

# Substation Placement Optimization Method Using Delaunay Triangulation Algorithm and Voronoi Diagram In East Java Case Study

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**Abstract**— In anticipation of the growth of electricity demand in the region, required the addition of new substations and the development of substation-substation that has operated previously. State Electricity Company developed a plan to determine the number, capacity and location of the substation in order to reconcile the needs of electric current with future electricity needs. This plan requires the identification of the electrical load in each region as well as the capability development of substations existing substations. Expenses allocated to a substation based on the distance between them by seeking the minimum transportation cost. Cost is optimized for all of the substation through the allocation of the burden to the appropriate substation. This final project is aimed at optimizing and find the service area (service area) by APJ by applying Voronoi diagram and Delaunay Triangulation.

**Keywords**—component; Substation; Optimization; Voronoi Diagram; Delaunay Triangulation Algorithm..

## I. INTRODUCTION

To meet and anticipate growth in electricity demand in the region, required the addition of a new substation and substation development that has gone before. State Electricity Company (PLN) develop a plan to determine the number, capacity and location of substations in order to reconcile the needs of electric current with future electricity needs. This plan requires the identification of the electrical load in each area as well as capacity development of substation-existing substations.

Expenses allocated to a substation, based on the distance between them by seeking the transport costs to a minimum. Cost is obtained by summing the burden with the distance to the substations that serve them. This fee is optimized for all of the substation through the allocation of appropriate load substations.

In addressing these matters the authors propose some resolution through this final project by applying the method of Delaunay Triangulation Algorithm and Voronoi Diagrams to help plan the location of new substations optimally. Optimal plan will meet the needs of the power grid, the allocation in the right area, and considering the condition of the surrounding community

The contents of the paper in the next section will explain some parts like: section two describes the literature used, Voronoi Diagram, Delaunay Triangulation Algorithm, geographic information system (GIS), distribution system consisting of substations, location, capacity and its service area later described also the point of peak load. Section three described how the modeling methods used in ArcMap application, how to implement the network service area and unite the two methods with data obtained from PLN. Section four describes how the method gets the service area network and power distribution lines of a number of pre-installed feeders, and from that we can see which areas not reached by electricity service area. Section five is the planning done for the years ahead, in this section is taken three APJ region. The final section is the conclusion of the work process optimization.

## II. LITERATURE REVIEW

### A. Voronoi Diagram

Voronoi Diagrams in this paper are applied to get a service area of each substations location has been established through the p-medians. Obtained a number of points (coordinates) based on the results p-median calculation for  $p$  point in the plane Euclidean[1].

$$P = p_1, p_2, \dots, p_n \quad (1)$$

All regions of this field is connected with elements closest  $P$ , with regard Euclidean distance.

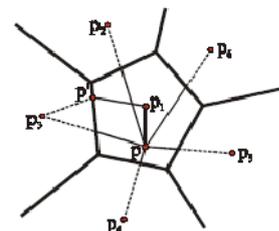


Fig.1. Voronoi Diagram On the Flat Field

Explanation Voronoi Diagram more generally is as follows[2]:

There is a set coordinates  $P = p_1, p_2, \dots, p_n$  where  $2 \leq n \leq \infty$  and  $x_i \neq x_j, i, j \in I_n$ . Regions obtained from equation:

$$V(p_i) = \{x / \|x - x_i\| \leq \|x - x_j\|, \text{ for } j \neq i, j \in I_n\}^{(2)}$$

A VORONOI polygons connected with  $P_i$ . Based on the above equation, will be acquired set  $V[3]$ :

$$V = \{V(p_1), V(p_2), \dots, V(p_n)\} \quad (3)$$

### B. Delaunay Triangulation Algorithm

Delaunay is a main segmentation algorithm—merging algorithm and point by point insertion method of Triangulation algorithm, the algorithm of the current Triangulation using less, segmentation—merging algorithm relatively more complex, so little data in the cases, point by point insertion method is the simplest, occupying less memory approach[4]. The three corresponding points Voronoi adjacent polygons are the culmination of a public and this is also vertex Delaunay Triangulation circumcircle the center. Voronoi polygon by polygon composed of a group of continuous, polygon boundary by linking the two neighboring segments of the perpendicular bisector line. Delaunay Triangulation is shared with an adjacent Voronoi polygon edges relevant point connection from the triangle[5].

