Optimization of the placement and construction capacity of the Mantingan Substation using the imperialist competitive algorithm method

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ABSTRACT

Optimizing the substation (SS) placement and development capacity is an essential issue in planning the transmission distribution system. Furthermore, the construction of new substations is intended to determine the SS's readiness to serve the load growth in the future so that optimal location and capacity are essential things to consider. The metaheuristic-imperialist competitive algorithm (ICA) method is used in this study to determine the optimal capacity and location for SS expansion. The constraints used are geographical conditions and feeder stress of 0.90-1.05 p.u. The planning carried out is one-stage planning, with a period of 8 years (long term). The study results propose that three feeders, i.e., Walikukun, Trinil, and Sine, were transferred to a new SS in Mantingan. With this scenario, we get the transformer capacity of the Mantingan substation is 60 MVA, the location of the substation construction is at coordinates -7.4027, 111.1282, and the total construction cost of the substation is 85.541 billion rupiahs.

ABSTRAK

Optimasi penempatan dan kapasitas pembangunan gardu induk (GI) merupakan permasalahan yang penting dalam perencanaan sistem transmisi-distribusi. Pembangunan gardu induk baru direncanakan dalam menentukan kesiapan GI untuk melayani pertumbuhan beban di masa datang sehingga lokasi dan kapasitas yang optimal menjadi hal penting untuk dipertimbangkan. Metode *metaheuristic-imperialist competitive algorithm* (ICA) dalam penelitian ini digunakan dalam menentukan kapasitas dan lokasi perluasan GI secara optimal. Kekangan yang digunakan yaitu kondisi geografis dan tegangan penyulang sebesar 0,90 p.u. sampai dengan 1,05 p.u. Jenis perencanaan yang dilakukan adalah perencanaan satu tahap, dengan periode waktu 8 tahun (jangka panjang). Hasil penelitian mengusulkan tiga penyulang; Walikukun, Trinil dan Sine dipindahkan ke GI baru yakni di Mantingan. Dengan skenario tersebut, didapatkan bahwa kapasitas transformator pada GI Mantingan sebesar 60 MVA, lokasi pembangunan GI pada koordinat -7.4027, 111.1282 dan total biaya pembangunan GI sebesar 85,541 milyar rupiah.

1. Introduction

Optimal development of the electricity network is one of the most critical problems in planning the electric power system, both in the generation, transmission, and distribution sectors. For example, the transmission system aims for optimal development to serve the increasing demand for electricity in the future; how many channels, where is the optimal location, and when is the right time to predict the increase in load. Transmission line development problems can be formulated by several methods, one of which is the mixed-integer programming method. Several studies using this method can be described in aspects; modeling [1-2], solving method [3-5], line congestion [6-7], reactive power planning on transmission lines [2, 8], and environmental impact problems [9].

In addition, an essential factor in the development of transmission is the development of substations (SS). Optimal substation development planning is carried out by considering the appropriate location, conductor capacity, and transformer capacity. In addition, the voltage constraints on each bus, forecasting the magnitude of the load that must be met, and the reliability of the electric power system in meeting load demands are important factors [10]. The increase in electricity consumers can affect the supply security index. For example, with an increase in load, the voltage stability in the electric power system is disrupted so that it collapses [11]. In addition, energy not supplied (ENS) will increase if there is a contingency of N-1 taking into account the growth in electricity demand [12].

Forecasting load demand in the electricity sector is divided into two parts; short-term forecasting (a few minutes, hours, or days ahead) and long-term forecasting (up to 20 years). Short-term forecasting is usually used to determine energy regulations to determine to buy and sell commodities at market prices. Meanwhile, long-term forecasting is used in determining the development of large systems, for example, determining the capacity of substations to meet the demand for the next few years.

The Magetan and Ngawi regions have experienced a significant increase in electricity demand and are predicted to experience the highest load increase in the province of East Java. The increase was due to the existing infrastructure built following the government's plan and the increasing industrial area. The electricity provider predicts that the installed capacity of the Ngawi Substation and Magetan Substation will not respond to the significant new load addition. This study develops substations by building new subsations and determining the appropriate load transfer strategy for the feeder so that the transformer capacity can be met following the established standards. Some of the methods used in planning the development of substations are metaheuristic methods (tabu search, simulated annealing, and genetic algorithms), integer programming methods, and dynamic programming algorithms. In 2007, a metaheuristic method was found, namely imperialist competitive algorithm (ICA) [13]. As has been studied in [14], ICA has better performance than other meta-heuristic methods such as genetic algorithm (GA) for some cases.

