Substation Optimization Planning Based on the Improved Orientation Strategy of Voronoi Diagram

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***Abstract*—Voronoi diagram is an important branch of computational geometry,which plays a significant role in both computational geometry theory and application. Voronoi diagram has been widely applied in many fields,especially in the field of geography spatial facilities location.In this paper, Voronoi diagram was applied in power system substation optimization planning,and it advanced an improved orientation strategy , namely the most greatly convex polygon electrical load orientation strategy which is used in the power syetem substation optimization location.The method of this paper could effectively combine the computational geometry and the power system substation optimization planning.The efficiency and applicability of this method have been proved by the case study of 220kV substations optimization planning in a city.**

Keywords—voronoi diagram; power syetem substation optimization planning;the most greatly convex polygon electrical load orientation strategy

I. INTRODUCTION

Voronoi diagram can be called Tessellation Polygon, which was proposed by a Russian mathematician named M.G.Voronoi in 1908.He limited the effective range of each discrete point in mathematics,and the range was defined as the voronoi diagram[1]. Voronoi diagram has been widely applied to many fields,especially the field of geography spatial facilities location[2].

Nowadays,Voronoi diagram has already been applied to power system substation optimization planning,too.In the process of the substation optimization planning, references[3],[4],[5] all adopt the most greatly hollow circle orientation strategy that the center of the most greatly hollow circle is the priority substation site.However,those methods didn't take into account the conditions that the power system load would not distribute equally in the whole hollow circle beacause of the difference of the economic geography . Especially in the higer voltage of the substation optimization location,the hollow circle may cover more widely area in which the electrical load may distribute irregularly bescause of the complicated geographical environment. Thus it can be seen that it can not very well take into account the effective utilization of substation when adopting the the most greatly hollow circle orientation strategy.

To solve this problem,this paper proposes an improved orientation strategy ,namely the most greatly convex polygon electrical load positiong strategy.And the method can not only make the distribution of substations more reasonable and enable the the structure of power grid more rational,but also enhance the effective utilization of substation.This paper may effectively apply the computational geometry to the power system substation optimization planning. The efficiency and applicability of this method have been proved by the case study of 220kV substations optimization planning in a city .

II. THE BASIC CONCEPT AND CHARACTER OF THE VORONOI DIAGRAM

A. The Basic Concept of Voronoi Diagram

The mathematical definition of voronoi diagram can be describe as below:

Suppose a control set of points on the plane: P={P1,P2,…,Pn} and any point of the control point set of the voronoi diagram is defined as the following formula:

$$V(P_i)=\{x\in V(P_i)\,|\,d(x, P_i)\leq d(x, P_j), j=1,2,\cdots,n, j\neq i\} \quad (1)$$

Where $d(x, P_i)$ (or $d(x, P_j)$) denote the euclidean distance between the point x and P_i (or P_j) which is in the control point set,and $P_i \neq P_j$,$i\neq j, i,j\in\{1,2,\cdots,n, i\neq j\}$.

The region $V(P_i)$ can be called the voronoi polygon in which the vertex is P_i.The voronoi polygon of each point together constitutes the voronoi diagram which is in the sense of the nearest point.

Voronoi diagram, in the geometric sense ,can be looked upon as each point which is in the point set $P=\{P_1,P_2,\ldots,P_n\}$ expand outward as the same speed until they meet each other and come into being the diagram.The outermost points may form the exoteric regin.In addition,the rest points may all form a convex polygon.And the descriptions of those points are great similarity with the substation location and the division of power supply area,namely the polygon of each point is one's power supply area.Such as figure 1.

