DISTRIBUTION NETWORK PLANNING WITH THE CONSIDERATION OF DIFFERENT POWER CONSUMPTION TYPES

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ABSTRACT

For the convenience and rationalization of distribution network planning, we proposed a new concept – power consumption type, which indicates the development of power consumption and the importance of consumers in different districts. The distribution network planning model with the consideration of different power consumption types was established and then was implemented in the planning of an actual network.

Keywords: distribution network planning; power consumption type; PCTI.

1. INTRODUCTION

Distribution network should provide electricity to many areas with different location, function and economic foundation. Different areas usually have different load characters, such as load density, maxim load use hours, load growth rate and the importance of load. For the convenience of the planning of distribution network, we proposed a new concept – power consumption type to describe these characters.

As the final stage in the transfer of power to the individual customers, distribution network’s structure must coordinate with power consumption type. Power consumption type differs from one area to another area, even areas which connect to each other. In order to plan a proper distribution network, we should take power consumption type into count firstly. However, some traditional planning methods usually consider the network as a whole one and set a common target on reliability, line loss ratio and voltage acceptance rate, regardless of the different demand of different areas. Some distribution network even constructed with the highest standard established on the most importance area, causing a large increase of the costs and investment. Some planning methods consider the need of different consumers, but they only adjust their planning results in the last step. As methods, to some extent, they lack scientific and systematic.

In the view of this point, a distribution network planning method that based on the conception of power consumption was discussed in this paper. And this method tries to meet the need of both electricity consumers and power supply companies.

2. POWER CONSUMPTION TYPE

2.1. Power Consumption Type

The sum of power consumed by all the electrical equipments in a power system is called integrated load. Integrated load is a concept which can reflect the general load character in one area. However, load characters of different power consumers in one system are different for the following aspects:

- Load density – reflect the intensity of power consumption;
- Maxim load use hours – reflect the continuance of power consumption;
- Load growth rate – reflect the development of power consumption;
- Importance of load – reflect the importance of power consumption.

We divided load into three types, and type I is the most important, which include hospital and school. Furthermore, there are other factors which can reflect load characters such as the main equipments of consumers, the environment of consumers etc.

While planning a distribution network, all the aspects above should be considered, which make the planning process very complicated and confused. To make the planning simpler and modular, we proposed a new concept named power consumption type to replace these complicated factors.

Power consumption type is a single index that indicates the load characters. It has two main elements. One is electricity consumption, which reflects the development of different power consumption types in a district, including load density, maxim load use hours and load growth rate. The other is importance of customers, which reflect the importance of different power consumption types, including importance of load.

2.2. Relationship between Power Consumption Type and Distribution System Indexes

As the final stage that connected with power consumers directly, distribution system index must coordinate with various power consumption types of different areas in the following aspects: distribution substation’s capacity-load ratio, distribution lines’ load rate, distribution lines’ connection mode, power supply radius, distribution transformer’s load rate, reliability, voltage acceptance rate, general line loss ratio, N-1 ratio etc. Take the power supply radius of 10kV step-down substation for instance:
with load density increasing, the optimal radius should decrease correspondingly. In our planning example, we calculated some curves [1, 2] shown as figure 1-4, which can illustrate the relationship between distribution system indexes and each element of power consumption type.

Fig. 1 Relationship between optimal 10kV power supply radius and load density

Fig. 2 Relationship between line loss ratio and load density multiply maxim load use hours

Fig. 3 Relationship among reliability, N-1 ratio and proportion of load type I

Fig. 4 Relationship between line voltage loss and power supply radius

2.3. Division of Distribution network based on Different Power Consumption Types

It is an essential step to divide the planning areas into several districts based on different power consumption types. Power consumption types can be indicated by power consumption type index (PCTI) which calculated as follows:

\[
PCTI = \text{Load density} \times \text{Maxim load use hours} \times \text{Proportion of load type I}
\]

The value of PCTI will influences main power system index such as power supply radius, voltage acceptance rate, general line loss, N-1 ratio and distribution lines’ connection mode.