Delaunay point by point interpolation algorithm for the basic rules of each triangle is not included within the circumcircle other coordinates. Some of the basic properties of Delaunay Triangulation[6]:

- a.  $ab \in TD(S) = \text{Vor}(a) \setminus \text{Vor}(b)$  is an edge of  $DV(S)$
- b.  $c \in abc \in TD(S) = \text{Vor}(c)$  is a vertex of  $DV(S)$

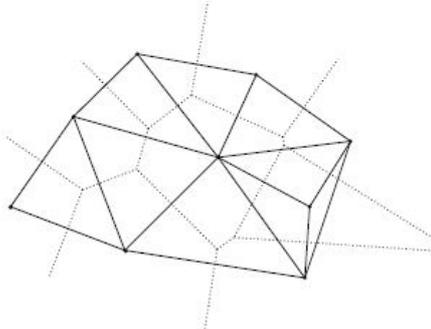


Fig. 2. Delaunay Triangulation from the Point and Make Vertices

- c.  $v_{abc}$  is the circumcenter of  $\_abc$
- d.  $TD(S)$  is a triangulation of  $S$  such that the circumcenter of each triangle is empty i.e. no input point lies inside it.
- e. A pair  $ab \in TD(S)$ , a circle  $C_{ab}$  passing through  $ab$  such that  $\text{interior}(C_{ab}) \cap S = \emptyset$

### C. Geographic Information System

Is a system that about the location and the phenomena that occur. The system also includes a spatial decision-making and implementing it in the specified location[7].

The system-based computer that functions for entering, storing, processing and analyzing data for purposes related to mapping and planning [8].

Geographic information system also has several parts, as follows:

- a. Data Manipulation and Analysis
- b. Data Output
- c. Data Management
- d. Data Input

### D. Power Distribution System

#### 1) Substation

The main purpose of the substation is to channel high-voltage electric power (500 KV / 150 KV) transmission or sub-transmission level, lowering the voltage (150 KV to 20 KV), then channeled into several primary voltage primary voltage feeder / feeder to be distributed to area around.

Performance substation is more important than cost substations indicated. Substation reconcile transmission system to the distribution system, so the substation plays many roles to affect the total cost and performance of both systems. Proper planning at the level of substation is a key to the success of planning distribution system[9].

Substation represents the last point of distributed transmission system. Substation was the location where the transmission system should supply power for total load on all feeder connected to the substation the (level distribution).

#### 2) Location substation, capacity and service area

Electricity supplied to each consumer comes from substation located adjacent to consumers or can just came from more distant places. Territorial service area electricity service area is divide into several substations, as illustrated in the figure below[10].

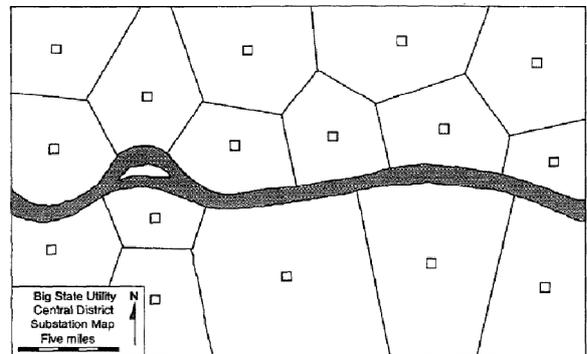


Fig.3. Territorial Division Based Service Area Substations Parent

Each substation (denoted as small box) that serve specific area (the boundaries of the line in the figure) must have sufficient capacity to serve the maximum demand of all consumers in the area. Service area in this case in the form of dots load scattered around the substation. The load point is point demand from consumers who are not necessarily the same between one consumers with other consumers, depending on the characteristics of each customer

For consumer's industry, the load required will certainly be greater if compared to household consumers, so

as two identical service area, the total load is not necessarily the same.

Substations existing or planned always include the best location in terms of economic and in terms of operations, reliability and service. A service area can be said to be optimal if in the area served by substation most 'good' compared to other substations in terms of overall system cost reduction[11].

The addition of new substations will be done when the capacity of the substation-station in the area (already pre-installed) have been unable to meet demand consumer. Thus, the addition of a new substation to be as much as possible to overcome substations overloaded.

### 3) Center of gravity of loads

The best way for substation can serve consumers to the maximum but the minimum cost is put a substation in the central service area or load center. Here is how to determine the location of the substation with consider another substation has been installed previous:

- a) Draw a straight line between the substation layout plan with each new substation adjacent.
- b) Draw a line perpendicular in each of the line (dividing line in step 1 into two parts with an angle elbows).
- c) The lines generated in step 2 and mutual intersect, showing the service area of substations new.
- d) Target load (capacity) to be paired at substation the new aircraft is the total of the load around the service area.

