A Grid-Based Method for Distribution Network Planning in Urban Areas

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Abstract. This paper proposes a grid-based method for distribution network planning. Firstly, based on the analysis of the economic and social development targets and distribution network status in the region, the central area is meshed and classified according to the relevant principles and objectives of distribution network planning as well as the nature and development depth of the land. Load forecasting based on grid layout is carried out to determine the saturated load corresponding to the current planning of the area. Finally, according to the current grid, load forecasting results and planning targets, the target grid and transition grid of the planning grid are determined. The above method is applied to the grid planning of a distribution network in Hangzhou China. The planning index is greatly improved, the target network frame of the distribution network is strong, the power supply range is clear, and the power supply reliability is high, which verifies the effectiveness of the method.

1. Introduction

Distribution network is an important part of the power grid and an important infrastructure in the area. To ensure the distribution network to provide high-quality power supply for the economic and social development of the region and the improvement of people's living standard is the main problem facing the distribution network planning. Currently, in the development process of distribution network, due to the lack of effective combination of distribution network planning and urban planning, insufficient planning depth, decentralization of the main distribution network projects and uncertain time series of construction, the objective facts such as the difficulty of the construction of the distribution network and the stability of the path resources have seriously affected the development and construction of the distribution network. In order to reverse this situation, it is necessary to find a new method of distribution network planning, so as to form a binding regional power grid planning method to realize the effective leading role of the regional economic development.

There are many existing distribution network planning methods. With the development of mathematics, operations research and computer science and technology, more new methods and new theories have emerged, and they are gradually applied to the distribution network planning. Genetic algorithm [1] is a new optimization method, which searches and optimizes according to the principle of survival of the fittest. It can consider various objective functions and constraints and is suitable especially for the optimization of integer variables. The effects of various genetic algorithms applied to distribution network planning are compared in [2] and the genetic algorithm is applied to urban medium voltage distribution network planning in [3]. However, when the fitness function is established in the above literature, many optimization objectives are unified into the form of economic dimension and

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weighted together, and the unity of dimension and the selection of weights are not convincing. The establishment of multi-objective programming model and the application of advanced multi-objective optimization algorithm are the trend of distribution network planning [4]-[5]

In this paper, a grid-based distribution network planning method is proposed. On the basis of urban control planning, this method divides the urban central regional planning and construction land into a number of grids, and classifies the grid according to the nature of land use and the depth of development, determines the load model index based on the measured data so as to ensure the accuracy of load forecasting. Finally, according to the current grid, load forecasting results and planning targets, the target grid and transition grid of the planning grid are determined. The above method is applied to the grid planning of a distribution network in Hangzhou China. The planning index is greatly improved, the target network frame of the distribution network is strong, the power supply range is clear, and the power supply reliability is high, which verifies the effectiveness of the method.

2. Grid-based distribution network planning method

2.1. Basic concept and planning method process

Using the electricity demand as the guidance, according to certain principles, the distribution network is divided into relatively independent power supply areas, such as the large area, the District, the block and so on, considering the administrative division, the economic development situation of the region, the current development depth and the function orientation. Grid-based distribution network planning is based on these "grid" as the basic unit for planning and management, to achieve "one grid one plan".

In the grid-based distribution network planning, basic data analysis is the basis for carrying out grid-based distribution network planning. The basic data are divided into two main categories: one is the basic data of the current distribution network, including the data related to the distribution equipment (such as the length of the distribution line, the number of transformer, the load rate of the line and the transformer) and the related data of the grid structure of the distribution network (such as the ring rate of the cable network, the connection rate of overhead lines, the number of overhead lines, the N-1 pass rate of the line); the other is the overall planning of regional development and the detailed planning data of control. The load forecast is based on the data of the land nature and building areas in the regional general regulations or control rules. There are two key technologies of grid distribution network planning: one is grid partition, the other is grid-based spatial load forecasting, as described below:

2.2. Grid partition principle

The purpose of grid division is to strengthen the self-healing management ability in the distribution grid, so as to simplify the management difficulty from the distribution network planning and design to the dispatching operation, and improve the management efficiency as well. The division should be centered on the characteristics of "medium voltage grid independence" and "self-healing", and consider the convenience of power supply company management and data collection statistics.

2.2.1. The principle of large area division.

- Within the planning area, large areas are divided into townships, functional areas and large parks.
- According to the conditions of regional economic development, current development depth and function orientation, the large area is cut into small areas, in principle, the large area should not exceed 100 square kilometers.

2.2.2. The principle of small area division

- In the large area, the district is divided by the village, street and small park based on the general rules or control rules. In principle, the area should not exceed 15 square kilometers.
- Merge residential areas moderately according to the location of the areas, the depth of development, and the power grid conditions. In principle, one residential area should contain or have plans for a 110 kV or above substation.

2.3. Spatial layout load forecasting

The usual load forecasting methods are divided into two categories: historical electricity consumption and electricity load forecasting and direct forecasting of electricity load.

