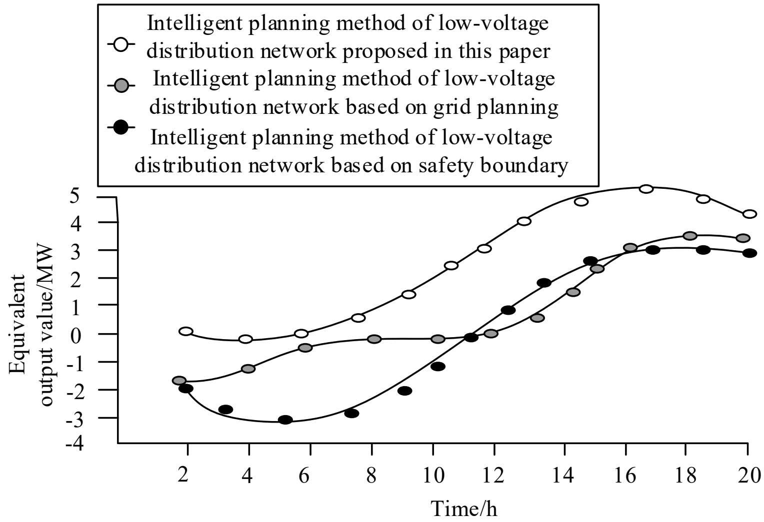

Fig. 3 Comparison results of equivalent power output

6 Conclusion

In this paper, a new intelligent planning method for distribution networks is proposed by combining adaptive particle swarm algorithm to address the problem that conventional distribution network planning methods cannot perform multi-objective planning. By collecting distribution network operation data and performing stratified sampling, so as to obtain a typical scene collection, a more reliable data support can be provided for the subsequent algorithm. The distribution network planning algorithm constructed on this technology adopts a multi-objective planning approach, and the comprehensive performance of its optimization results is better than that of the conventional single-objective planning method, which has a specific certain feasible value.

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