Furthermore, load growth rate, which reflect load rate of 10kV step-down substations, distribution lines and distribution transformers, should also be considered when dividing the planning area.

In our planning example, we divided the whole area firstly and then classify the sub areas into A, B, C, D four districts based on the value of PCTI as well as load growth rate. Each district has its own distribution network constructed standard, which decided by the relationship curves discussed in section 2.2. Table 1 shows the detailed traits of the four districts.

3. NETWORK PLANNING MODEL BASED ON POWER CONSUMPTION TYPES

3.1. Determine the Location and Capacity of Each Substation

Firstly the planning area is classified into different districts according to different power consumption types in Table 1. So network construction standards of each district will be known. Then using the method proposed by Ref. [3], the location and capacity of each 10kV step-down substation will be decided.

After these processes, we could establish a model to optimize the number of outlet distribution lines of each substation, the length of each outlet distribution lines and the connected mode of each line. We take voltage acceptance rate, 10kV line loss rate, 10kV power supply radius, low-voltage power supply radius and N-1 ratio of each district as constraint conditions, and take the general reliability, line loss rate, voltage acceptance rate and investments as objective functions.

3.2. Mathematical Model of Network Planning

3.2.1. Constraints

Each district type has its own constructed standard listed in Table 1, which should be embodied in the constraints of the model.

1) Line voltage-drop rate

\[
u_i \% = \frac{P_{iH}}{H \times LDF} \times 100\%
\]

where \(H\)–unit voltage regulation constant,
\(H = \frac{10U^2}{r \cos \phi + x \sin \phi}\)
Tab.1 Power consumption types and corresponding network indexes of the four districts

<table>
<thead>
<tr>
<th>Districts</th>
<th>Indexes</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCTI</td>
<td>&gt;20</td>
<td>2~20</td>
<td>&lt;2</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Load Growth Rate (%)</td>
<td>&gt;13%</td>
<td>8%~13%</td>
<td>&lt;8%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Voltage Acceptance (%)</td>
<td>99.6</td>
<td>96</td>
<td>93.5</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>10kV Line Loss Rate (%)</td>
<td>4</td>
<td>4.5</td>
<td>5.5</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>10kV Power Supply Radius (km)</td>
<td>2.5</td>
<td>4</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Low-voltage Power Supply Radius (km)</td>
<td>0.15</td>
<td>0.25</td>
<td>0.5</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>General Line Loss Rate (%)</td>
<td>about 57%</td>
<td>about 65%</td>
<td>about 75%</td>
<td>about 50%</td>
<td></td>
</tr>
<tr>
<td>N-1 Ratio (%)</td>
<td>85</td>
<td>70</td>
<td>50</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

$LDF_{ij} = \text{load distribution coefficient,}$

$$LDF_{ij} = \frac{p_{ij}}{H \times U \%} = \frac{2m_{ij}}{m_{ij} + 1}$$

$p_{ij}$—real power of 10kV distribution line j in substation i;

$l_{ij}$—length of 10kV distribution line j in substation i;

$m_{ij}$—the number of branch lines of $l_{ij}$;

$U$—rated voltage of distribution line;

$\cos \phi$—power coefficient;

$r, x$—unit resistance and reactance of distribution line;

$\eta_{ij}$—line voltage-drop rate of $l_{ij}$ in substation i;

$n$—total number of distribution lines in substation i;

2) Line losses

$$\Delta P_{ij} = \Delta P_{ij}^{\text{p}} + \Delta P_{ij}^{\text{v}} = \left(\frac{p_{ij}}{U}\right)^{2} r l_{ij} \left(\frac{1}{3} \frac{1}{2m_{ij}} + \frac{1}{6m_{ij}^{2}} \right) + \left(\frac{p_{ij}}{U}\right)^{2} \frac{a_{ij} r_{ij}}{m_{ij}}$$

(3)

where $\Delta P_{ij}^{\text{p}}$—line losses of distribution line $l_{ij}$;

$\Delta P_{ij}^{\text{v}}$—line losses of branch lines of $l_{ij}$;

$a_{ij}$—the length of branch lines of $l_{ij}$, we assume that all the branch line’s length on the same distribution line are equal;

$r_{ij}$—unit resistance of branch line

3) N-1 ratio

We suppose $n_{ij}$ is the number of distribution lines which connected with line $l_{ij}$, then the load rate of line $l_{ij}$ can be calculated out. Line $l_{ij}$ can pass N-1 standard only if $n_{ij} \geq 1$.

