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Planning Research on Power Distribution System under the Access of Electric Heating Equipment Represented by Electric Boiler

Xu Wang[1,3], Dan Wang [1,2*] , Zhengji Meng [1], Peiting Wang [1], Yang Lei [1]
1 Key Laboratory of Smart Grid of Ministry of Education, Tianjin University, Tianjin 300072, China (Correspond Author)
2 Qindao Institute for Ocean Technology of Tianjin University, Qingdao, Shandong Province 266235, China
3 State Grid Nanchang City Honggutan Power Supply Company, Nanchang 330000, China

ABSTRACT

In recent years, due to the influence of extreme weather, it is difficult to meet the demand for heating in non-concentrated areas in China. How to solve the problem of heating in non-centralized heating areas has become a research hotspot. This paper first introduces the advantages of electric heating technology and the impact of electric heating equipment access to the distribution network. Then, taking the electric boiler as the typical electric heating equipment, aiming at the expansion cost of the distribution network lines and the lowest investment cost of the electric boilers, the planning model considering the electric heating equipment accessing the distribution network is constructed, and the corresponding algorithm is used to solve the problem. Finally, a planning scheme for considering the connection of electric heating equipment to the distribution network is proposed, and the feasibility of the proposed scheme is proved by a study case.

Keywords: electric heating technology; electric boiler; distribution network; planning method

1. INTRODUCTION

In China, how to solve the problem of heating in areas where centralized heating pipelines cannot be laid is a hot research topic. Electric heating equipment such as electric boiler is suitable for non-centralized heating areas due to its safety, less pollution, low investment and operating costs and high power utilization rate. Meanwhile, electric heating equipment has the characteristics of large operating power and high running rate, which will have a profound impact on distribution network planning [1]. There have been some researches on technical application and planning algorithms [2] for electric heating technology and distribution network planning problems, but they are basically studied separately. The influence of the access of electric heating equipment on the distribution network and the corresponding countermeasures are the focus of this paper. In this paper, firstly, a model for electric boilers is constructed. Secondly, with the lowest cost of the distribution network expansion lines and the optimal investment in the access to electric boilers, the distribution network planning model for accessing the electric boilers is established, and the particle swarm optimization algorithm is used to solve the problem. Finally, a distribution network planning scheme considering the electric boilers access is proposed.

2. CONSTRUCTION OF DISTRIBUTION NETWORK PLANNING MODEL CONSIDERING ACCESS TO ELECTRIC HEATING EQUIPMENT

2.1 Comparison between electric boiler and other electric heating equipment

Common electric heating equipment mainly includes electric boiler, heat pump and some decentralized electric heating equipment. In comparison, the electric boiler heating system has low construction and maintenance cost, small floor space, high thermoelectric conversion efficiency, long-term economic and environmental benefits, and is suitable for non-centralized heating areas in China [3].

2.2 Electric boiler modeling

The modeling of electric boilers is mainly used to reflect the relationship between the power consumption and the heat load generated as follows

$$P_{\mathrm{EB}}^{h}=\eta_{\mathrm{EB}}P_{\mathrm{EB}}^{e} \tag{1}$$

where P_{EB}^{e} = electric energy consumed by the electric boile, η_{EB} = efficiency of the electric boiler, P_{EB}^{h} = thermal energy generated by the electric boiler.

2.3 Objective function

The access of electric boilers puts more demands on the power supply capacity of the distribution network. Determining the location of electric boilers access and the line that needs to be expanded, so that the distribution network can withstand the new load of electric heating is the focus of this paper. In this paper, the optimal cost of distribution network expansion and electric boilers investment are used as the objective function to model and study.

The objective function is

$$min\ F=C_a+C_b \tag{2}$$

where C_a = expansion cost of the distribution network line, C_b = investment cost of electric boilers. Further, shows as follows

$$C_a=\sum_{i=1}^{n_a} I_i L_i W_{bi} \tag{3}$$

where n_a = total number of lines in the planning area, I_i = logical variable, in which 0 means that the i-th line is not expanded, 1 means that the i-th line needs to be expanded, L_i = length of the i-th line, W_{bi} = fixed investment costs per unit length of the i-th line.

Another shows as follows

$$\begin{cases} C_b=\sum_{k=1}^{n_b} I_k x_k U_{\mathrm{EB}} \\ x_k=\left\lceil \dfrac{Q_k^{max}}{Q_{\mathrm{EB}}} \right\rceil \end{cases} \tag{4}$$

where n_b = total number of nodes that can be connected to electric boilers, I_k = logical variable, in which 0 means that the k-th node is not access electric boiler, 1 means to access, x_k = number of electric boilers access into the k-th node, Q_k^{max} = maximum load of the k-th node, Q_{EB} = rated capacity of the electric boiler, U_{EB} = investment cost of an electric boiler.

