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Research on substation planning of distribution network with microgrid

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Abstract. In recent years, as a powerful supplement to large power grid, microgrid can meet the requirements of new energy consumption and has been applied in many practical projects. In the process of microgrid access to distribution network at present, there are many problems in microgrid and distribution network. Among these problems, the planning of the distribution network substation with microgrid is one of the most important problems to be solved urgently. In this paper, the distribution network substation planning model considering microgrid is established first, including the determination of substation number and the optimization of substation location, in which the principle of equal load moment minimization is selected to establish the substation location model. Secondly, the multiple source continuous method is used to solve the substation planning model. Finally, the feasibility and excellence of the planning model and planning method are verified by a typical distribution network planning example.

1. Introduction

In recent years, as a powerful supplement to large power grid, microgrid can meet the requirements of new energy consumption and has been applied in many practical projects. With more and more electric vehicles will be connected to the distribution network, its large capacity battery has the ability to store and output electric energy, which can be used as a buffer for new energy and distribution network, and improve the absorptive capacity of new energy. The distribution network, which plays a connecting role in the generation, transmission and distribution transformation, is in the period of drastic change of reform. Under the demand of the national supply-side reform, the distribution network planning is endowed with new connotation [1]. In the process of microgrid access to distribution network at present, there are many problems in microgrid and distribution network. Among these problems, distribution network planning with microgrid is one of the important problems to be solved urgently [2,3,4].

The planning of microgrid access to distribution network is studied at home and abroad, including microgrid model research, microgrid access capacity and location optimization, distribution network substation with microgrid, grid planning and etc. The literature [5,6] establishes the mathematical model of microgrid power generation and electricity consumption characteristics, and studies the planning method of the initial stage of microgrid access distribution network, which provides a theoretical guidance for the initial stage of microgrid access to the distribution network. In literature [7,8,9], the planning problems of distributed power generation in microgrid systems are explored, with the aim of



ensuring the continuity and reliability of important load power supply. The above research is focused on the microgrid level, and does not involve the planning problem of the microgrid access distribution network. In the face of planning problems, the algorithm is the main part to be considered, and the distribution network planning problem is actually the optimal solution problem in mathematics. At present, the research hot spots at home and abroad mainly focus on intelligent algorithms [10,11,12]. Among them, the quantum particle swarm optimization algorithm with more applications has a fast convergence speed, but its global search ability is weak [13,14,15]. This paper mainly focuses on the study of substation planning model of distribution network considering microgrid, and adopts multiple source continuous method to solve the substation planning model.

This paper firstly establishes a substation planning model for distribution network considering microgrid, including the determination of the number of substations and the optimization of substation location. The principle of minimum load moment is chosen to establish the substation location model. Secondly, the multiple source continuous method is used to solve the substation planning model. Finally, the feasibility and excellence of the planning model and planning method are verified by a typical distribution network planning example.

2. Substation planning model of distribution network with microgrid

The determination of substation planning address and construction capacity is an important part of urban power network planning nowadays, and its advantages and disadvantages directly affect the future development of the power network in this area. There are many factors to be considered in selecting the geographical location of a new substation: (1) Close to the user center to reduce transmission losses and cable costs; (2) Convenience of new substation outlet; (3) Environmental factors and policy factors around the substation; (4) The impact of distributed power, microgrid, and electric vehicle charging facilities on the distribution network.

2.1. Determination of the number of substations

The number of substations in the planning area should be determined first before the location selection of the substation. Among them, the capacity selection of a single transformer can be combined with the common transformer capacity to adopt a trial method to ensure the distribution of the substation and the reasonable setting of the transformer in the station at last. The number of substations is not only related to load demand, but also to the capacity of microgrid. In order to ensure that the substation meets the demand of the load in the planned area and the load in the microgrid under any conditions, the formula (1) is used to determine the number m of substations.

$$m = \frac{k\lambda(\sum_{i \in \Phi_L} P_{L,i} + \sum_{j \in \Phi_{mg}} P_{mg,j})}{nS_n} \quad (1)$$

In the formula: k — Capacity load ratio (capacity/load); λ — Load node simultaneous rate; $P_{L,i}$ — Load power of load node i ; $P_{mg,j}$ — The absorption power of the microgrid node j ; Φ_L — The collection of loads in the planning area other than the microgrid; Φ_{mg} — Planning area microgrid load collection; S_n — Single transformer capacity; n — The number of transformers used in each substation.

