Construction and Application of Distribution Network Grid Planning System

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Abstract. For the problems of complex structure, unclear network and fuzzy boundary of power distribution network, grid planning is carried out in the power distribution network according to the idea of "Divide it into small grids, and manage separately". Firstly, according to the modularization idea and the rule of land use and time development, a three-level grid planning system of power supply functional area, power supply mesh and power supply unit is constructed. Secondly, in the grid planning system, the spatial load forecasting method is given at three levels from bottom to top: at the level of power supply unit, the recommended value of saturated load density index is given, and the calculation method of the simultaneity rate in power supply unit is put forward. At the level of power supply mesh, based on the land nature of each power supply unit, the simultaneity rate of different land is given. Finally, based on the actual planning case of a certain region, the effectiveness of the grid planning method is verified.

1. Introduction

Distribution network planning is a key link in the construction and transformation of power distribution network. It plays an important role in optimizing the frame structure of power distribution network and improving the power supply reliability of distribution network\textsuperscript{[1-2]}. However, as the distribution network is at the end of the power system, the project construction and transformation are mainly according to the superior’s arrangement\textsuperscript{[3]}. Meanwhile, in the early power distribution network, the middle voltage output line adopted the "radiation type" to meet the surrounding load demand, leading some problems in substations such as unclear boundary of supply area, unbalanced distribution of capacity to load ratio, and large difference in load rate of main transformer\textsuperscript{[4-5]}. If we want to build a strong and reliable modern power distribution network, we must change the way of thinking and explore a scientific and effective way to develop grid planning.

Combining with the regional development situation, this paper built a grid planning system which covered 3 levels: power supply functional area, power supply mesh and power supply unit. At the same time, the key solutions such as spatial load forecasting and simultaneity rate selection in the process of grid planning were put forward. Finally, the results were applied to the actual construction and reconstruction of distribution network in a city core area, and good planning and reconstruction results were obtained.
2. Construction of grid planning system

"Grid" planning includes three levels: "power supply functional area", "power supply mesh" and "power supply unit". The main idea is to divide the power supply grid and power supply unit in the corresponding functional area under the guidance of the long-term target grid under the saturated load state of the planned functional area. According to the development of power supply grid and unit load, gradually build the structure specification, flexibility, reliability and adaptability. The grid structure with strong adaptability reflects the influence of land use function attribute on power supply reliability, capacity and other power demand, and realizes the lean planning of distribution network. The schematic diagram of "grid" planning system is shown in Figure 1.

![Schematic diagram of distribution network "grid" planning system](image)

Figure 1. Schematic diagram of distribution network "grid" planning system

- **Power supply functional area**: Based on the division of distribution network power supply area, combined with the functional positioning of urban regional development, it is divided into several relatively independent functional areas with similar leading functional attributes.

- **Power supply mesh**: on the basis of functional area division, according to the principle of clear grid structure and relatively independent power supply of 10kV long-term target, several relatively independent power supply areas with clear relationship between load transfer and mutual supply are divided with consideration of distribution network construction, operation and maintenance, emergency repair service and management authority.

- **Power supply unit**: on the basis of power grid division, according to the principle of similar power supply reliability requirements, similar development degree and appropriate scale, reasonably merge the 10kV line wiring groups adjacent to corridors and basically consistent structure, forming the wiring group combination that can basically independently undertake normal power supply tasks and load transfer.

3. Spatial load forecasting

Saturated load forecasting results are the basis of "grid" planning. First, load is classified (such as residential, commercial, municipal, medical, etc.), and then cells are generated in the area to be predicted according to the boundary of functional area. Combined with land use information, the load value of each cell is calculated, and the required spatial load forecasting results are obtained by superposition according to the level of power supply unit, power supply grid and functional area Fruit.

3.1. Prediction process

3.1.1. Plot load forecast ($P_3$). (1) The load density index method of unit building area is applicable to
the detailed control planning. The formula for calculating the maximum load of the plot based on the building area of the plot is as follows:

\[ P_3 = M \times D \times W \]  

(1)

Where \( m \) is the building area, \( D \) is the load density per unit building area; \( W \) is the demand coefficient.

It is necessary to consider the demand factor of each type of load when converting the building electrical load forecast to the plot load.

(2) The unit construction land load density index method is applicable to the existing detailed control planning. The planning land is known, but the building area is not clear. The calculation formula for the maximum load of the plot based on the construction land area of the planning plot is:

\[ P = S \times V \]  

(2)

Where \( S \) is the floor area, \( V \) is the load density of unit construction land.