2.4 Constraints

When planning the distribution network with electric boilers access, in addition to the constraints of the distribution network power flow, voltage and power during operating, it is necessary to fully consider the relevant constraints of electric boilers to ensure the reliability of distribution network. Ref.[4] has given the constraints of distribution network, this chapter mainly introduces the constraints of electric boilers.

The location of electric boilers needs to be selected among the specific load nodes in the distribution network, and the operating power of electric boilers needs to be within a reasonable range.

$$N_i^{\mathrm{EB}} \in \{N_1^e, N_2^e, N_3^e, \cdots, N_b^e\} i \in S_{\mathrm{EB}} \tag{5}$$

where N_i^{EB} = the i-th position of electric boilers access, S_{EB} = number of locations where electric boilers access into; b = number of load nodes where the electric boilers are able to access into distribution network, N_k^e = the k-th position selected from the distribution network where the electric boilers are able to access. Meanwhile, the output of each electric boiler needs to be less than its rated capacity.

$$0 \le P_{\mathrm{EB},i} \le Q_{\mathrm{EB}} \tag{6}$$

where $P_{\mathrm{EB},i}$ = output power of the i-th electric boiler.

2.5 Solution process

This paper uses the binary particle swarm algorithm to deal with the above problems [5].

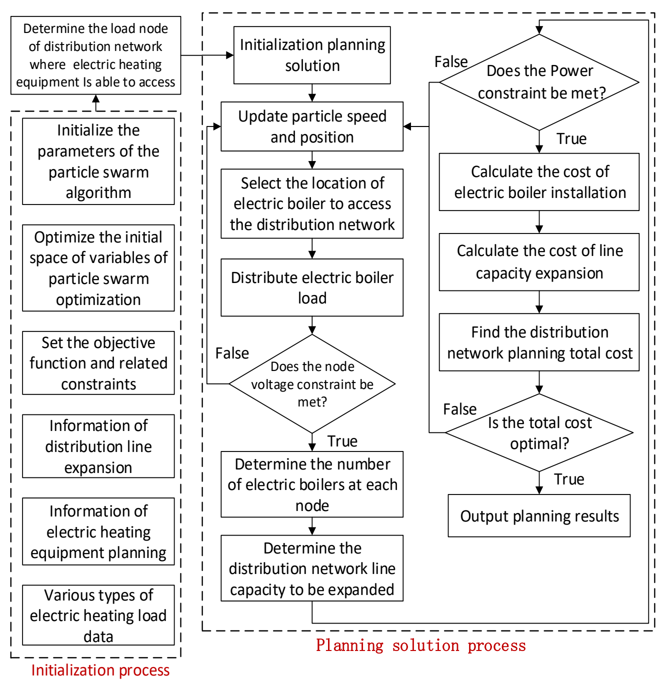

Fig.1 Distribution network planning flow chart for electric boilers access

Figure 1 shows the flow chart of the planning process. When the access of electric boilers is considered, distribution network planning can be mainly divided into the following steps.

1） Read initial information of distribution network, particle swarm algorithm parameters, electric heating equipment information, and various types of electric heating load data information, etc.

2） Solve the planning model, update the particle velocity and position, generate a planning scheme, select the location of electric boilers, and distribute the load to the nodes where electric boilers access into.

3） Determine whether the relevant constraints are met. If yes, determine the number of electric boilers access into each node and the expansion capacity of distribution network lines. Otherwise, return to step 2.

4） Solve the total cost of planning expansion and judge whether it is optimal. If yes, output the planning result. Otherwise return to step 2

3. CASE STUDY

3.1 Study setting

This chapter takes a certain area in southern China as a reference, selects the distribution network as shown in Figure 2 as the research object, and plans the distribution system considering the access of electric boilers.

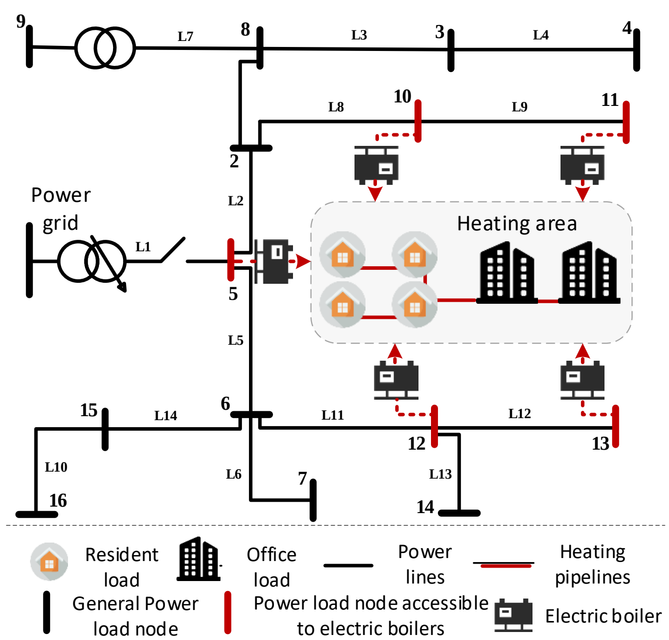

Fig.2 Schematic diagram of electric boiler equipment connecting to distribution system

The example consists of a 16-node distribution network and a heating area. The heating loads are connected to each other through a heat network, and accessed into distribution network through five adjacent nodes by electric boilers. The selected electric boiler parameters can be found in Ref.[6]. All heating loads will access into different nodes through planning, and the specific location is to be determined. Meanwhile, due to the different load distribution of each node, the number of installed electric boilers has yet to be determined.