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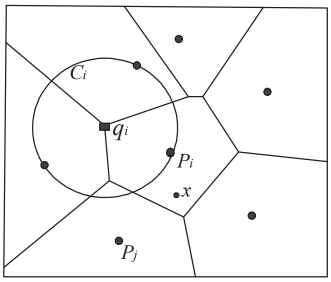

Figure 1. Voronoi Diagram

B. The Character of Voronoi Diagram

- In voronoi diagram,one vertex P_i in the space may uniquely correspond to a voronoi polygon. Voronoi diagram possess the property that any point inside the polygon (the vertex is P_i)is closer to the vertex P_i than any other vertex.This property is the same as the character that the power system substation should be located at the center of the power system load.
- The point q_i (in figure 1) is the intersection of three voronoi diagram borders. Therefore,the voronoi diagram is a plane which contains three points at least.
- We draw a circle C_i in which the center of the circle is the point q_i,and the circle C_i should pass through the vertexes(three or more) which link together with the point q_i.Then the circle C_i don't contain any other vertex in point set P.The circle C_i is called as the hollow circle.The circle wih largest radius can be called as the largest hollow circle.In voronoi diagram,the built-up substation location can be seen as the point set P,and the point set q_i are most likely to be the candidate substation locations.
- In voronoi diagram,if we add or remove a vertex,it generally affects the adjacent space which is closed to the vertex,that is,the changes only affect the local area in the voronoi diagram.It shows that if we apply the voronoi diagram in the power system substation optimization location, it only needs to adjust the supply of regional and local network connection,and this feature is accord with the engineering characteristics of the construction of power grid.

III. THE IMPROVED ORIENTATION STRATEGY

A. The Maximal Hollow Circle Orientation Strategy

The maximal hollow circle orientation strategy is based on the multi-distribution and short radius,and it takes advantage of the hollow circle character.The locations of the point q_i may be able to be the new substation locations,as shown in figure 1.If we need to build a new substation,the center of the maximal hollow circle(the largest radius one) would be the best location.And if we are goning to build m new substations(m >1) which belong to the multi-source allocating address,and then sort the point set q_i by the circle C_i radius in descending order,the top m points which are in the center of the circle C_i may be the new substation locations.The maximal hollow circle orientation strategy may make the distribution of substations more reasonable and enable the the structure of power grids more rational.

B. The Improved Orientation Strategy—The Most Greatly Convex Polygon Electrical Load Orientation Strategy

Actually ,the maximal hollow circle orientation strategy is founded on the status that the power load distribute equably on the hollow circle.However,It don't take into account the fact that the distribution of the power load is anomalous because of the difference of the economic geography condition in the hollow circle.As a matter of fact,in the process of substation optimization location,especially in the higer voltage substation,the power load distribute very irregularly as a result of the wide coverage planning region which is covered with complex terrain and geomorphological structure.Some region may have high electrical load density because of the advanced economy and superior geographical location.However,some region may have low electrical load density for there are maybe vast mountains, rivers,lake and forest covering with it without factory and mankind's activity.

For example,figure 2 brings forth the regional of one city with 220kV substations voronoi diagram which has been simulated in MATLAB software,and the real line represents the the boundaries of the city,and the dotted line represents the boundaries of the mountains, rivers,lake and forest which are the non—power supply area. In order to illustrate the problem effectively,we suppose that the electrical load density in the built-up area are about the same,namely,the regions which are outside the dotted line and in the real line have the same electrical load density.We also suppose that we need to add a new substation in the planned period.

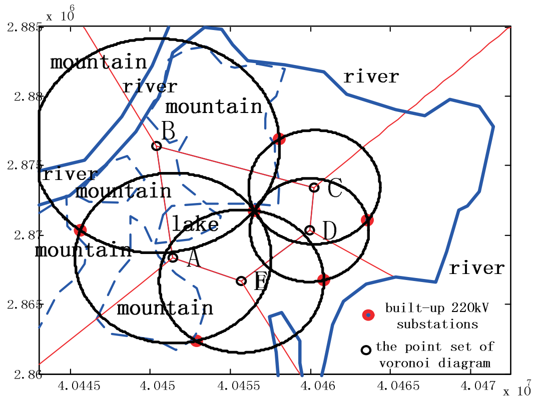

Figure 2. Voronoi diagram of 220kV substations in one city

In figure.2, A~E points are the voronoi diagram point set q_i and the vertex are the built-up 220kV substations in the voronoi diagram.Figure 2 shows that the priority of the point to be the new substation is B point,A point,E point,D point and C point wnen according to the maximal hollow circle orientation strategy.And the follow three figures shows that the effective power supply area of the new substation when the point B,point E and point C respectively become the new substation, respectively.