2.2. Substation location optimization

The common principles for substation location selection are: the equal load principle applies to situations where the load in the planning area is relatively close and the power consumption distribution is relatively uniform, such as residential areas and university towns; the principle of minimum initial investment applies to planning areas where more cables are used, which is due to the fact that the cost of copper cored cables is much higher than that of overhead cables; the principle of minimum network operating cost applies to the situation where the maximum number of calculated load hours at each load

point varies greatly; the principle of minimum load moment is most suitable for conventional distribution network.

The load considered in this paper is set up for the whole year operation, the cable used is consistent and the load size is different, therefore, the most common principle of equal load moments is selected to establish the substation location model:

$$\min C = C_1 + C_2 \quad s.t. \begin{cases} \sum_{i=1}^m \delta_{ij} = 1 (j \in \Phi_L) \\ \sum_{i=1}^m \delta_{ik} = 1 (k \in \Phi_{mg}) \end{cases} \quad (2)$$

$$C_1 = \sum_{i=1}^m \sum_{j \in \Phi_L} \lambda_1 \delta_{ij} P_j \sqrt{(x_i - u_j)^2 + (y_i - v_j)^2} \quad (3)$$

$$C_2 = \sum_{i=1}^m \sum_{k \in \Phi_{mg}} \lambda_2 \delta_{ik} P_k \sqrt{(x_i - u_k)^2 + (y_i - v_k)^2} \quad (4)$$

In the formula: m — The number of substations; Φ_L — The set of load points except MG in the planning area; Φ_{mg} — The collection of MG nodes in the planning area; λ_1, λ_2 — The load is the simultaneous rate of the microgrid load; δ_{ij}, δ_{ik} — 0-1 variables, $\delta = 1$ means that the substation i supplies power to node j/k , $\delta = 0$ means that the substation i does not supply power to node j/k ; P_j — Load point power; P_k — Microgrid node load power; x_i — Substation i horizontal coordinates; y_i — Substation i longitudinal coordinates; u_j — Load j horizontal coordinates; v_j — Load j longitudinal coordinates; u_k — Load k horizontal coordinates; v_k — Load k longitudinal coordinates

3. Solution method of substation planning for distribution network with microgrid

For the location optimization problem of a single substation, it is essentially a load weighted distance minimization problem. The necessary conditions can be obtained from the calculus theory as

$\partial C / \partial x = \partial C / \partial y = 0$, order $d_j = \sqrt{(x - u_j)^2 + (y - v_j)^2}$, then:

$$\begin{cases} x = (\sum_{j \in \Phi} P_j u_j / d_j) / \sum_{j \in \Phi} P_j / d_j \\ y = (\sum_{j \in \Phi} P_j v_j / d_j) / \sum_{j \in \Phi} P_j / d_j \end{cases} \quad (5)$$

Among them, Φ is the set of all the load nodes, (x, y) can be solved by numerical iteration: the initial value is taken as the average of the coordinates of each load point (x_0, y_0) ; the initial value substituted into d_j , d_j is substituted into the above formula to obtain (x_1, y_1) ; the iteration is stopped until the difference between (x_{k+1}, y_{k+1}) and (x_k, y_k) is within the set accuracy range. Under the condition of satisfying the requirement of engineering planning, selecting higher precision can effectively reduce the processing time of the program and improve the planning efficiency. This method is called single source continuous location selection method.