In this study, a search for the location of a continuous substation construction will be carried out using the imperialist competitive algorithm method through matrix laboratory simulation (MATLAB) and google maps imaging. This type of planning is carried out using eight years (long term) with several constraints that cannot be violated, namely the voltage drop limit on the feeder, substation capacity, and graphic restraints. In addition, it will look for the distribution of the load in the five sub-districts of the Mantingan Substation service area and the number of costs needed in planning the construction of the Mantingan Substation.

2. Research Methodology

2.1. Imperialist Competitive Algorithm

Imperialist Competitive Algorithm (ICA) is one of the meta-heuristic algorithms used to solve optimization problems. This method was created because it was inspired by imperialistic competition in the past [15]. The population in the ICA is called the country. The population is divided into two types: imperialist and colony. The battle between imperialists is the main part of this algorithm. This method in SS development planning is still scarce compared to other meta-heuristic methods such as GA [16].

Like other evolutionary methods, ICA begins by generating the initial population (country). Some of the best countries in the population will become imperialists, and the rest will become colonies of established imperialists. The colonies in the initial population were divided into imperialists based on their strength. Imperialists and their colonies are called a kingdom. The power of an empire is proportional to its fitness and inversely to its cost. After the division of colonies into imperialists, each colony began to move closer to their imperialist country or called the process of assimilation. The assimilation process in the imperialist competitive algorithm can be seen in Figure 1. The movement of the colony to the imperialist is x and with theta angle. The parameters in the ICA program determine the size of x and theta. The greater the value of x, the faster the convergence will occur, but it can cause convergence to occur at local peaks. Therefore the value of x should not be too large.
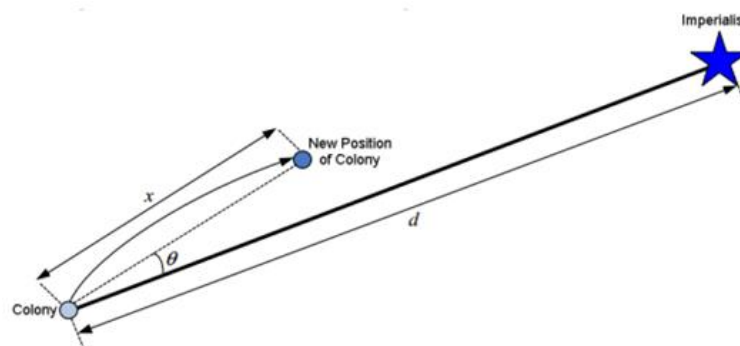

Figure 1. The imperialist competitive algorithm assimilation process

After the assimilation process, the following process is revolution. The revolution in the ICA was where some of the colonial countries refused to move towards their imperialist countries and randomly took new positions. This process is carried out to prevent convergence from occurring in the local area and increase exploration [17]. The parameters contained in the ICA determine the final result and the speed of program execution, while the parameters are as follows:

a. Number of starting countries. The number of initial states is the total population of the algorithm. The larger the number of countries, the longer the time required per iteration, but the number of iterations required to find the optimal value will be less.

b. Number of imperialists. The number of imperialists determines the time it takes for all the imperialists to merge into one.

c. Number of colonies. The number of colonies and the number of imperialists are inversely proportional. The number of colonies is obtained from the number of initial countries minus the number of imperialists.

d. Total iterations. The total iteration is the maximum number of iterations. The larger the number of iterations, the better the final results found for some cases.

e. Coefficient of revolution. The coefficient of revolution determines the exploration level of the population. A small revolution coefficient can cause convergence to occur in the local area.

f. Assimilation rate. The assimilation coefficient also determines the exploration level of the population. The greater the assimilation coefficient, the faster convergence occurs in the local area.

g. Uniting threshold. The uniting threshold is used to determine the minimum distance between two or more unified kingdoms.

h. Zeta coefficient. The zeta coefficient determines the effect of the cost generated by the colony on the total cost of a kingdom.

