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A City Clustered Oriented Power Distribution Network Planning Method and its Application

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Abstract: In view of balancing the electric power and energy and decreasing the transmission pressure of the urban central areas, a city clustered oriented distribution network planning method is put forward in this paper, based on the clustered city planning theory. Firstly, by analyzing the different function of clusters, both the load forecast and the location choice of substations take the differential orientation of clusters into account. Then, based on the planning principles of hierarchy, network is divided into several functional layers cooperatively connecting with each other to reach the combined operating mode. The scattered power substation and distribution lines are integrated and the network data and planning method with similar industrial function are collected. Finally, the standard for city clustered planning is established. The practical application in the distribution network of Livable Education City in the city of Zhengzhou shows that the proposed method will meet the demand of practical work in distribution network.

Key words: Cluster, urban distribution network, differential principle, hierarchical principle, functional orientation

INTRODUCTION

As the urbanization of cities is rapidly developing in China, the clustered planning strategy was born to avoid the normal spreading development mode. Clustered city planning, in essence, is to form a developing group according to the functional orientation of the city. In detail, supported by the industrialization process, the city is divided into several areas according to each function and forms a clustered structure with multiple centers. Each cluster is independent with its own specific development orientation, while the clusters are also correlative with each other.

The traditional city planning method mainly focuses on the planning of central urban area and other areas are regarded as satellite town. However, based on the clustered planning theory, the rural areas and satellite towns are all brought into whole planning of the city. As a result, the ties between the central urban areas and the surrounding area are enhanced. At present, lots of large and medium-sized cities have adopted the polycentric and group urban expansion strategy. It explicitly demonstrates functional orientation of each cluster, as well as the industrial structure and development tendency (Zhou, 2005; Wang and Wu, 2006). Li (2006) elaborates the planning method of the road network of clustered cities which will help in the field of distribution network planning.

From the power network perspective, as the power load rapidly increases, the problems of high load density, long construction cycle and rising cost of transmission lines and substations (Liang *et al*., 2009; Li and Zhang, 2008) emerge in the urban areas. Facing these problems, the paper aims to propose a planning method to realize the balance of the electric power and energy. Furthermore, it will enhance the connection among the areas to achieve the complementary and cooperative load distribution and decrease the load density of the urban central areas and its transmission pressure.

IDEAS AND PRINCIPLES OF CLUSTERED POWER DISTRIBUTION NETWORK PLANNING

Ideas of clustered power network planning: In the traditional power network planning, the planning areas are divided according to the administrative regions. The city has not the corresponding administrative hierarchy. The power supply station is the basic unit for the planning

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Table 1: Cluster function classification and relevant planning index

Industria structure	Spatial structure	Fnnctional orientation	Distribution network planning index			
			Framework structure standard	Substation location standard	Security index	Reliability index
Agriculture	Block-shaped	Forestry, animal husbandry, fishery,	Single radiation structure for 110~35kV, double radiation or loop for conditional regions	Semi-outdoor or fully-outdoor substation	HV Meets N-1; MV partly Meets N-1	≥99.828%
Industry	Star-shaped	Manufacturing, power, gas, architecture	Chain structure for 110~35 kV, double radiation or double loop structure could also be taken	Semi-outdoor or fully-indoor substation	HV meets N-1, Partly meets N-1-1; MV basically Meets N-1	≥99.99%
Service	Centripetal	Business, finance, education	Chain structure for 110~35 kV, double radiation or double loop structure could also be taken	Semi-outdoor or fully-indoor substation	HV meets N-1, Partly meets N-1-1; MV basically Meets N-1	≥99.965%

and dispatching. The function and responsibility is not clear. And it is difficult to establish a unified standard to guide the planning of new areas.

The clustered planning ideas of power network is that integrative planning of scattered power substation and distribution lines, collect the network data and planning method with similar industrial function form unified functional cluster and the planning result is able to be standardized.

The division of clusters depends on the industry structure, spatial structure and functional orientation of the areas at the present situation. For example, for the city whose industrial land accounts for a large proportion of the total land, the distribution network planning centers on the industry layouts. For the city whose service industry is rapidly developing, the substations location and line path selection extremely focus on the service industry. The cluster function classification and relevant planning indexes are shown in Table 1.