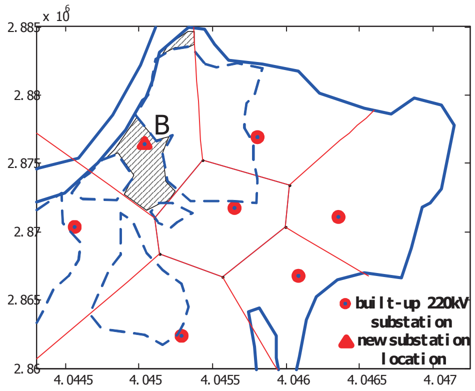

Figure 3. Effective power supply area when B is the new substation

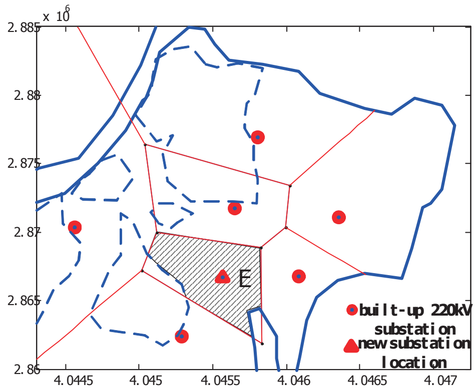

Figure 4. Effective power supply area when E is the new substation

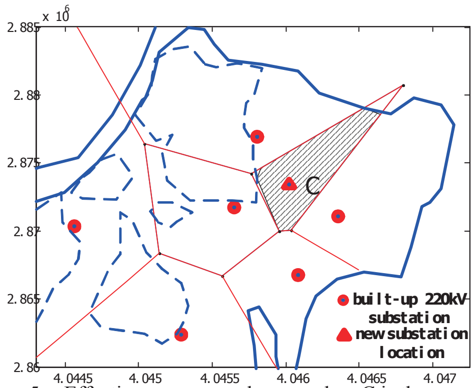

Figure 5. Effective power supply area when C is the new substation

The shadow area expresses the effective power supply area in above figures.We can regard the effective power supply area as the shadow area because the electrical load density in the built-up area is all about the same.We can easily draw a conclusion that the practical priority of the point is C point,E point and A point.However,adopting the maximal hollow circle orientation strategy ,the priority of the point is A point,E point,C point.Thus it can be seen that it can't enhance the effective power supply area if we adopt the maximal hollow circle orientation strategy in substation optimization location.

In fact,the essential of the maximal hollow circle orientation strategy is that we choose the center of the largest circle as the new substation,and the largest circle may enable the point possess more effective power supply area when the distribution of electrical load is symmetrical in the full of the circle .

Thus,this paper advances the most greatly convex polygon electrical load orientation strategy to solve the problem that the electrical load may distribute unequally in the largest circle. The stages of research are as follows:

a) Construct the voronoi diagram in which the vertexes of the voronoi diagram are the built-up substations.

b) Select the best load moment of the next voltage substation(110kV substation in this paper) and determine the threshold value ω by the average electrical load density in the planned period.The threshold value ω is the minimum allowable values of the distance between the two substations.And calculate the value d_{ij} which is the distance between the point q_i and q_j ($i \neq j, i,j=1,2,\cdots,n$),if the value d_{ij} is less than ω,we should compare the value of the radius that the point q_i and q_j which are the center of the maximal hollow circle in the voronoi diagram, respectively.Then we should delete the point q_x from the point set that its corresponding radius is the less one.

c) Construct the voronoi diagram in which the vertexes of the voronoi diagram are the built-up substations and the point q_i is one of the modified point set.And then mesh the convex polygon which the point q_i is corresponding of.In the course of gridding,the Grid Cell can be the regular squareness ,a jerkwatertown or functional districts. Follow the formula below to calculate the load W_i in the convex polygon:

$$W_i = \sum_i^n p_i = \sum_i^n S_i \times \varepsilon_i \tag{2}$$

Where, p_i ,S_i,ε_i denotes the planning power load,grid cell area and electrical load in the i grid cell, respectively. In addition,the value of ε_i may equal to zero while the grid cell is covered with non-power supply area such as the mountain, river,lake,forest ,etc. The result of the gridding of the convex polygon of B point is as shown in the following figure:

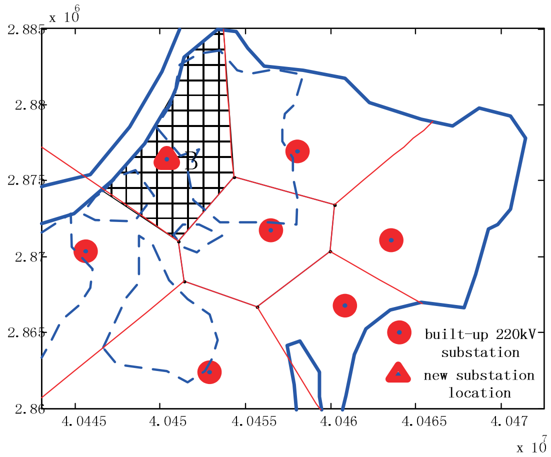

Figure 6. The result of the gridding of convex polygon of B point

If the electrical load density of the built-up area in planning region is all about the same or proportional,we can compare the power supply area instead of calculating the power load W_i in the convex polygon.

After calculating the power load W_i in each convex polygon of the point set q_i,we sort the value of the W_i in descending order.

d) Suppose we need to add m new substations,the top m points which are corresponding of convex polygon and have been sort by the value of W_i in descending order would be the m new substations location.

e) The chosen substations location(point q_i)may be likely to sit on the region which is not suitable for construction such as lake,street, the busiest section of town,etc.Thus this paper refer to the document[6],the environment of the new substations are investigated.We should define the plan for moving the substations to aim at substations which need the positional adjustment.Fit together all the capable plans from which we choose the most economical and practical one.

f) Construct the voronoi diagram again in which the vertexes of the voronoi diagram are the built-up substations and the positional adjustment substations.The region of the convex polygon(the vertex is P_i) is the power supply area that the vertex P_i is the substation location.

IV. APPLICATION

Take the city 220kV substation optimization planning as an example as shown in figure 2, Its total area is about 424.3 square kilometers.The percentage of forest cover about 30% in the hilly city(as shown in figure 3).The total power forecasting load in the planned year is about 2000MW and the electrical load density of the built-up area is about 238kW/ha.There are six built-up substations now,and it need to add three new substation in the planned year by calculation.

The application of this paper are carried out in the MATLAB simulation software,the priority of the point to be the substation location is A>C>E>B>D when adopt the the most greatly convex polygon electrical load orientation strategy,And the new substation locations by adjusting and their power supply area are as shown in the following figure when the three point A,C,E are the new substation locations.

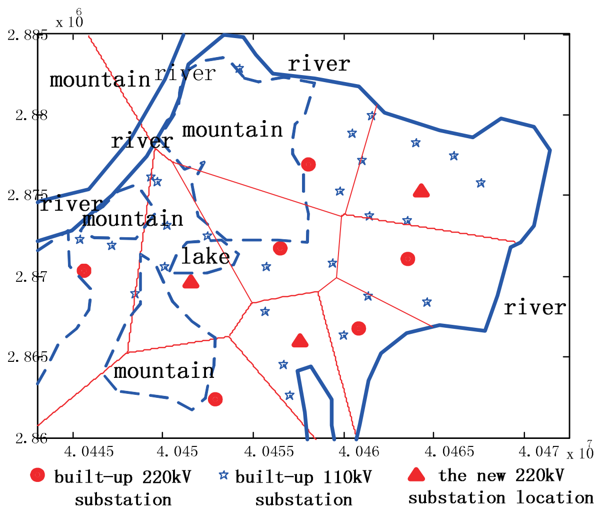

Figure.7 The result of the 220kV substations optimal planning based on the voronoi diagram

V. CONCLUSION

This paper put forward an improved orientation strategy—the most greatly convex polygon power load orientation strategy which ccan effectively take into account the fact that the difference of the economic geography may make the electeical load distribute unequally.

The improved orientation strategy may not only make the distribution of substations more reasonable and enable the structure of power grids more rational,but also enhance the effective utilization of substation .

According to the result of the application,the research methods of this paper possess its own exceptional advantages, The algorithm is simple and practical,and enable the choosing of the new substation location more efficient and rational,especially in the higher voltage substation optimization location.And it is made to solve the substation optimization planning in another way.

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