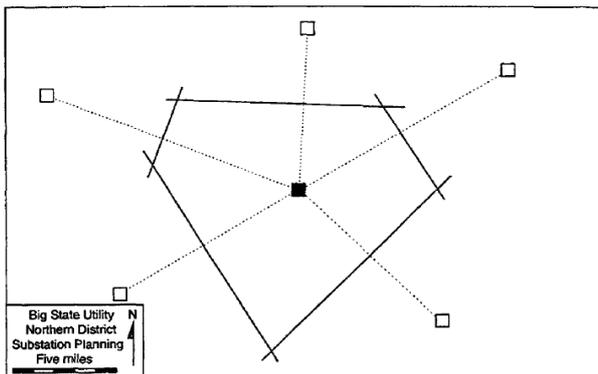


Fig.4. Gravity Center Load

The impact of laying new substation can reduce the burden borne by the substation-substation in the vicinity. This will affect the boundaries service area of each substation[12].

## III. DESIGN MODELLING

### A. Modelling Voronoi Diagram Into ArcMap 10.3

In ArcMap model a method cannot directly process with its data, there should be a tool that contains a script and method. The tools in ArcMap application wrapped into one by the name of toolbox. In the toolbox can accommodate more than one function or method, but can only be used in the python programming language. Voronoi Diagram

method used here to determine the service area is determined from the point vertices of each APJ feeders[13].

### B. Modelling Delaunay Triangulation Algorithm into ArcMap10.3

Then implemented method of Delaunay Triangulation Algorithm in order to get the electricity distribution network and service area is optimal. This method is executed on Voronoi Diagram methods that have previously been implemented, using the point vertices of the feeder as well. The output of this method is a line that forms a triangle from the point vertices.

### C. Implement Area Network Services According to Data from PLN

In an effort to show the maximum results in accordance with the circumstances that are owned by PLN (State Electricity Company)[14], the author makes per APJ region by way digitization based on the original data. Then produce a map format containing file .shp per APJ regions.

### D. Implement Two Methods with Existing Data

Once the method has been incorporated in the toolbox, per APJ region was formed and point substations and feeders have been applied, then the next step is to implement both methods with existing data. Both methods are Voronoi Diagram and Delaunay Triangulation Algorithm processes the data in the form of point feeders in order to create a service area as well as the electric distribution network that will be used as a parameter to determine the location of the new substation.

### E. Comparing the Similarity with Data Created from PLN

Based on data that has been planned by PLN for the construction in 2016, there were about 9 new substations will be built which are spread throughout Eastern Java. This study will prove that the results will be produced by the method of Voronoi Diagram and Delaunay Triangulation Algorithm is the same to the results issued by PLN.

## IV. IMPLEMENTATION

### A. Implementation of Service Area Network

At this stage, discussing how to build a service area network (APJ) in accordance with the data obtained from PLN East Java Distribution. Due to the one generated file .cdr format (file format in Corel Draw application), it is required to export prior to .jpg file format.

There are as many 16 regions APJ specified by PLN, i.e. APJ Ponorogo, Mojokerto, Madiun, Kediri, Bojonegoro, Jember, Situbondo, Malang, Banyuwangi, Pasuruan, Pamekasan, Sidoarjo, West Surabaya, Gresik, South Surabaya and North Surabaya. Then divided into 16 different colors corresponding to the number of APJ. Each color representing a coverage area of APJ in East Java region.



Fig. 5. Service Area Network (APJ)

**B. Substation Project Implementation Existence in ArcMap**

At this stage it will be shown how to project substation existence on a map APJ previously in digitized. Here are the steps being taken in order to show existing substations:

- Step 1. Open the attribute table of data to be calculated geometry.
- Step 2. Add a new column to the coordinates x and y.
- Step 3. Then right-click on a column to coordinate-calculate geometry. And the result will be show in the Figure 6.

There were approximately 97 substations have been installed at this time and is active at areas East Java. To facilitate the search for areas lacking electricity distribution, the authors implement it into the map substations have been installed by looking for the location of the point coordinates in the form of longitude and latitude.