Based on the grid division, this paper forecasts the load of spatial layout. According to the collected detailed control plan, the spatial load forecasting is carried out for the plots with different land use properties and development depth, and the spatial load distribution of each grid is clearly defined.

2.3.1 Long term load forecasting

- Load classification according to the regulatory area of the urban central area, and divide the land according to the nature of land use.
- To investigate the load density with the same type which has been fully developed, and take these load density indicator as the main basis for setting the load density index of the planning area. At the same time, some classifications with obvious regional characteristics, such as industry and residence, should be set up in combination with local actual conditions.
- According to the selection results of load indices in different industries, the load distribution is predicted according to the plot ratio of planned land, and the total load and classified load are counted.

2.3.2 Short term load forecasting. Considering the construction status, planning situation and the development depth of each block, for the built-up area, the current load level and the long term load calculation results are compared to form the load forecasting year by year. In the new area, based on the user development time series and the long term load calculation results, selects the different saturation year by year, selects the larger saturation for the area developed first, and selects the smaller saturation for the later plots, and forms the load forecast year by year. The load forecasting of semi-built area can be carried out year by year respectively according to the new areas and the built-up areas

3. Planning objectives and principles

3.1. Planning objectives

Distribution network planning is required to meet the requirements of power supply reliability and voltage qualification rate. Its overall goal is shown in Table 1**.**

Table 1. Planning target of power supply reliability and voltage qualification rate.

Power Supply Area	Power Supply Reliability	Voltage Qualification Rate
A	Average annual blackout time is not more than 1 hours	99.9%
B	Average annual blackout time is not more than 2 hours	99.8%
C	Average annual blackout time is not more than 3 hours	99.6%
D	Average annual blackout time is not more than 4 hours	99.5%
E	Meet the basic demand for electricity consumption	

In order to further improve the power supply level of the distribution network and meet the high reliability requirements for the economic and social development of the planning area, according to the overall goal of the planning, the focus of the work is to improve the power supply capacity, optimize the structure of the power grid, reduce the failure rate of the power grid equipment, and improve the automation level of the distribution network. The specific work objectives are as follow.

3.1.1. Improve power supply capacity. The distribution network should have enough relatively stable and reliable power supply to meet the increasing power demand. The distribution network of each division has a general clear power supply range, no overlapping, and the power supply range of the zoning distribution network will be adjusted with the increase of the new high voltage substation and load.

3.1.2. network frame. All the substations have stopped one main transformer without losing load. All the 10 kV lines are connected. The connection mode is mainly composed of double loop network, single ring network and double shot are subsidiary, the contact rate is 100%, and at least 80% are inter station liaison. The power supply area is reasonably divided, and the power supply radius is less than 3 km.

3.1.3. Equipment level. The main line section of the main line should be selected according to the long-term plan, so as to ensure that there is no need to replace the wire for quite a long time. Combined with the construction of the trench, the original overhead line is transformed into the ground.

3.1.4. Distribution automation. The coverage rate of distribution automation is 100%, switch stations, ring network cabinets, cable branch boxes and column switches are three remote functions, and the optical fiber communication coverage rate is 100%.

3.1.5. Specification of user load access. According to the actual installed capacity of new users, select the corresponding voltage level, reasonably regulate the power supply mode of users, and strictly control the number of dedicated lines. When the user access capacity is 6000 kVA and above, it can be supplied by the special line of the substation. When the user access capacity is 3000 to 6000 kVA, the power supply can be supplied by the special line of the 10 kV switch station. When the user's access capacity is less than 3000 kVA, the public grid is connected by the ring network unit.

3.2. Planning Principles

3.2.1. Division of power supply area according to land plot. Division of power supply area according to land plot is easy to set up the target grid differently, and the grid structure adopted by different power supply areas is different. A and D two types of power supply areas are taken as an example: in A-type power supply area, the 110 kV power grid adopts single and double chain structure, 10 kV distribution network should adopt inter station contact, double ring cable network connection; in D-type power supply area, the 110 kV power grid uses single chain and double radiation structure, 10 kV distribution network should base on the substation distribution, contact between stations, and areas whose condition are not available can also use inter station contact, single ring cable network

3.2.2. Division of power supply area according to development depth. Division of power supply area according to development depth of the land divides the land into new built, built and half built in time attributes, so as to facilitate the combing of new and reconstruction projects.

4. Case analysis

The above method is applied to the grid-based planning of a certain district in Hangzhou. The details are as follows.

4.1. Grid division of planning area

This area belongs to the B type power supply area, according to the principle of grid division, the area is divided into 6 grids, as shown in figure. 1.

