# Power Supply Meshes based Line Routing for Urban MV Distribution Network Planning

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Abstract: Considering that it is difficult to determine the load points or the locations of user access facilities in urban areas for the planning years, an optimization method for the routing planning of urban medium - voltage (MV) trunk lines is proposed based on power supply meshes. Firstly, based on the results of load forecasting and high voltage substation planning, power supply meshes are generated in the entire planning area according to the principle of selecting standby substations close to loads. Then, based on the thinking line of "trunk firstly, branch then", a shortest path based two-step algorithm is proposed to find the shortest trunk lines for the load centres of power supply meshes and the shortest trunk tie-line be-tween the load centres of each mesh. A numerical example shows that the method is practical and feasible, which can provide a reference for the reasonable routing scheme of medium voltage trunk lines.

## 1 INTRODUCTION

At present, most of the medium-voltage line routing planning methods need to know the layout of load points or the locations of user access facilities (such as distribution transformers, switching stations or ring network units) for the planning years (Song Meng, Liu Jian, Liu Gongquan, 2005; LI You, CHANG Xianrong, 2013; LU Zhi-ying, TIAN Shuo, CHENG Liang, et al, 2014; GE Shaoyun, WU Qing, et al, 2005; Koutsoukis N C , Georgilakis P S, 2017). Those methods may be suitable for the rural distribution network planning, but are not effective enough for the urban distribution network planning because of the difficulty in determining the locations of user access facilities for the planning years. In recent years, the power supply meshes based MV distribution network planning has been carried out successively in power grid enterprises (Ming Xu, Wang Zhuding, Wang Jingyu, etc, 2018; Wang Jingyu, Wang Zhuding, Zhang Yongbin, et.al, 2018; Gu yuan, 2018). For the large-scale MV distribution net-work planning, the main purpose of power supply meshes based planning is to transform the large-scale complex network planning of whole planning area into relatively simple and independent network planning for much smaller power supply meshes with the mesh generation being satisfying the technically feasible and economically optimal principle for the whole network planning.

In this paper, the power supply meshes are firstly generated in the entire planning area according to the principle of selecting standby substations near loads, and then based on the thinking line of "trunk firstly, branch then", a shortest path based two-step algorithm is proposed for MV line routing planning to find the shortest power supply trunk lines for the load centres of power supply meshes and the shortest trunk tie-line between the load centres of each mesh. It is shown through a numerical example that the thinking line and method presented in this paper are of great practical value for MV line routing planning.

## 2 MESH OPTIMIZATION GENERATION

In this paper, a mesh is defined as the moderately sized area supplied by the two substations (i.e., the main supply one and standby one). Based on the layout of main channels, the standby substations



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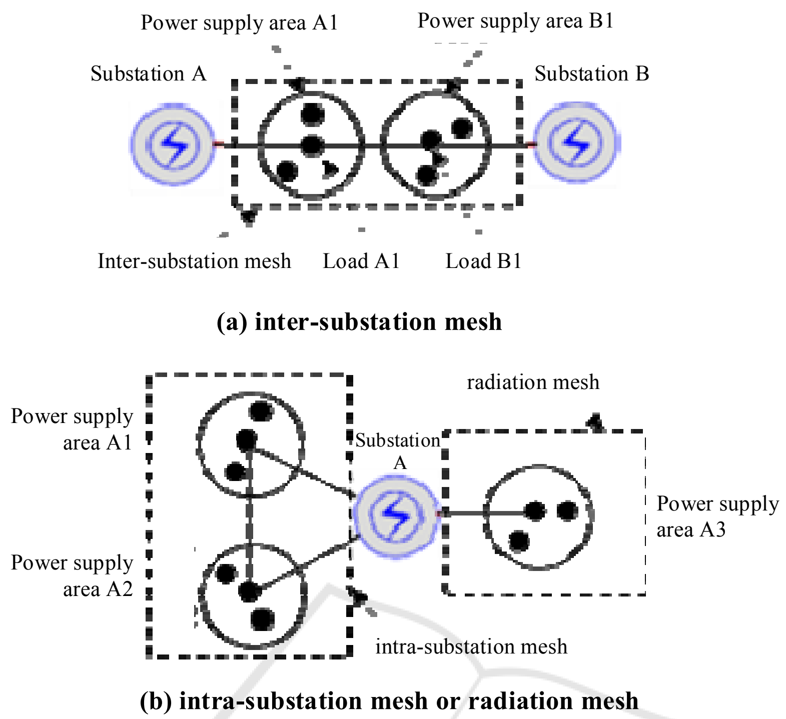



Figure 1. Diagrams of tie-line mode based mesh classification.

close to loads are selected in the whole planning area, resulting in the optimized meshes. The specific steps of mesh optimization generation are as follows (Ming Xu, Wang Zhuding, Wang Jingyu, etc, 2018):

(1) Determining the main supply substation for each load

Firstly, the power supply area of each substation is obtained according to the substation optimization planning (Wang Yujin, 2011; HUO Kailong, WANG Zhuding, ZHANG Daihong, et al, 2017), and then each substation is called the main supply substation of the loads in its power supply area. Taking the simplified system shown in Fig.1 (a) as an example, if loads A1 and B1 respectively are located in the power supply areas of substations A and B, the main supply substations of loads A1 and B1 are respectively substation A and substation B.