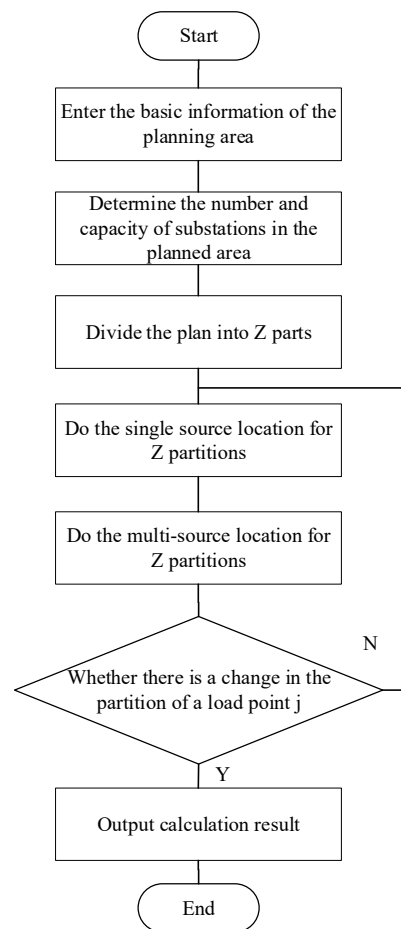


Figure 1. The flow chart of substation site optimization calculation program

For multiple substations, load points are added and iterated on the basis of single source continuous location selection method, that is, multiple source continuous location selection method. The specific flow is as follows:

The n load points are roughly divided into Z areas, that is, the whole load nodes in the planning area are divided into Z subsets. The principle of division can be based on the principle of average distribution, or according to actual conditions (such as geographical relationship, national policy and etc.).

The single source continuous location selection is used for Z areas, and the substation's sites (x_i, y_i) is obtained. Among them, $i=1, 2, Z$.

Calculate the load moment $P_j d_{ij}$ of each load point to each substation, and select the minimum load moment of load point j to substation i as $\min(P_j d_{ij})(i=1, 2, \dots, Z)$ to obtain a new grouping (ie, re-divide n load points into Z parts).

If the new grouping is inconsistent with the previous grouping, the new grouping jumps to step (2) and iterates again. If the nodes belong to the same set, the iteration is completed and the planning result is output. The planning process is shown in Fig. 1.

It needs to be noted that the initial division of the power supply range is a fuzzy work. It is difficult to divide the power supply range of each substation after determining the number of substations. The appropriate initial division range can improve the efficiency of optimization. Generally speaking, the primary power supply area should be to balance the power supply load of each substation. For each substation, the first thing is to distribute the load points supplied by the substation, and the random distribution for the uncertain load points. Then, the optimization of multiple source continuous location verification is carried out. A more feasible method is to divide the initial power supply area into a circular

area with Z-1 lines extending outwards from the center of the circle. An angle of $360 / (Z-1)^\circ$ is obtained for each sector area composed of two lines and the boundary of the planning area. The load points are searched from outside to inside in the sector region. When the total transformer capacity of a single substation is reached, the search stops and forms a Z-1 initial power supply area. If the load point is still not searched, the power supply area of the Z substation is formed, and they are located around the center of the circle. In addition, national policies and geopolitical relationships must be taken into consideration when initializing the initial supply area.

4. Calculation example simulation

4.1. Calculation example description

The area of distribution network to be planned of the calculation example in this paper is shown in Fig. 2. The planned area is 16 square kilometers. The area consists of 32 ordinary load nodes and 3 microgrid nodes, and the corresponding numbers are given to them. The positions of microgrid nodes and load nodes are expressed as plane coordinate axes. The basic data of active, reactive and coordinate loads of ordinary loads are shown in Table 1, and the load data in microgrid are shown in Table 2.