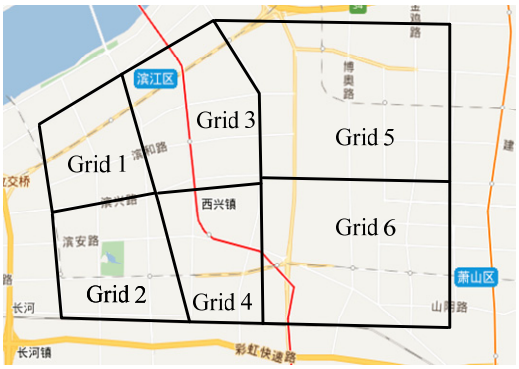

Figure 1. Grid-based planning of a certain district in Hangzhou.

4.2. Load forecasting

Through analyzing and summarizing the current situation of distribution network in this area, the main indicators of distribution network are shown in table 2. It can be seen from the above table that there is a big gap between this area and first class distribution network in the aspects of contact rate, N-1 pass rate, the average power supply radius, the insulation rate of medium voltage line and the reliability of power supply.

Using load density index method, the results of target annual load forecasting in this area are shown in table 3. According to the trend extrapolation method, the load forecast structure of the area in 2022 is shown in table 4.

Table 2. Main index of distribution network.

Project	Index	Year 2016	First Class Distribution Network Index
Strengthen the construction of net frame	Connection rate of medium voltage line/%	86	100
	N-1 pass rate of medium voltage line/%	86	100
	Average power supply radius of medium voltage line/km	4.22	2
	Average segment number of medium voltage line/segment	3.85	3.8
	10kV insulation rate of overhead lines/%	67.2	98
	Cabling rate of medium voltage line/%	19．3	70
Upgrade the equipment level	Old line ratio(overhead line before 2000)/%	0	10
	Old switches (column switches before 2000)/%	0	0
Improve operation level	Average capacity/（kVA·household-1）	2.5	5.4
	Reliability of power supply（RS-3）	99.89	99.97
	Heavy and overload line ratio/%	0	<2

Table 3. Target annual load forecasting result in this area.

Area	Target Annual Total Load/MW
Grid 1	10.25
Grid 2	13.47
Grid 3	8.56
Grid 4	12.21
Grid 5	19.08
Grid 6	13.25
The integration of the area (considering 0.8 simultaneous rate)	61.45

Table 4. Load forecast results in year 2022

Area	Target Annual Total Load/MW
Grid 1	11.08
Grid 2	14.47
Grid 3	9.34
Grid 4	13.35
Grid 5	20.32
Grid 6	14.28
The integration of the area (considering 0.8 simultaneous rate)	66.27

Table 5. Recommendation table for target grid structure of medium voltage distribution network

Type of power supply area	Recommended power grid structure
Type B	Overhead network: multi segment moderate contact Cable network: double and single loop

Table 6. Situation of target grid / transition grid in medium voltage distribution network

Land	Double loop network	Single loop network	Medium voltage line
Grid 1	1/0	0/1	3/2
Grid 2	0/0	1/0	5/1
Grid 3	0/1	1/1	3/3
Grid 4	1/0	0/1	6/1
Grid 5	1/0	1/1	4/5
Grid 6	1/1	1/0	5/2
Total	4/2	4/4	26/14

Table 7. Comparison of main planning indexes in distribution network

Project	Index	Year 2016	Target year	First Class Distribution Network Index
Strengthen the construction of net frame	Connection rate of medium voltage line/%	86	100	100
	N-1 pass rate of medium voltage line/%	86	100	100
	Average power supply radius of medium voltage line/km	4.22	2.5	2
	Average segment number of medium voltage line/segment	3.85	4	3.8
	10kV insulation rate of overhead lines/%	67.2	99	98
	Cabling rate of medium voltage line/%	19．3	100	70
Upgrade the equipment level	Old line ratio(overhead line before 2000)/%	0	0	10
	Old switches (column switches before 2000)/%	0	0	0
Improve operation level	Average capacity/（kVA·household-1）	2.5	5.6	5.4
	Reliability of power supply（RS-3）	99.89	99.99	99.97
	Heavy and overload line ratio/%	0	0	<2

4.3. Evaluation of Planning Effect

The main indicators comparison of the medium voltage distribution network in this area is shown in Table 7. Through planning, the power supply range of the medium voltage line in the distribution network is clear, the structure of the distribution network is strong, the power supply reliability is high, the main indexes all reach the level of the first class distribution network, and the validity of the grid-based planning method is verified.

5. Conclusion

This paper has proposed a grid-based method for distribution network planning. Based on the analysis of the economic and social development targets and distribution network status in the region, the central area has divided and classified according to the relevant principles and objectives of distribution network planning as well as the nature and development depth of the land. Load forecasting based on grid layout has carried out to determine the saturated load corresponding to the current planning of the area. According to the current grid, load forecasting results and planning targets, the target grid and transition grid of the planning grid have been determined. The above method has been applied to the grid planning of a distribution network in Hangzhou China. The planning index has been greatly improved, which has verified the effectiveness of the method.

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