(2) Determining the standby substation for each load

Based on the layout of main channels and an allowable power supply radius, the possible standby substation close to a load is found. Taking Fig.1 (a) as an example, the standby substations of loads A1 and B1 are respectively identified as substation B and substation A because they are closest to loads A1 and B1 except for the loads' main supply ones.

(3) Generating inter-substation meshes

In this paper, the inter-substation mesh is defined as the area whose power supply substations can be transferred between two substations. The inter-substation mesh generation method is to firstly d classify the loads of the same main supply substation and the same standby substation into one supply area, and to then merge the two supply areas with opposite main and standby substations into one inter-substation mesh.

Taking Fig.1 (a) as an example, the main and standby substations of all loads (e.g. load A1) in supply area A1 are respectively substation A and substation B, and the main and standby substations of all loads (e.g. load B1) in supply area B1 are respectively substation B and substation A. Since the main and standby substations of supply area A1 and supply area B1 are opposite, they can be merged into an inter-substation mesh involving substations A and B.

(4) Generating intra-substation meshes and radiation meshes

In this paper, an intra-substation mesh is defined as the power supply area whose supply feeders can be transferred between the different feeders from the same substation, and a radiation mesh is defined as the power supply area with no standby supply substation or tie-line.

For the loads which cannot be classified into inter-substation meshes and are within the power supply area of a certain substation, they are classified into moderately sized areas based on expert experience or a load clustering method. Then, according to actual demand and the principle of selecting standby feeders close to load centres, the intra-substation meshes or radiation meshes are generated with the main channel layout and the power supply radius being satisfied, as shown in Fig. 1 (b).

(5) Manual intervention

Other issues of a power supply mesh may include clear physical geography and management boundaries, the same or close load classification levels, the same power supply reliability requirement, and the approximate same load sizes of supply areas. Planners need to use their experience to first analyse and then further adjust a mesh generation scheme through manual intervention.

# 3 NETWORK MODEL

Based on an urban road network, the network model of candidate channels for line routing and corresponding network node types are defined.

## 3.1 Channel Network

With an urban road network being regarded as the candidate channels for line routing, a channel network can be represented by the weighted undirected graph $G_g = (V_g, E_g, W_g)$, where $V_g = (V_{g1}, V_{g2} ... V_{gn})$ and $E_g$ respectively represent channel nodes and the set of edges between channel nodes (i.e., the segments of candidate channels), $W_g$ is the set of comprehensive costs for the corresponding edges in $E_g$.

As in (WANG Zhuding, QIU Jun, 2002), all network edges (or segments) can be divided into two subsets: 1) branches and 2) links. The branches are the edges constituting the graph tree of network along with the nodes, and the other network edges are the links.

## 3.2 Node Classification

Channel network nodes are geographically divided into three types: high voltage substation nodes, load centre nodes and common nodes. In Fig.2, node #51 is a substation node, and node #26 is a load centre node.

# 4 OPTIMIZATION MODEL OF TRUNK LINE ROUTING

## 4.1 Optimization Model

For each of relatively independent meshes, the optimization planning of trunk line routing is carried out with the objective of minimizing the overall cost of trunk lines with the connectivity of trunk line channels being satisfied and the supply areas' load centres being passed through by trunk line channels (hereafter abbreviated as a load centre constraint). The corresponding routing optimization model can be expressed as follows.

$$\begin{cases} \min \quad f_{g,i} = \sum_{b \in E_{g,i}} C_{g,b}, \qquad i = 1, \ldots, N_m \\ s.t. \quad \begin{array}{l} \varphi_{\mathrm{MV}}(E_{g,i}) = 1 \\ \vartheta_{\mathrm{MV}}(E_{g,i}) = 1 \end{array} \end{cases} \tag{1}$$

Where, $N_m$ is the total number of all power supply meshes, $E_{g,i}$ is the set of channel segments (or edges) for the trunk line in mesh i, $C_{g,b}$ is the comprehensive line cost of channel segment (edge) i, $\vartheta_{\mathrm{MV}}(E_{g,i})$ and $\varphi_{\mathrm{MV}}(E_{g,i})$ are respectively the judgment functions of load centre constraint and connectivity of trunk line channels corresponding to $E_{g,i}$ (Being equal to 1 represents that the load centre constraint or the connectivity is satisfied).

