THE AUTOMATIC ROUTING OF 10KV SWITCHING STATION IN URBAN DISTRIBUTION NETWORK BASED ON SPATIAL GIS

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ABSTRACT

There is a special connection mode of higher reliability named switching station network in urban MV distribution network except for substation directly supplying connection modes. The paper firstly introduced and analyzed some connection modes of switching stations in urban distribution network of Shanghai. Then, the best numbers and locations of switching stations based on spatial GIS of distribution network and the method of substation locating and capacity calculating are gained. After doing this, the paper develops automatic routing of incoming lines. From analyzing the actual example, the method introduced in this paper is proved to be feasible.

INTRODUCTION

By using 10kV switching stations, the problems of restrictions on numbers of 10kV outgoing lines switch cupboards at HV substations and 10kV outgoing lines corridors in the urban area can be solved, which is due to the significant reduction of numbers of lines in the same routes and the enhancement of the utility rates of HV substation outgoing lines. When establishing switching stations, three aspects should be concerned to ensure the reliability of distribution network. These are strengthening links among all HV substations, optimizing distribution network structure, improving technical practicability and economic reasonableness of your program.

In practice, a switching station is composed of buses and switches. It maybe used when long lines are needed for direct electricity transmission from substations to the load far away. And there could be two different establishing plans, one is to design a switching station close to the load, the other is to build it in a place where all conditions permitted. On the one hand, these two proposals would be more expensive than other distribution network programs because of the investment on switching station; on the other hand, it would be much more reliable because of the shorter outlines adapted (see in [1]). Thus, 10kV switching station is quite popular in the urban areas where reliable power supply is greatly demanded. Nowadays, cable network has replacing the overhead network progressively in the cities like Shanghai, thus establishing 10kV switching station reasonably is important in reality.

It is functional to adapt switching station when designing the route of 10kV cable lines. But the problems are how many switching stations are needed, how to locate them and how to plan the incoming lines? At present, designers often make decisions according to the requirements of upper grade grid and actual load; there has not been a systematic and scientific model to use.

ESTABLISHING PRINCIPLES AND CONNECTION MODES OF SWITCHING STATIONS

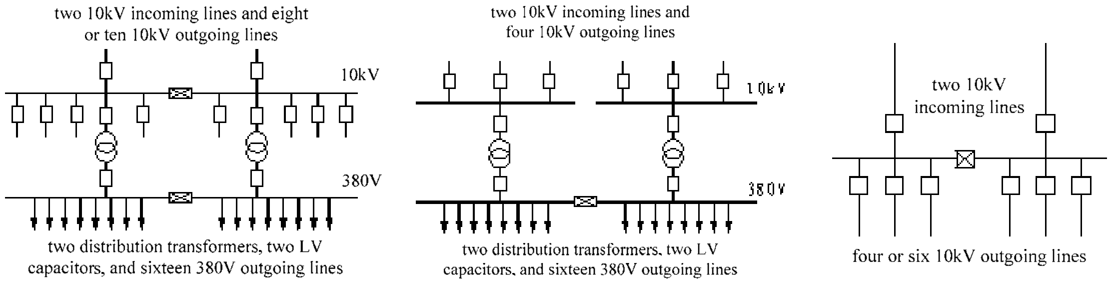
Establishing principles

Along with the rapid development of economy and society, cable network with better capacity has replacing the overhead network progressively in urban network of Shanghai. According to "The Tenth Five-Yeared Planning of Shanghai Urban Distribution Network" (see in [2]), series of problems which are caused by low utility rates of 10kV outgoing lines at 110-35KV substations, and imbalanced proportions between K-model and P-model MV substations still exist. These problems are the ones such as shortages of 10kV outgoing lines, difficulties in outgoing cable pathways of substations and so on.

By establishing 10kV switching stations around substations, 10kV outgoing lines supply for switching stations only (a few high load customers which need direct electricity transmission are also included), and then distribution substations are supplied by switching stations. The routing model above enhances utility rates of outgoing lines, reduces requirements of outgoing cable channels at substations, and also improves the ability of transferring loads among all substations. In other words, switching stations should be built close to load centre, so as to be convenient for maintenances, daily management, and laying cables. Issues of reducing cable lengths, minimizing investment, setting development spaces and routing simply should also be considered (see in [3]).