Fig. 6. Substations Existence in East Java

Titik Koordinat					
FID	Shape *	Id	Nama Gardu	Latitude	Longitude
13	Point	0	ALTA PRIMA	-7.206809	112.637966666667
19	Point	0	BABADAN	-7.40406	112.680333333333
99	Point	0	BABAT	-7.131417	112.095
4	Point	0	BALONG BENDO	-7.4129	112.557816666667
100	Point	0	BANARAN	-7.83426	112.032
57	Point	0	BANGIL	-7.601045	112.779133333333
73	Point	0	BANGKALAN	-7.058713	112.795
40	Point	0	BANYUWANGI	-8.189419	114.356133333333
38	Point	0	BLIMBING	-7.940662	112.64265
44	Point	0	BLITAR	-8.073393	112.185916666667
54	Point	0	BOJONEGORO	-7.181542	111.865483333333
76	Point	0	BONDOWOSO	-7.937181	113.833
112	Point	0	BRINGKANG	-7.257484159480	112.647687336738
24	Point	0	BUDURAN	-7.390881	112.760183333333
49	Point	0	BULUKANDANG	-7.695456	112.68835
94	Point	0	BUMI COKRO	-7.605737	112.725
101	Point	0	CARUBAN	-7.581714	111.675
27	Point	0	CERME	-7.198218	112.575366666667
14	Point	0	DARMO GRANDE	-7.28738	112.674516666667
56	Point	0	DOLOPO	-7.7799	111.52385
18	Point	0	DRYOREJO	-7.368556	112.603983333333
7	Point	0	GEMBONG	-7.241306	112.751333333333
77	Point	0	GENTENG	-8.380345	114.146

Fig. 7. Longitude and Latitude From Each Substations

Then at substations parent is also classified into 3 capacities, which is 500 KV, 150 KV and 70 KV. For substations with capacity of 500 KV much as 6 units, as many as 77 units of 150 KV and 70 KV 14 units. Each substation spread into 16 APJ.



Fig. 8. Capacity of Substation

**C. Implementation of Voronoi Diagram Method Form Toolbox**

In this step, author use the method of Voronoi Diagram to get the service area of each feeder are there, so when it was getting service area will see which areas that lack or have not even covered electricity distribution entirely. Feeder in the map symbolized by stars.

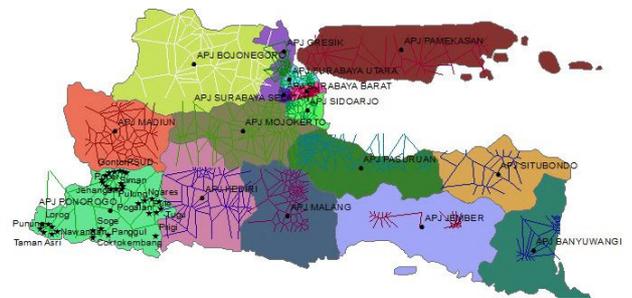


Fig. 7. Voronoi Diagram Implementation

To facilitate the use of the method, use a tool such as a toolbox that can be filled with functions and methods, but this toolbox can only read the python programming language. [15]. The process of making the method Voronoi Diagram in the form toolbox python can be seen from the following flowchart.

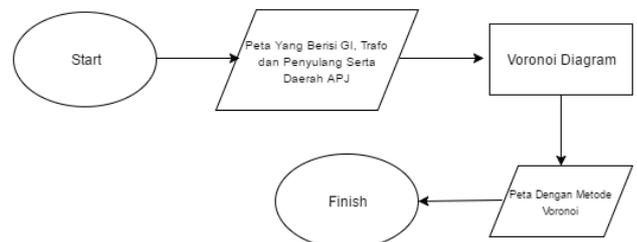


Fig. 7. Modelling FlowchartVoronoi Diagram Toolbox

**D. Implementation of Delaunay Triangulation Algorithm Method Form Toolbox**

In this step, author use the method of Delaunay Triangulation Algorithm to get the electricity distribution network system of any existing feeders and the results of Voronoi Diagram in the previous step.

Delaunay Triangulation Algorithm here using points feeders and a service area formed by the method of Voronoi Diagram to create a system of power distribution network, there are as many as 1.161 feeder is mounted for East Java area. This implementation results on a map in ArcGIS applications in the form of a triangular area and connecting line between the feeders. Feeder in the map symbolized by stars.

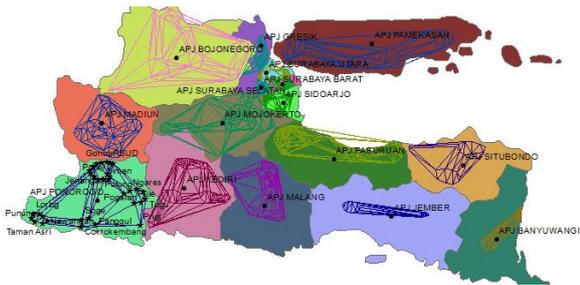


Fig. 8. Delaunay Triangulation Algorithm Implementation

Same as Voronoi Diagram, to facilitate use of the method use a tool such as a toolbox that can be filled with functions and methods. The process of making the method Delaunay Triangulation Algorithm in the form toolbox python can be seen from the following flowchart.