## 4.2 Determining of Load Centres

Let the coordinates of load point j in power supply area i be (xj, yj). Considering that a load moment (i.e., a load power multiplied by the distance between the load and its supply substation) is approximately proportional to the corresponding voltage loss, investment and operation cost, the selection of load centre position (xA,i, yA,i) for supply area i should minimize the sum of all load moments for the load points within power supply area i,. Thus, we have

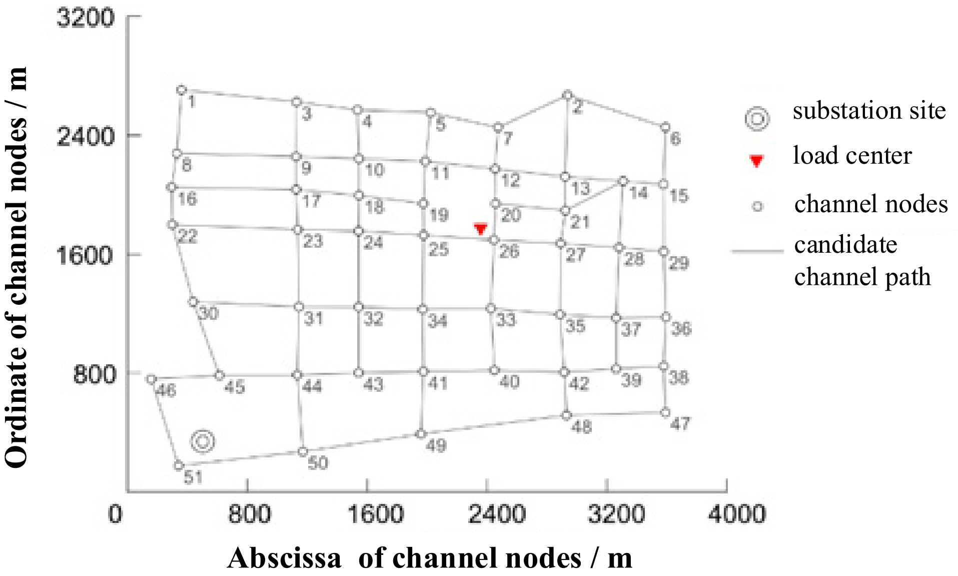



Figure 2. Diagram of node classification.

$$\min \; f_{A,i} = \sum_{j\in S_{LP,i}} P_j L_{ij} = \sum_{j\in S_{LP,i}} P_j \sqrt{\left(x_{A,i} - x_j\right)^2 + \left(y_{A,i} - y_j\right)^2} \qquad (2)$$

Where $P_j$ is the active power of load point j, $S_{LP,i}$ is the set of all load points within power supply area i, $L_{i,j}$ is the distance between the load centre of supply area i and load point j.

Let $df_{A,i} / dx_{A,i} = 0$ and $df_{A,i} / dy_{A,i} = 0$, the load centre coordinates of power supply area i can be given by

$$x_{A,i} = \frac{\sum_{j\in S_{LP,i}} (P_j x_j / L_{ij})}{\sum_{j\in S_{LP,i}} (P_j / L_{ij})}, \quad y_{A,i} = \frac{\sum_{j\in S_{LP,i}} (P_j y_j / L_{ij})}{\sum_{j\in S_{LP,i}} (P_j / L_{ij})} \qquad (3)$$

Given the initial load centre location of a power supply area, the final load centre location can be obtained iteratively by an alternating method of location and power allocation (Wang Yujin, 2011).

## 5 SHORTEST PATH BASED TWO-STEP ALGORITHM

If the load centres of supply areas are known, based on the shortest path algorithm (Gong Qu, 2009), the routing of trunk lines from the load centres to their main supply substations is performed firstly, and then the routing of the trunk lines between the two load centres in a mesh is carried out.

(1) Routing from a load centre to its main supply substation

Firstly, a virtual node is created and the comprehensive costs between the virtual node and all main supply substations are assumed to be zero, while the comprehensive costs between the virtual node and the other channel network nodes are assumed to be a large number. Then, taking the virtual node as the root node of a shortest path tree, all other channel network nodes are added to the shortest path tree one by one according to the adjacent relationship between the nodes and the comprehensive line costs of paths between them and the root node by using a shortest path algorithm, until the shortest path tree contains all load centre nodes. Based on the parent node information, the shortest path from a load centre node to its main supply substation node is obtained (i.e., the trunk line path).