Connection modes of switching stations

According to the experience of construction and operation, there are three main modes of switching stations in electric network of Shanghai. These switching stations are supplied by upper grade substations through two YJV-$3\times400\text{mm}^2$ incoming cable lines with 50% load rate for each.



(a) Central mode (b) Middle mode (c) Simplex mode

Fig.1 Main connection modes of switching stations.

NUMBERS AND LOCATIONS OF SWITCHING STATIONS

Spatial data structure of switching stations

Fig.2 explains the practical connection mode of a switching station in 10kV urban distribution network. In the sketch map below, black triangle KB15 represents 10kV switching station, YJV-3×400mm^2 cables are used as its' incoming lines SK0503 and SK0703, whose power supplies are two different 35kV substations SK05 and SK07. And YJV-3×120mm^2 cables are used as outgoing lines which are connected as four circles just like KB1501, KB1502, KB1503 and KB1504 in the map to supply power for 10kV terminal distribution substations or transformers in load areas around.

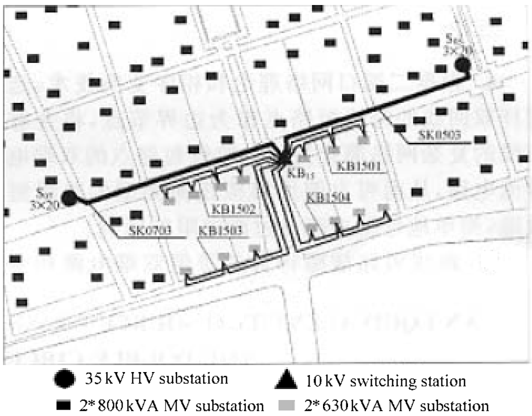


Fig.2 Sketch map of switching station in urban distribution network.

According to Fig.2, locating switching stations is closely related to spatial GIS in distribution network, then the spatial data structure for the automatic routing of connection modes using switching stations is designed. The details are as follows.

Table 1 Spatial data structure of switching station.

Name	Type	Description
switching station name	character	name of a switching station
switching station ID	integer	unique ID for each switching station
topologic type	character	topologic type: point
location of switching station	float	relative coordinate of switching stations
ID number of a certain district	integer	divide cities into districts according to main streets, ID number of the district that has switching stations
load of switching stations	float	amount of the load supplied by a switching station
numbers of incoming lines	integer	numbers of incoming lines of a switching station
numbers of outgoing lines	integer	numbers of outgoing lines of a switching station

Numbers of switching stations

Numbers of switching stations can be decided on the basis of the rules below.

(1) According to practical experience, switching stations are established when large load concentrates in urban areas where HV substations are far away. They also can be used to solve the problems of restrictions on numbers of outgoing lines corridors at downtown.

(2) To decide the numbers of switching stations in a planned year of a certain area in future, designers should consider the total load of that area, the capacity of an incoming line and the principle of "N-1". In addition, the established rule which believes two outgoing lines are needed for a switching station should also be concerned.

(3) Besides factors above, the problem of limited land resources for construction, the overall load of the city in the certain planned year should not be omitted.

How to locate switching stations

The 10kV switching stations which are supplied by upper grade substations provide power supply for 10kV terminal distribution substations or transformers through their outgoing lines. Then it is obvious that although switching stations are composed of buses and switches, they play similar roles in MV urban distribution network as HV substations do. Thus, locating 10kV switching stations may result from references to locate HV substations.

Mathematic model of switching station planning

The optimizing planning of 10kV switching stations can be described as the situation that when load of a planned year and distribution of HV substations are known, taking approximate minimum annual investment and operation costs of switching stations and network as object function, full load ability of switching stations as constraints, how to get their locations, capacities and full extent covered. Thus, the expression is as follows.

$$\begin{cases} \min F = ZY_{SS} + Z_L + Y_L \\ s.t. \quad \sum_{j \in J_i} P_j \le S_i \cos\varphi \quad i = 1,2,\cdots,N \end{cases} \tag{1}$$

ZY_{SS} represents converted annual investment and operation costs of a switching station to be established, while the expenses used for daily examining, repairing and maintenance are included. Z_L and Y_L refer to converted annual investment and estimated annual operation costs. J_i and S_i are the total load and capacity of the *i*th switching station, while P_j is the active power of load *j,* cosφ represents power factor and N refers to the numbers of switching stations to be built.