The ICA method is used to find the optimal location for substation development. Several scenarios have been compiled to see the effect of the parameters used in the search results and the speed of execution. There are seven scenarios for ICA that will be tested with different parameters from one another. The scenario can be seen in Table 1.

Table 1. ICA parameter scenarios

Parameter	Algorithm scenario						
	1	2	3	4	5	6	7
Number of countries country (N)	90	90	50	90	90	90	90
Number of imperialists (Imp)	9	4	5	9	9	9	9
Number of colonies (Col)	81	86	45	81	81	81	81
Coefficient of revolution (R)	0.30	0.30	0.30	0.60	0.30	0.30	0.30
Assimilation coefficient (A)	2	2	2	2	1,30	2	2
Zeta coefficient (Z)	0.02	0.02	0.02	0.02	0.02	0.06	0.02
Uniting threshold	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Number of iterations	150	150	150	150	150	150	150

2.2. Objective Function

Based on [18], the purpose of SS development planning can be modeled by equation (1), where Cinv is the investment cost incurred for SS development. Copt is the operating cost of all substations involved in serving the load in the region's scope and the main 20kV feeder. The investment cost for additional capacity of the existing SS is undoubtedly different from the investment cost for constructing a new SS in a new location.

$$Min\ Ctotal = Cinv + Copt\ . \tag{1}$$

Equation (1) can be described as in equation (2)-(4):

$$f = \sum_{n=1}^{N}(CCNSn + CALSn) + \lambda \sum_{n=1}^{N}\left[\sum_{m=1}^{M} CLLmn\right]. \tag{2}$$

$$CALSN = \lambda[PLn(NLL) + PLn(ALL).(LLn)^2.ALF] \tag{3}$$

$$CLL\ mn = \lambda\left[3\left(\frac{Pm}{3V}\right)^2 Dist\ mn.R.ALF\right]T \tag{4}$$

Where:

CCNSn	= construction cost of the n-th SS (Rp)
CALSn	= cost of losses on the n-th SS (Rp)
CLLmn	= feeder losses from the n-th SS to the mth load block (Rp)
λ	= basic cost of electricity supply (BPP) (Rp/kWh)
N	= total SS
M	= total blok load
PLn(NLL)	= n-th no-load (kW) SS (transformer) losses
PLn(ALL)	= n-th SS (transformer) losses under load (kW)
LLn	= n-th SS loading (%)
ALF	= annual load factor (%)
T	= total operating hours (Th x 365 x 24) (hours)
Th	= planning period (years)
Pm	= m-th load block size (kW)
Dist mn	= distance from n-th SS to m-th load block (km)
R	= line resistance per unit length (ohm/km)

Some of the constraints used in this study include:

a. Geographical constraints. SS candidates must be in the Magetan area, and there are several locations where SSs cannot be built, such as rivers, lakes, or other extreme places.

b. Voltage drop restraint. The further the distance between the SS and the load, the more significant the voltage drop. The electricity provider has a standard maximum voltage limit of 5% above standard voltage and a minimum voltage limit of 10% below standard voltage (0.9 pu < V < 1.05 pu)

c. SS capacity constraints. The SS loading based on the 2015-2024 PLN RUPTL is 70-80% of the transformer rating value. Loading is calculated using the annual peak load, which is the maximum load in 1 year.

2.3. Research Flow Chart

The ICA method was utilized in this study's stages, which were similar to those used by [19].

2.4. Load Density Mapping

Figure 2. shows a flow chart of the load density calculation process used in the districts of Sine, Mantingan, Karanganyar, Ngrambe, and Widodaren. First, geographic data for Ngrambe, Widodaren, Sine, Mantingan, and Karanganyar, in the form of polygons, were obtained from google maps in the form of files with the extension .kmz (Figure 3(a)). The file is converted into data of type struct with MatLab and displayed again as a polygon. The data can be processed using MatLab; the areas of Ngrambe, Widodaren, Sine, Mantingan, and Karanganyar are divided into square units of 0.25 km² (Figure 3(b)). Each block is represented by a coordinate located at the block's midpoint; the coordinates use latitude and longitude.
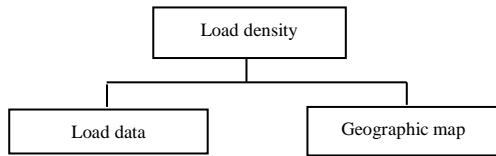
Figure 3. Determination of load density