(2) Routing between load centres

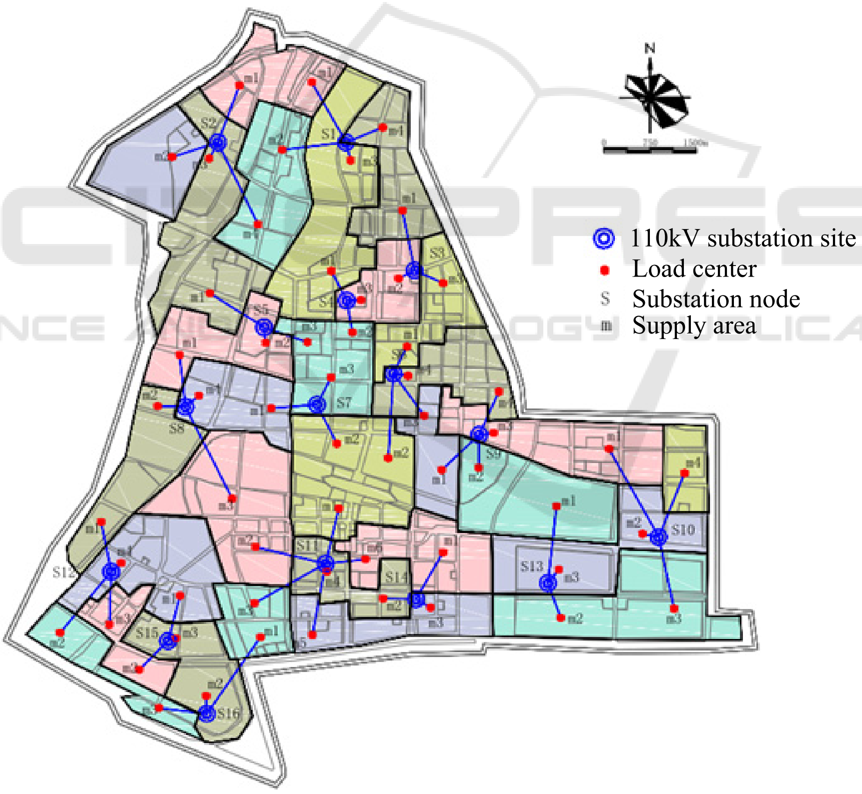
Firstly, a virtual node is created and the comprehensive costs between the virtual node and all load centres are assumed to be zero, while the comprehensive costs between the virtual node and the other channel network nodes are assumed to be a large number. Secondly, taking the virtual node as the root node of a shortest path tree, all other channel network nodes are added to the shortest path tree one by one according to the adjacent relationship between the nodes and the comprehensive line costs of paths between them and the root node by using a shortest path algorithm, until the shortest path tree contains all channel network nodes. Then, the basic loop of a link is identified based on the information of its end nodes and parent nodes (WANG Zhuding, QIU Jun, 2002). Finally, the shortest inter-substation or intra-substation path is extracted from the basic loop with the smallest comprehensive cost for each inter-substation or intra-substation mesh (i.e., the trunk tie-line path).

## 6 A NUMERICAL EXAMPLE

The following example is to perform the routing of 10kV trunk lines in an urban area where there are 16 110kV substations, 387 channel segments, 227 network nodes and 58 supply areas.

The meshes produced by the presented method are shown in Fig.3 (a). The adjacent patches with the same filling colour belong to the same mesh, and only two of them are radiation meshes for which only the trunk line paths need to be found.

According to the generated meshes and the load centres of supply areas, the routing results of trunk lines are shown in Fig.3 (b) where the purple channels contain 2 feeders, and the other channels contain 4 feeders. For the line wiring modes of different meshes, the typical modes such as double loops, N-supplies and one-backup and multi-segment moderate tie connection can be selected according to the actual situations (such as the load density, power supply capacity, economy and operability).




(a) Generated power supply meshes


(b) Trunk line routing scheme

Figure 3. Generated power supply meshes and trunk line routing scheme.



## 7 CONCLUSIONS AND DISCUSSIONS

A new method is proposed for the trunk line routing for urban medium voltage distribution network planning.

(1) A new thinking line is proposed for line routing in this paper: based on generated meshes, the routing of trunk lines is firstly performed along the channels of a road network, and then the specific scheme of user access to the trunk lines will be made in the future when the locations of user access facilities are known.

(2) To simplify the problem solution, the supply areas are taken as the basic units of a power supply mesh, and a power supply mesh may be taken as the basic unit to carry out the trunk line routing. With the constraints of channel resources and load centres being satisfied, the shortest trunk line paths for all supply areas and the shortest trunk tie-line paths for all supply meshes are determined by a shortest path algorithm.

(3) The proposed method results in a planning scheme of clear power supply areas, reasonable power supply radii and simple tie-lines, showing that the method is practical and can provide a reference for the trunk line routing of urban medium voltage distribution network planning.

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