The followed expression is used for calculating Z_L and Y_L .

$$Z_L = kC_{0L}\left[\frac{r_0(1+r_0)^{nl}}{(1+r_0)^{nl}-1}\right]\sum_{i=1}^{N}\sum_{j\in J_i} l_{ij} \tag{2}$$

While k represents the curve coefficient, C_{0L} refers to the investment cost converted to unit length, and l_{ij} is the length of the line routed between switching station (x_i, y_i) and load (x_j, y_j). What's more, r_0 is the discount rate and *nl* is the lifecycle of switching station outgoing lines.

$$Y_L = \alpha k \sum_{i=1}^{N}\sum_{j\in J_i} P_j^2 l_{ij} + W_L \tag{3}$$

It is notable that $\alpha = \dfrac{\alpha_1 \times \alpha_2 \times \alpha_3}{U^2 \times \cos^2\varphi}$, while α refers to the converted coefficient of line loss of outgoing line, α_1 is the coefficient expressing unit electricity loss converting into price, α_2 is the resistance of unit length of l_{ij}, α_2 is the loss hours of lines per year, U is the voltage grade of MV distribution network, that is 10kV, and W_L represents the annual expenses used for daily examining, repairing and maintenance of outgoing lines.

In addition, there are other principles to be considered when establishing switching stations (see in [4]).

PRINCIPLE 1: Switching stations establishment, city planning and construction should act in concert. It is better to be built in load center of the city together with greenbelt or other city installations and located near arteries. What's more, switching stations should have their specific supplying area, while the outgoing cables may not span the main streets.

How to calculate capacities of switching stations

Firstly, designers should decide the lead type and connection mode of incoming lines, then the capacity could be obtained according to the remainder capacities of incoming lines. General speaking, switching stations often adopt two incomings lines supplied by two substations or different buses of the same substation, while 50% capacities are remained for each line. Thus, the capacity of switching stations is the biggest power that can be transmitted by their incoming lines.

How to locate switching stations

The method used to locate switching stations in this paper is locating among several central points on plane (see in [5]), which is one of the automatic locating ways for substations. Locating among several central points on plane is to choose several median points on the basis of given load, it is fit for establishing several switching stations within the planned area. By using locating among several central points on plane, the weighted centre of load can be obtained so as to minimize investment and line loss of outgoing lines.

Based on the discussions above, the automatic locating of 10kV switching stations can be described as the situation that when load is given plane position coordinates (x_j, y_j) and load weight w_j (w_j >0), J represents total load ($j \in J$), taking aggregate capacity of switching stations as $\{S_1, S_2, \cdots, S_N\}$, then how to decide location of the *N*th switching station (x_{qi}, y_{qi}), $i = 1,2,\cdots,N$,($N \ge 2$) on the basis of meeting conditions in function expression (1). Notably, $w_j = \gamma W_j$, γ results from linearizing non-linear investment and line loss of outgoing lines. The detailed formula for calculating is as follows.

$$\gamma = \alpha\overline{P} + \frac{C_{0L}}{\overline{P}}\left[\frac{r_0(1+r_0)^{nl}}{(1+r_0)^{nl}-1}\right] \tag{4}$$

$\overline{P}$ above equals to $\frac{1}{M}\sum_{j=1}^{M} P_j$, it refers to the average load in the supplying area of a switching station, and M represents the overall load supplied by a switching station.

How to calculate supplying areas of switching stations

Calculating supplying areas of switching stations can be described as the question below. There are N switching stations with active economic capacity $S_i$cosφ ($i = 1,2,\cdots,N$), and there also exists M loads with their own load P_j ($j = 1,2,\cdots M$). Suppose the expense for electricity transmission from the *i*th switching station to the *j*th load per power is w_{ij} ($i = 1,2,\cdots,N$; $j = 1,2,\cdots M$), the problem is how to obtain a project with the least transmission fee. It is assumed that the power transmitted from the *i*th switching station to the *j*th load is P_{ij}, then a model of calculating supplying areas could be achieved.

$$\begin{cases} \min s = \sum_{i=1}^{N}\sum_{j=1}^{M} w_{ij}P_{ij} \\ \sum_{j=1}^{M} P_{ij} \le S_i\cos\varphi \quad i = 1,2,\cdots,N \\ \sum_{i=1}^{N} P_{ij} = P_j \quad j = 1,2,\cdots,M \\ P_{ij} \ge 0 \end{cases} \tag{5}$$

Notably, besides the mathematic model above, some other issues should also be concerned. For example, it is better that supplying radius not to be too long and outgoing cables not to span arteries, railways, rivers and so on.