Principles of clustered power network planning:

- **Diversity:** As the difference of load characteristics and orientation among the clusters, there is not a unified standard for the network planning (Li and Liang, 2009). On the basis of the total load demand and combined with the function difference, the load forecasting varies according to the load's features and relevantly the location choice of substations should take the functional orientation into account
- **Hierarchy:** The hierarchy of urban distribution network exists in the power network among the clusters or inside the cluster (Zhu *et al*., 2009). To this principle, the network is divided into several layers according to voltage levels and regional features. Each layer adapts to its specific indexes such as load demand, power quality, reliability, security and so on. Otherwise, to reach the combined operating mode, the layers cooperatively connect with each other in the information interaction

For example, the transmission lines among the clusters are generally longer than ones inside the clusters and their security index is required to be of good quality. The lines are generally the overhead line with the large-capacity and multi-circuit constructing feature. While the cable are suitable for the lines inside the clusters and the layout varies in the different voltage levels.

CLUSTERED POWER DISTRIBUTION NETWORK PLANNING METHOD

Basic flow of clustered power network planning: Based on the thoughts and principles presented in the above section, the basic flow of the clustered power network planning is presented as follows:

- Function analysis of clusters. It aims to present the load characteristics and functional orientation of the target clusters
- Referred to the existed power network planning scheme in which the geographical environment, economic development and city functional orientation of the clusters is similar to the target ones, the planning method is proposed to benefit the development of new clusters
- Load density method is applied to the difference-based load forecast and finally verified by compared with the existing results of the clusters with similar functions
- According to the thoughts of hierarchy, the location of substations and path selection of transmission lines among the clusters or inside the clusters are respectively planned. Finally the results are verified by compared with the existing results of the clusters with similar functions

Function analysis of clusters: Combined with the current condition of the network and from the aspects of the geographical environment, economic and social developing situation, administrative levels and the

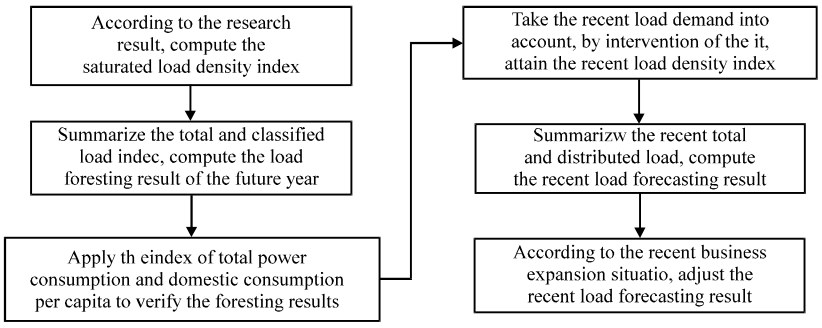

Fig. 1: Flow of the load forecast

planning scheme analyzes the industry structure of the target clusters and finally determines their functional orientation. Throughout this part, the developing tendency of each primary industry is determined to guide the following planning works.

Load forecasting methods: As is oriented to the clustered city planning, the distribution network planning is for a specific area or the combination of some small pieces of areas with similar city functions. From this point, load density method is suitable for the load forecast of clustered planning.

By depth research and horizontal comparison, the saturated load index at a particular moment can be found to compute total amount and space distribution of the load in target year (Kong *et al*., 2009). Then, according to the electrical consumption structure of the specific consumer and reference of load condition of clusters with similar functional orientation, the similar load density index will be computed. Otherwise, this method has a better forecasting limit and stronger intervention to adapt to the emergency. Thus, it is appropriate for the clustered network planning. The flow of the load forecast towards the clustered network planning is shown in Fig. 1.

Substation locating methods: With the overall consideration of economic development, infrastructure distribution, area function coordination, the location selection of substation is determined according to the thoughts of hierarchy.

The first layer is the network that mutually connects between the central clusters and its surrounding clusters. The emphasis of this layer is to enhance the two-way interaction among the clusters. As the unbalanced load distribution or overload of the central cluster emerges, a part of load supply could transfer to the other areas through the connecting lines between the clusters. Otherwise, the economic growth of the surrounding clusters is promoted with the supports of the central clusters.

The second layer is the 220 kV transmission network inside the clusters. The network is divided into several areas and partitions based on distribution of 220 kV lines. Its operation mode is generally double loop network.

The third layer is the 110kV distribution network inside the clusters. Centering on the 220kV substations, the operation mode is open looped and chained in the normal condition. It is also of good ability to transfer the overload under the accident conditions.

APPLICATIONS

The paper takes the Livable Education City for example, which is a part of the city planning named "6 Cities and 10 Clusters" in Zhengzhou. Based on the city clustered developing strategy, the distribution network planning of the specific area is researched as follows:

Function analysis: Livable Education City is an essential cluster of the urban area of Zhengzhou. The cluster function is oriented to the service industry, which mainly involves the functions of resident, education, touring and high-tech industry. Integrating the education training, business services, modern industry and leisurely resident, the city cluster enables to highlight the education construction.