3.1.2. Power supply unit level load forecast (\( P_2, 10kV \) wiring group level). The power supply unit load forecast is the plot load forecast considering the accumulation of simultaneous rate, and the calculation formula is as follows:

\[ P_2 = \sum_{i=1}^{m} P_{3i}k_2 \]  

(3)

Where \( m \) is the number of plots, \( P_{3i} \) is the load forecast value of the \( i \)th plot; \( k_2 \) is the coefficient of simultaneous rate between plots.

3.1.3. Power supply mesh level load forecasting (\( P_1, 10kV \) target grid layer). The load forecast of power supply grid refers to the load forecast of power supply unit considering the accumulation of simultaneous rate. The calculation formula is as follows:

\[ P_1 = \sum_{i=1}^{m} P_{2i}k_1 \]  

(4)

Where \( m \) is the number of power supply units, \( P_{2i} \) is the load forecast value of the \( i \)th power supply unit; \( k_1 \) is the simultaneous rate coefficient between power supply units.

3.1.4. Load forecast at functional area level (\( P_0, \) upper substation level). The function area load forecast is the load forecast of power supply grid considering the accumulation of simultaneous rate, and the calculation formula is as follows:

\[ P_0 = \sum_{i=1}^{m} P_{1i}k_0 \]  

(5)

Where \( m \) is the number of power supply grid, \( P_{1i} \) is the load forecast value of the \( i \)th power supply grid, \( k_0 \) is the simultaneous rate coefficient between power supply units.

3.2. Selection of spatial load index

3.2.1. Load density index of planning unit building area. The planning unit building area load can refer to the local actual situation and planning energy supply requirements, and be determined according to local conditions. In order to better carry out the saturated load prediction of different power supply areas, the planning unit building area load indexes of category A+, A and B areas are as table 1.
Table 1. Load index of unit building area

| Building category                  | Load index of unit building area(W/m²) |
|-----------------------------------|---------------------------------------|
| Type of power supply area         |                                       |
| Residential construction          | A+ 40~60  A  35~50  B  30~45            |
| Public buildings                  |                                       |
| Industrial Building               |                                       |
| Warehouse logistics building      |                                       |
| Municipal facilities building     |                                       |

3.2.2. Selection of demand coefficient. Different types of users have different demand coefficients. The demand coefficients of various users provided in this paper are shown in the table 2.

Table 2. Summary of various user demand factors

| Classification                        | Demand coefficient |
|---------------------------------------|--------------------|
| Administrative and office users       | 0.5-0.6            |
| Commercial, financial and service users | 0.5-0.6           |
| Communal facilities                   |                    |
| Sports users                          | 0.47               |
| Medical users                         | 0.5-0.6            |
| Science and education users           | 0.3-0.5            |
| Class I of residential users          | 0.22-0.25          |
| Live                                  |                    |
| Class II residential users            | 0.2-0.23           |
| Demolition and resettlement users     | 0.19-0.22          |
| Class I industrial users              | 0.4-0.5            |
| Industry                              |                    |
| Class II industrial users             | 0.4-0.6            |
| Class III industrial users            | 0.5-0.6            |

3.2.3. Load density index of construction land of planning unit. Refer to the table below for the load density of construction land in the code for urban power planning, and each region can be determined according to the local conditions.

The unit construction land load indicators of different types of power supply areas are as table 3.

Table 3. Load index of power supply area planning unit building area

| Category of urban construction land                                      | Unit construction land load index(kW/hm²) |
|-------------------------------------------------------------------------|------------------------------------------|
| Type of power supply area                                               |                                         |
| Residential land (R)                                                    | A+ 200~350  A  150~300  B  100~250       |
| Land for commercial service facilities (B)                              | 600~1000  500~900  400~800               |
| Land for public management and public service facilities (A)            | 400~700  350~600  300~500                 |
| Industrial land (M)                                                    | 200~500  300~700  300~800                 |
| Land for logistics and storage (W)                                      | 25~35  25~40  20~30                       |
| Land for road and traffic facilities (S)                                 | 20~30  15~25  15~25                       |
| Land for utilities (U)                                                  | 170~250  160~230  150~200                 |
| Green land and square land (G)                                          | 15~30  15~25  10~20                      |
3.2.4. Selection of simultaneity rate. Simultaneous rate selection is the key and difficult point of spatial load forecasting. Based on the division system of functional area, power supply mesh and power supply unit in the "grid" planning system, the power consumption property of each plot is single, and the method based on load curve superposition is selected to obtain relatively accurate simultaneous rate. By selecting two different typical load curves after normalization for superposition, we can get two kinds of simultaneous rate of no load characteristics.