AUTOMATIC ROUTING OF INCOMING LINES OF SWITCHING STATIONS

Ordinary connection modes of incoming lines

As Fig.1 shows, regarding to the connection mode of a switching station, there should be 50% spare capacity for each incoming line so as to meet the requirement of “N-1” principle. Thus, capacity of a switching station is chosen according to the maximal safe capacity permitted.

Automatic routing methods of incoming lines

After capacity and location of a switching station are obtained, the automatic routing of incoming lines could be done as follows. Taking switching stations and HV substations as tops, arteries as routes, Genetic Algorithm is adopted to seek for the shortest pathway between them. PRINCIPLE 2: Two incoming lines of a switching station should be connected from two different upper grade substations or two different buses of the same substation. What’s more, the overall capacities of 10kV switching stations supplied by a HV substation should not more than the capacity of substation itself.

CASE STUDY AND ANALYSIS

The case analyzed in this paper is MV distribution network planning of Pujiang Central Town in Shanghai, P.R. China. After locations and capacities are obtained, ten 3×20MVA 35kV HV substations should be built in the planned year. By analyzing the load distribution, loads in the middle and southern town are denser, compared with lower load in vila districts at northern part. Based on the situation above, several places in the town are suitable for establishing switching stations, as HV substations supply for large areas.

By using principles and methods mentioned in the paper, numbers and locations of switching stations are achieved. Fifteen switching stations are needed to be built in the planned year, while eight of them adopt central mode as Fig.1(a) shows, and seven of them choose middle mode as Fig.1(b) represents. Concerning their specific locations, Fig.3 provides a practical plan. Because of the limited length, this paper could only introduce the planning solution of the southern town. Thick real lines in Fig.3 represent incoming lines of switching stations obtained by applying methods discussed above. And YJV-3×400mm^2 cables are used as incoming lines, all of which are supplied by two different substations or different buses of the same substation. From the figure, it is obvious to find that the planning solution could absolutely satisfy demands of actual urban MV distribution network to switching stations and their incoming lines, so as to prove the feasibility of the method discussed in the paper.

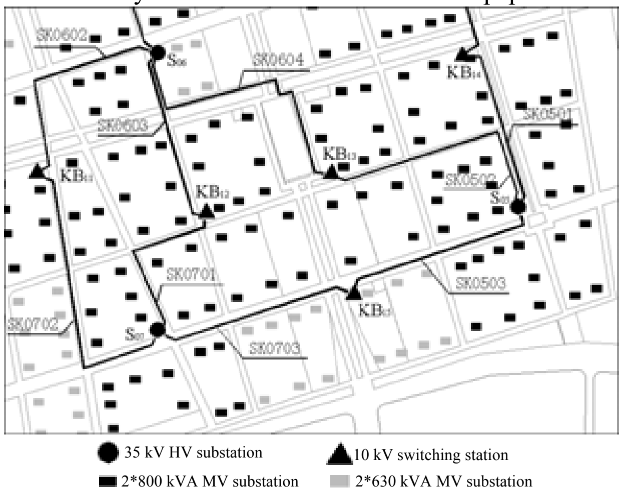


Fig.3 Sketch map of switching stations and their incoming lines in south of a center town in Shanghai.

CONCLUSION

Nowadays, cable network is replacing the overhead network progressively in the cities like Shanghai, then establishing 10kV switching stations reasonably has been taken into agenda. This paper firstly introduces three ordinary connection modes applied in urban network of Shanghai, then the issue of locating switching stations based on spatial GIS of distribution network is discussed using the method of choosing locations and deciding capacities of substations as its reference. And the automatic routing of incoming lines of switching stations is also concerned. Finally, the method mentioned in the paper is proved to be feasible through case study and analysis about practical distribution network planning.

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BIOGRAPHIES

Saiyi WANG was born in Ningbo, Zhejiang Province of P.R. China, on January 30, 1978. He received his Ph.D. in electrical engineering in Tianjin University. His research interests include power network planning and he is now working in Urban Power Supply Company, SMEPC, SGCC.