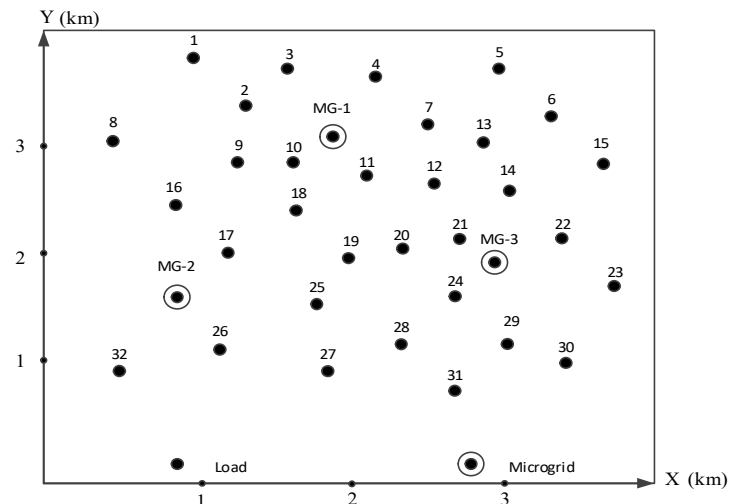


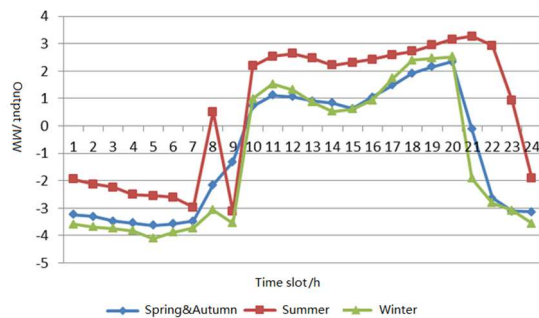
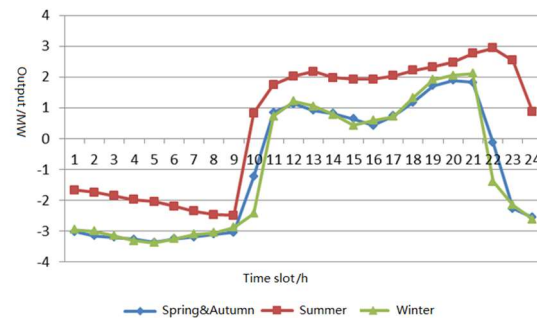
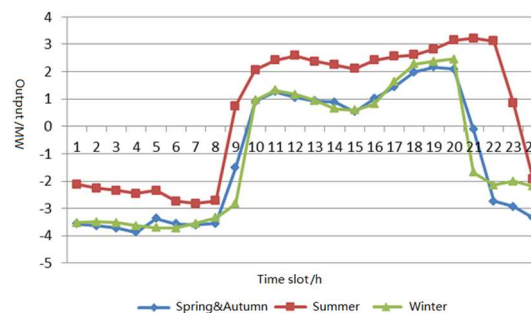
Figure 2. A planned distribution network area

Table 1. Normal load data

Node number	P (MW)	Q (MVar)	Coordinate (km)	Node number	P (MW)	Q (MVar)	Coordinate (km)
1	1.56	0.68	(100.91,103.78)	17	2.81	1.24	(101.21,102.00)
2	2.93	1.47	(101.45,103.48)	18	2.41	1.18	(101.76,102.43)
3	3.53	1.64	(101.71,103.64)	19	2.48	1.29	(102.03,101.92)
4	4.06	2.05	(102.32,103.62)	20	3.12	1.21	(102.32,102.04)
5	2.44	1.67	(102.97,103.64)	21	2.88	1.43	(102.75,102.07)
6	3.62	1.88	(103.39,103.31)	22	3.73	1.66	(103.34,102.08)
7	3.25	1.92	(102.59,103.17)	23	2.46	1.14	(103.80,101.72)
8	2.65	1.25	(100.41,102.90)	24	2.97	1.42	(102.70,101.70)
9	4.08	1.91	(101.38,102.82)	25	3.38	1.44	(101.81,101.63)
10	3.59	1.69	(101.64,102.83)	26	3.33	1.34	(101.11,101.10)
11	3.15	1.57	(102.09,102.78)	27	3.12	1.56	(101.83,100.89)
12	2.27	1.51	(102.65,102.76)	28	3.76	1.71	(102.30,101.12)
13	2.85	1.47	(102.92,103.06)	29	3.54	1.81	(103.04,101.13)
14	3.41	1.66	(103.04,102.62)	30	2.81	1.32	(103.46,100.98)
15	3.69	1.81	(103.75,102.82)	31	4.17	2.05	(102.68,100.72)
16	2.74	1.35	(100.82,102.48)	32	2.76	1.37	(100.47,100.86)

Table 2. Microgrid load data

Microgrid number	Active load (MW)	Reactive load (MVar)	X-axis (km)	Y-axis (km)	Important active load (MW)	Important reactive load (MVar)
MG-1	5.32	1.69	101.90	103.06	2.23	0.42
MG-2	5.44	1.70	100.74	101.72	1.78	0.80
MG-3	6.65	2.18	102.96	101.90	2.22	1.56