Load forecasting: Livable Education City belongs to the clusters surrounding the urban central area. In the load forecast (Table 2), Livable Education City is divided into 3 areas according to the difference in functions: Area A is mainly the green fields; Area B is the core zone integrating the industry, business and education; Area C is mainly the residents.

Table 2: Load forecast result in future year (before adjustment)

Cluster	Partition	Area (km^2)	Not consider load diversity Load capacity (MW)	Consider load diversity (0.7) Load capacity (MW)	Consider load diversity (0.7) Load density (MW km^{-2})
Livable education city	Area A	24.90	0.00	000.00	0.00
	Area B	68.60	1199.76	839.83	12.30
	Area C	52.20	115.90	081.13	1.60
	Total	145.60	1315.65	920.96	6.30

Table 3: Load forecast result of different areas in 2017 (after adjustment)

Cluster	Partition	Area (km^2)	Not consider load diversity Load capacity (MW)	Consider load diversity (0.7) Load capacity (MW)	Consider load diversity (0.7) Load density (MW km^{-2})
Livable education city	Area A	24.88	0.00	0.00	0.00
	Area B	41.54	514.37	360.06	8.70
	Area C	47.47	36.20	25.34	0.50
	Total	113.89	550.57	385.40	3.40

Table 4: Load density index of some other areas in future year

Name of clusters	Tianjin TEDA development zone	Suzhou industry zone of I phase development	Zhengzhou high and new tech development zone	Suzhou industry zone exit A
Load density (MW km^{-2})	12	20	26.56	35

Table 5: 220 kV transformation capacity of livable education city

Cluster	Year		2011	2017	2020	Future year
Livable education city	Maximum of load (MW)		129.78	385.40	615.64	920.96
	Output of power plant below 220 kV		0.00	0.00	0.00	0.00
	Power consumer above 220 kV		0.00	0.00	0.00	0.00
	Exchanged capacity outside the cluster		129.78	0.00	0.00	0.00
	220 kV power load (MW)		0.00	385.40	615.64	920.96
	Variable capacity	Upper limit (Capacity-load Ratio is 2.0) (MVA)	0.00	770.80	1231.28	1841.92
		Lower limit (Capacity-load Ratio is 1.7) (MVA)	0.00	655.18	1046.59	1565.63
	New capacity	Upper limit (MVA)	0.00	770.80	1231.28	1841.92
		Lower limit (MVA)	0.00	655.18	1046.59	1565.63

Table 6: 220 kV network developing and planning of livable education city

Voltage level (kV)	Year	2012	2017	2020	Future year
220	No. of substations	0	2.00	3.00	3.00
	No. of main transformers	0	3.00	5.00	7.00
	Variable capacity (MVA)	0	720.00	1200.00	1680.00
	Length of overhead line (km)	0	75.94	84.06	84.06
	Length of cable (km)	0	0.00	0.00	0.00
	Total length of lines (km)	0	75.94	84.06	84.06

As there is a certain gap between the load level of year 2012 and future year, the load density indexes differs from the future ones. However, the major factor to cause that is the difference in land utilization rate. There is little difference in the ratio of load density among the areas. Thus, not just considering the developing target and unbalanced growth rate, the difference of load density ought to be taken into account. The load forecasting result is adjusted as the index changes (Table 3).

To verify the reasonability of the forecasting result, we collect the load density data of some other areas whose functional orientation is similar to Livable Education City (Table 4).

The load density of Livable Education City in future year is 21 MW km^{-1} which is just above the Suzhou Industry Zone of I Phase Development and below the Zhengzhou High and New Tech Development Zone. The comparison shows that the forecasting result is reasonable and suitable for the functional orientation of the cluster.

Substation locating: Take the 220 kV network of Livable Education City for example. According to the load forecasting result, we analyze load growth condition and compute the transformation capacity as Table 5 shows.

According to the transformation capacity and economic development condition, the 220 kV substations are planned as Table 6 shows.

The planning scheme of 220 kV network lists the location selection of substation and the path selection of transmission lines from recent years to future years. It fits the hierarchical principle and meets the requirements of clustered planning.

SUMMARY

Referred to clustered city development planning, the paper puts forward a planning method applied in clustered power network. The method combines with the difference in cluster functions and hierarchy of city planning. The application in the power network of cluster of Livable Education City in Zhengzhou has proved that the methods and steps of the power planning method proposed is able to simplify the complexity of planning and decrease the load pressure in the central cluster. In brief, it can meet the demand of the network development under the situation of the rapid growth of load.

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