This chapter selects the period of high heating demand in this region to study. Each type of thermal load characteristic curve is shown in Figure 3. During this period, when distribution network is in the original state, the maximum transmission power of each line is shown in Figure 4. The access of electric boilers and the planning of distribution network will be carried out on the basis of this power load. In this chapter, the various phases of the line are regarded as the whole. The unit expansion cost of each line varies with line type, length and phase number, the line construction and transformation cost parameters refer to Ref.[7].

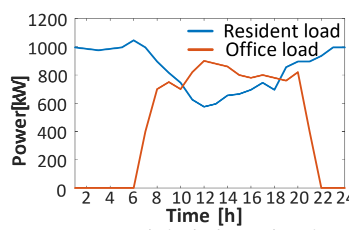

Fig.3 Typical daily heat load curve of heating load in winter

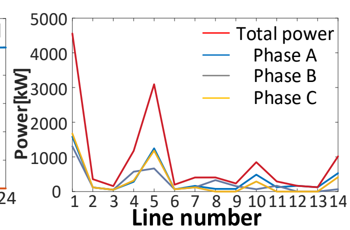

Fig.4 Maximum transmission power of line of original network

3.2 Simulation result analysis

According to the planning method proposed in this paper, the results of electric boilers planning and load distribution are shown in Table 1. The electric boilers are accessed to distribution network through the 5th, 12th, and 13th nodes. Under the condition of ensuring the normal operation of the system and the sufficient supply of heating load, the load distribution of each node is 26%, 42%, 32%, and the number of boilers is 5, 8 and 6, respectively, with a total investment of 666,000 yuan. Affected by the access of electric heating load, the maximum transmission power of lines L1, L5, L11 and L12 is greatly improved, which will exceed the transmission power limit. Other lines are affected by power flow, but the overall change is not obvious, such as Figure 5 shows. Therefore, individual lines need to be expanded and transformed. The investment details is shown in Table 2, with a total cost of 1376500 yuan.

Table.1 Result of load distribution and electric boiler planning

Electric boilers location	Load distribution	Maximum electric heating load /kW	Electric boilers number	Cost /yuan
5	26%	497.29	5	170000
12	42%	799.71	8	272000
13	32%	593.12	6	204000

This shows that the location selection of the access of electric heating load into distribution network is mainly related to the lines expansion and transform cost. Moreover, the distribution of electric heating load has a great impact on the investment cost of electric boilers. The network studied is small, the load is constant, the network loss is small, and the operating cost has little impact on the planning result, but it has an impact on the economic calculation of the planning result, which needs further study. Under the premise of meeting the system operating constraints, the load distribution results in this chapter have the following characteristics. The maximum electric heating load of each node is close to the rated output power of all electric boiler installed at the node, which maximize the utilization of equipment and prevent equipment investment redundancy.

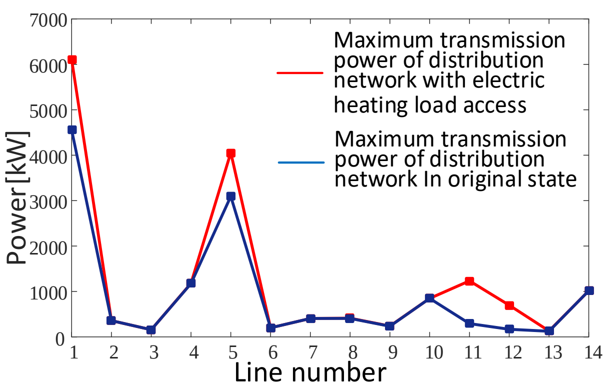

Fig.5 Comparison of transmission power of electric heating load access lines

Table.2 The cost of distribution line expansion investment

Line number	Capacity expansion/kW	cost /yuan
L1	1600	841200
L5	1200	213500
L11	1000	201100
L12	600	120700
Total cost		1376500

4. CONCLUSIONS

In this paper, electric boiler as a kind of electric heating equipment to access into distribution system is selected. With the lowest cost of the distribution network expansion lines and optimal investment cost of electric boilers, the distribution network planning model is established, and the particle swarm optimization algorithm is used to solve the problem. Finally, a distribution network planning scheme considering the electric boilers access is proposed. By planning the distribution network in a certain area of southern China with winter heating demand, the optimal planning result is finally obtained, which proves that the proposed plan is economical and feasible.

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