For the most extreme occasion in which all the number of connected line of each distribution line are 1 except radiate lines, at least the N-1 ratio of a substation is:

$$\sum_{i=1}^{N} \frac{n_{ij} - n_{ij}}{n} \geq A$$

(4)

4) Other constraints

For the network of the whole area, there are still some other constraints:

The sum of power supply area of each distribution line should not smaller than all the planning area:

$$\sum_{i=1}^{N} \sum_{j=1}^{n_{ij}} \frac{p_{ij}}{H \times LDF_{ij}}$$

(8) for each objective function, we assigned a membership coefficient as follows:

$$\mu_{ij} = \exp \left[ - \left( F_i - F_{i}^{\text{min}} \right) / F_{i}^{\text{max}} - F_{i}^{\text{max}} / F_{i}^{\text{min}} \right]$$

(11)

$F_{i}^{\text{min}}$ is the lowest limit of objective function i, while $F_{i}$ is

$\sum_{i=1}^{N} \sum_{j=1}^{n_{ij}} \frac{p_{ij}}{H \times LDF_{ij}}$
the objective value of the function. The final planning model can be simplified into the following form:

$$\max(\mu_{F_1}, \mu_{F_2}, \mu_{F_3})$$

s.t. $G$

(12)

where $G$ is constraints (2)~(7).

Finally genetic algorithm is used to solve the model[5].

4. APPLICATION OF THE PLANNING METHOD TO AN ACTUAL NETWORK

Figure 5 shows our example planning area in China. We divided the whole area into several sub areas based on their respective power consumption types listed in Table 2, and then rank for each sub area. When the division was done, we decided the location and capacity of each substation shown in figure 5. After that the model in section 3 was used to determine the final planning program and the result was shown in Table 3. Figure 6 shows the connected manners of each line.

5. CONCLUSIONS AND PROSPECTS

In this paper, we made an attempt to improve the planning method on distribution network and propose the concept of power consumption type. It is approved form the example that our method meets the need of both power supply companies and customers, and suit for engineering practice. However, the method ignores the existent network, which may not optimal for the model. So we must adjust the planning result with it in the final step.

<table>
<thead>
<tr>
<th>Sub Areas</th>
<th>Substation Number</th>
<th>Substation Capacity (MVA)</th>
<th>Substation Load Rate (%)</th>
<th>Number of 10kV Distribution Lines</th>
<th>Total Length of 10kV Distribution Lines (km)</th>
<th>Power Supply radius (km)</th>
<th>Load Loss Rate of 10kV Distribution lines (%)</th>
<th>Voltage Acceptance Rate of 10kV lines (%)</th>
<th>N-1Ratio (%)</th>
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<tr>
<td>Chenda</td>
<td>#1</td>
<td>63</td>
<td>71</td>
<td>13</td>
<td>55.3</td>
<td>3.75</td>
<td>4.20</td>
<td>87.5</td>
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<td></td>
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<td>90</td>
<td>69</td>
<td>13</td>
<td>57.3</td>
<td>3.87</td>
<td>4.33</td>
<td>93.33</td>
<td>84.6</td>
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<td>Liedong</td>
<td>#3</td>
<td>100</td>
<td>76</td>
<td>19</td>
<td>53.4</td>
<td>2.45</td>
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<td>76</td>
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<td>73</td>
<td>8</td>
<td>25.7</td>
<td>2.82</td>
<td>3.16</td>
<td>100</td>
<td>87.5</td>
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<td>100</td>
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<td>12.9</td>
<td>1.21</td>
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<td>88</td>
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<td>4.80</td>
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<td>57.8</td>
<td>4.18</td>
<td>4.68</td>
<td>95.46</td>
<td>92.3</td>
</tr>
</tbody>
</table>

REFERENCES


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