**Figure 3.** MG-1 output curve**Figure 4.** MG-2 output curve**Figure 5.** MG-3 output curve

The voltage grade of the high voltage side is 35 kV, and the voltage grade of the low voltage side is 10 kV. Node 1-32 represents 32 normal load nodes, and node MG-1-MG-3 represents 3 microgrid nodes. Among them the important load in microgrid refers to the power supply in which the microgrid enters the isolated island to ensure the important load when the microgrid node fails. As a result, this part is not included in the blackout loss. The total load of distribution network is 99.55 MW, the total load of microgrid is 16.81 MW, and the permeability of microgrid is 16.89%, it can be seen that the proportion of microgrid in this planning example cannot be ignored, so the next calculation can be carried out.

The power output of microgrid nodes is affected by seasons and periods. Combined with the changes of temperature, light and wind speed, one year can be divided into three seasons: spring and autumn, summer and winter. A day is divided into 5: 00~8: 00, 8: 00~12: 00, 12: 00~16: 00, 16: 00~19: 00, 19: 00~5: 00 total 5 time intervals, using Monte Carlo simulation, the daily output curve of microgrid can be obtained. The 24-hour output of the microgrid MG-1~MG-3 is shown in Fig. 3~Fig. 5.

4.2. Substation planning results

According to the calculation example, the voltage grade of the distribution network in the planning area is 35 kV, the transformer of 35/10 kV is used in the substation, each substation has three transformers, and the transformer capacity of each transformer is 25 MVA. According to the recommended value of the "Planning and Design guidelines for Urban Power Grid" issued by the Ministry of Energy and the

Ministry of Construction in 1993, the load capacity ratio of 220 kV substations should be controlled between 1.6-1.9. The capacity load ratio of 35~110 kV substation is controlled between 1.8-2.1, so the capacity load ratio of the calculation example is 1.9.

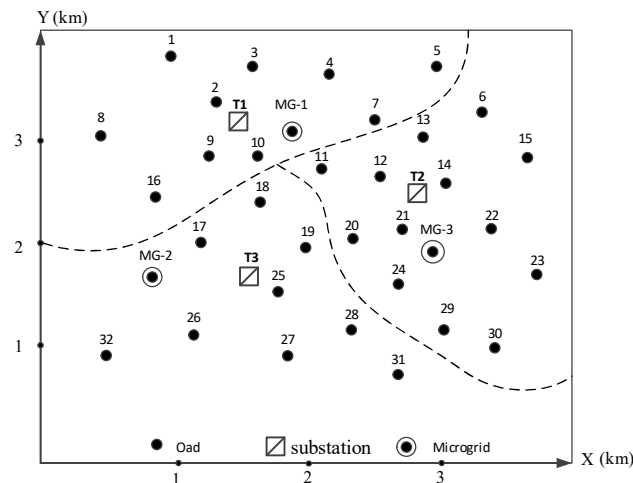


Figure 6. Planning results of a substation in a distribution network area

loads 1-5, 7-10, 16, and MG-1, and the substation T2 supplies power to loads 6, 11-15, 20-24, 29-30 and MG-3. The substation T3 supplies power to loads 17-19, 25-28, 31-32, and MG-2. The results of the substation location selection as well as capacity and the substation corresponding power supply objects are shown in Fig. 6 and Table 3.

Table 3. Substation planning results

Substation number	Capacity configuration (MVA)	Site coordinates(km)	Power supply object
T1	3×25	(101.44,103.21)	1-5,7-10,16, MG-1
T2	3×25	(102.83,102.38)	6,11-15,20-24,29-30, MG-3
T3	3×25	(101.51,101.71)	17-19,25-28,31-32, MG-2

5. Conclusion

This paper firstly establishes a substation planning model for distribution network considering microgrid, including the determination of the number of substations and the optimization of substation location. Among them the principle of minimum load moment is chosen to establish the substation location model. Secondly, the multiple source continuous method is used to solve the substation planning model. Finally, the feasibility and excellence of the planning model and planning method are verified by a typical distribution network planning example.

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