\[ \lambda_{1+2} = \frac{P_{1+2}}{p_1 + p_2} \]  

(6)

Where \( \lambda_{1+2} \) is the simultaneous rate between 1 and 2 loads, \( P_{1+2} \) is the maximum value of load curve after superposition of 1 and 2; \( p_1 \) and \( p_2 \) is the maximum value of 1 and 2 load curves respectively. According to the load characteristic curves of different typical users, the simultaneous rate of two different load characteristics can be obtained as shown in the table 4.

| Proportion | Industry | Resident | Simultaneity rate | Industry | Resident | Simultaneity rate |
|------------|----------|----------|-------------------|----------|----------|-------------------|
| 50%        | 50%      | 0.826    | 50%               | 50%      | 0.8976   |
| 33%        | 67%      | 0.7451   | 33%               | 67%      | 0.8447   |
| 25%        | 75%      | 0.7419   | Proportion        | 25%      | 75%      | 0.8309           |
| 67%        | 33%      | 0.8646   | 67%               | 33%      | 0.9331   |
| 75%        | 25%      | 0.8696   | 75%               | 25%      | 0.9234   |

| Proportion | Industry | Resident | Simultaneity rate | Industry | Resident | Simultaneity rate |
|------------|----------|----------|-------------------|----------|----------|-------------------|
| 50%        | 50%      | 0.9029   | 50%               | 50%      | 0.8818   |
| 33%        | 67%      | 0.9005   | 33%               | 67%      | 0.8793   |
| 25%        | 75%      | 0.9048   | Proportion        | 25%      | 75%      | 0.8507           |
| 67%        | 33%      | 0.8986   | 67%               | 33%      | 0.8892   |
| 75%        | 25%      | 0.8931   | 75%               | 25%      | 0.8954   |

| Proportion | Industry | Resident | Simultaneity rate | Industry | Resident | Simultaneity rate |
|------------|----------|----------|-------------------|----------|----------|-------------------|
| 50%        | 50%      | 0.6909   | 50%               | 50%      | 0.8875   |
| 33%        | 67%      | 0.7257   | 33%               | 67%      | 0.9004   |
| 25%        | 75%      | 0.7523   | Proportion        | 25%      | 75%      | 0.8844           |
| 67%        | 33%      | 0.7741   | 67%               | 33%      | 0.9719   |
| 75%        | 25%      | 0.834    | 75%               | 25%      | 0.8701   |

4. Grid case analysis

The selected area is a comprehensive urban center, covering an area of 12.36 km², including administrative office, culture, science and education, business and commerce, coastal tourism, residence and other functions. The nature of the land is mainly residential land, land for public management and public service facilities, land for commercial service facilities, land for roads and traffic facilities, land for public facilities, green land and square, which belongs to class A power supply area.
4.1. Current situation of power grid
At present, there are 3 110kV substations with 6 main transformers and 326 mva substation capacity for regional power supply. The total number of 10kV intervals was 66, the remaining 7, and the utilization rate of intervals was 89.39%.

There are 44 10kV lines in the grid, including 35 public lines and 9 special lines, with a total length of 155.43 km; there are 108 ring mesh boxes, 590 medium voltage distribution transformers, with a capacity of 436.61mva, including 229 public distribution transformers, with a capacity of 186.11mva, 361 special distribution transformers, with a capacity of 250.5mva.There are four types of medium voltage distribution grid structures in the grid, including four single loop network connections, 27 other structures, two double shots and two single shots, accounting for 11.43%, 77.14%, 5.71% and 5.71% of the total number of lines respectively.

4.1.1. The average power supply radius of 10kV medium voltage line is 2.33km, the cable rate is 93.63%, and the insulation rate is 100%. The average maximum load rate of the line is 47.29%, the average maximum load rate of the distribution transformer is 37.88%, the contact rate is 88.57%, and the passing rate of N-1 is 82.86%. There are 6 circuits of the line that do not meet the "N-1" calibration, accounting for 17.14%.The current indicators of medium voltage distribution network are shown in Table 5.

| Entry name | Index |
|------------|-------|
| Average trunk line length (km) | 2.33 |
| Cable rate (%) | 93.63 |
| Insulation rate (%) | 100 |
| Average value of maximum load rate of medium voltage line (%) | 47.29 |
| Average value of maximum load rate of distribution transformer (%) | 37.88 |
| Liaison rate (%) | 88.57 |
| N-1 pass rate (%) | 82.86 |

4.2. Grid division
According to the "grid" planning system established in this paper, the selected area is divided into a power supply mesh, which is divided into three power supply units in combination with the function positioning and distribution network structure of the power supply grid.