Fig. 8. Delaunay Triangulation Algorithm Toolbox

**E. Implementation Application of Two Methods in Data Substation, Transformer and Feeder**

After the method in the toolbox has been created, the next step is to combine the transformer, feeder and existence data to find the optimal locations to create a new substation and service area.



Fig. 9. Some Parts Final Implementation

**V. EXPERIMENTAL RESULTS**

**A. Forecasting for APJ SBU**

The following is the result of forecasting for the following APJ region SBU (Surabaya Utara), a total of 6 new points where possible. The results indicated by flag symbol.

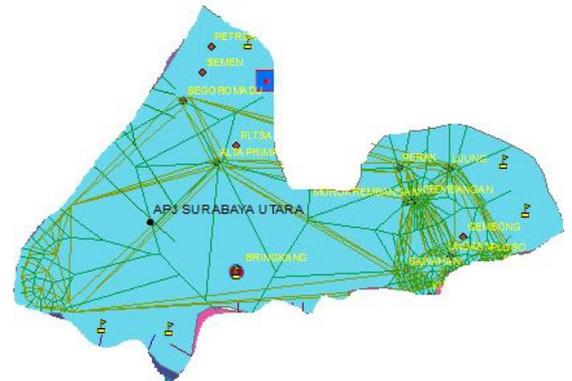


Fig. 10. Forecasting for APJ SBU

**B. Forecasting for APJ MJK**

The following is the result of forecasting for the following APJ region MJK (Mojokerto), a total of 4 new points where possible. The results indicated by flag symbol.

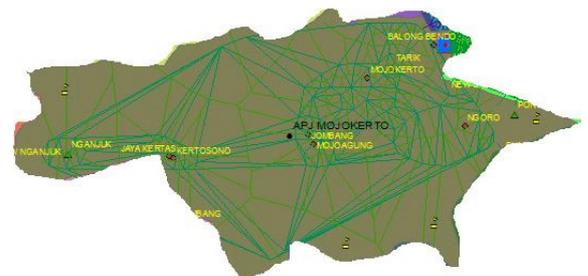


Fig. 11. Forecasting for APJ MJK

**C. Forecasting for APJ BJB**

The following is the result of forecasting for the following APJ region BJB (Bojonegoro), a total of 5 new points where possible. The results indicated by flag symbol.

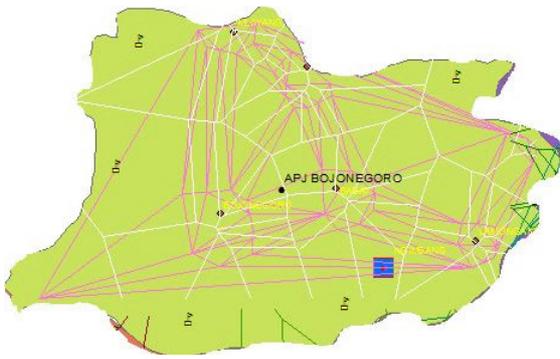


Fig. 12. Forecasting for APJ BJJ

#### D. Conclusion

Electricity is the primary requirement for human life. In Indonesia electric power can be generated from several sources such as light sun, water, steam, gas and other sources. Along with his walking when demand for electricity is increasing in proportion to the growth population. Indonesia, particularly in the area of East Java, demand for electricity continues increased, but there are based on data from PLN many areas not being fully met by electricity.

Many studies that study the demand for electricity, but rarely once that discussed for the allocation of substations where a source of electricity generation. In this study, the authors successfully find the location of substations optimal use of aid applications ArcGIS and tools inside it. With this application, may determine the location which allows the location to build the substation to meet East Java region's electricity needs, based on data from PLN numbering 98 substations, 244 a transformer and 1.161 feeders can have optimized using methods Voronoi Diagram to get service area of each feeder and Delaunay Triangulation Algorithm method to define the electricity distribution network.

The both methods can be run automatically by using the toolbox contained in ArcGIS applications, with a toolbox that can allow users to perform optimization. With the help of toolbox consisting of methods, author also get points areas not served by the electricity distribution network and service area as much 106 locations. With this study, the future can help PLN estimates that the construction of a new substation to meet the electricity needs of the area, since this study can predict the possible locations that lacked for several years. And the latter once the experiment is done, it can be proven there was 6 of 8 new substations planned by PLN have similar locations, so these studies guarantee resemblance to the data of about 80%.

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