The division results of power supply unit are shown in the figure 2. The summary of division results of power supply unit are as table 6.
Table 6. Summary of division results of power supply unit

| Power supply unit mesh name | Area (km²) | Block division | Nature of main land                           |
|-----------------------------|------------|----------------|-----------------------------------------------|
| 001 power supply unit       | 4.66       | 8              | Residence, Administrative office, Green space |
| 002 power supply unit       | 3.35       | 5              | Commercial, Residential, Green space          |
| 003 power supply unit       | 4.35       | 11             | Residential, Commercial, Green                |

4.3. Load forecasting

4.3.1. Index selection. According to the research results in Section II, the density index in the selected area is determined as table 7.

Table 7. Table selection results of load density indexes of different types of land in Grid

| Nature of land                   | Load index of building area (w/m²) | Demand coefficient |
|----------------------------------|------------------------------------|--------------------|
| Second class residence           | 40                                 | 0.2                |
| Administrative office            | 40                                 | 0.5                |
| Commercial Finance               | 80                                 | 0.5                |
| Commercial residential mix       | 60                                 | 0.3                |
| Educational research             | 40                                 | 0.5                |
| Medical and health work          | 50                                 | 0.6                |
| Land for public facilities       | 10                                 | 1                  |

4.3.2. Load forecasting results. The load forecast results for each year are as table 8.

Table 8. Table grid load forecasting results

| Unit No                       | Power supply area (km²) | Current maximum load (MW) | Load density (MW / km²) | Saturation annual maximum load (MW) | Load density (MW / km²) |
|-------------------------------|-------------------------|---------------------------|-------------------------|-------------------------------------|-------------------------|
| 001 power supply unit         | 4.66                    | 50.96                     | 10.94                   | 88.31                               | 18.95                   |
| 002 power supply unit         | 3.35                    | 49.4                      | 14.75                   | 102.72                              | 30.66                   |
| 003 power supply unit         | 4.35                    | 35.62                     | 8.19                    | 95.07                               | 21.86                   |
| Total(Simultaneity rate 0.9)  | 12.36                   | 122.38                    | 8.91                    | 257.49                              | 20.83                   |

4.4. Planning scheme

In saturation year 001, the power supply unit is powered by 5 groups of double ring network and 8 groups of single ring network, with 36 circuits in total. The average load of a single line is 2.45mw, and the line can meet the "n-1" calibration. The 001 topology of power supply unit in saturation year are shown in the figure 3.
In the year of saturation, the 002 power supply unit is powered by 5 groups of double ring network (2 groups shared with the outside area) and 8 groups of single ring network, with 32 circuits in total. The average load of a single line is 3.21 MW, and the line can meet the "N-1" calibration. The 002 topology of power supply unit in saturation year are shown in the figure 4.

003 power supply unit will be powered by 5 groups of double ring network and 6 groups of single ring network in the long term, with 32 circuits in total. The average load of a single line is 2.97 MW, and the line can meet the "N-1" calibration. The 003 topology of power supply unit in saturation year are shown in the figure 5.
4.5. Planning effectiveness

Through the planning, construction and transformation of the distribution network, the main analysis indicators of the distribution network in the grid have been significantly improved. In the year of saturation, the reliability of power supply has been increased to 99.999%, and the comprehensive voltage qualification rate has been maintained to 99.99%.

Table 9. Table Comparison of construction and transformation effects of power supply grid in new urban area

| Index name                  | Power supply mesh | Current year | Saturation year |
|-----------------------------|-------------------|--------------|-----------------|
| Maximum load (MW)           | 122.38            | 257.5        |
| Total number of lines       | 44                | 109          |
| Public lines                | 35                | 100          |
| Cable rate (%)              | 93.63             | 100          |
| Contact rate (%)            | 88.57             | 100          |
| Inter Station Liaison rate (%) | 31.43          | 0            |
| N-1 pass rate (%)           | 82.86             | 100          |
| Average line load rate (%)  | 47.29             | 32.19        |
| Power supply reliability (%)| 99.92             | 99.99        |
| Voltage qualification rate (%) | 99.95          | 99.99        |

5. Conclusion

The construction of grid planning system provides a new idea for distribution network planning. Through different levels of "grid" division, the planning scheme can realize reasonable transition in time and reasonable layout in space. At the same time, a spatial load forecasting method suitable for grid planning is constructed, accurate prediction of saturated loads at different levels of power supply units, power supply mesh and power supply functional area were realized, and the accurate planning and high-quality development of distribution networks were promoted.
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