Table 2. Classification of load density

Index	Description	Color	Load density per block (kVA)
H1	High load density	Red	35.00
H2	Medium load density	Purple	25.00
H3	Low load density	Yellow	18.75
H4	Very low load density	Green	5.00

The amount of power requirement per sub-district is calculated or, more specifically, the power requirement per area in a sub-district to find each block unit's level of load density. A different color represents each level of load density with information as shown in Table 2.
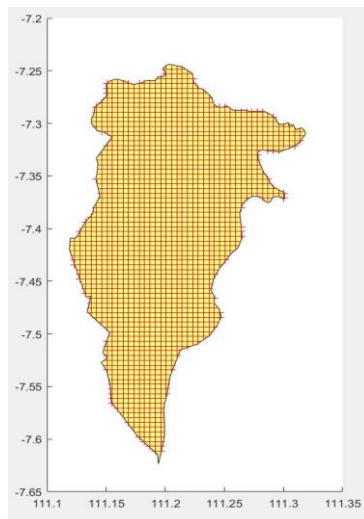
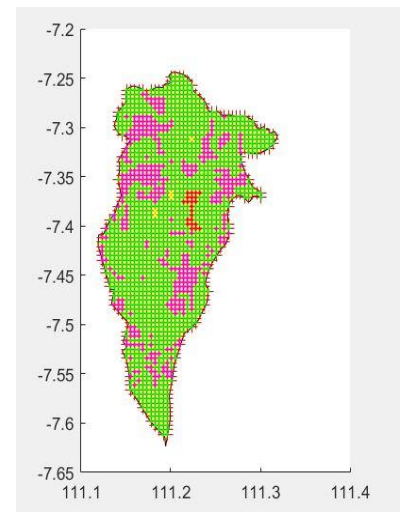## 3. Results and Discussion

3.1. Load Density Mapping

It can be seen in Figure 3. the number of block units for each load density. Each block has an area of 0.25km². Therefore the load density per block is four times the load density per km². The highest number of block units is the block unit with a very low load density or the green one (H4). The northern section, namely the Mantingan subdistrict, is dominated by blocks with a medium load density or purple color (H2). Around the Widodaren District, block units with a high load density or red (H1) are found. Around the Jamus tea plantations and on Mount Lawu, block units with a very low load density or green are found. The color presentation for each load density can be seen in Table 2. In Table 3. it can be seen the number of block units for each load density. Each block has an area of 0.25km². Therefore the load density per block is four times the load density per km².
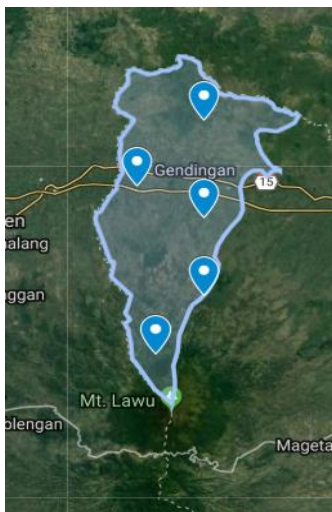
(a) Polygons from google maps **(b) Unit blocks on polygons** **(c) Load density mapping on unit blocks**

Figure 3. Mapping of the load density on the block unit

Table 3. Number of block units for each level of load density

Load density	Load density per block (kVa/block)	Number of blocks	Total area (km²)
H1	30	23	5,758
H2	20	492	123
H3	13.75	5.00	1.25
H4	5.00	1,232	308

3.2. Alternative for New Substation Construction

The search for the right location for constructing a new SS using the ICA method was carried out seven times to avoid the stochastic nature. The locations obtained for the program execution results seven times show the exact location, namely at points -7.4027, 111.1282, as shown in Figure 4. The total cost required to construct a new substation with a transformer capacity of 60 MVA and operating costs for ten years can be searched by equation (2)–(4).
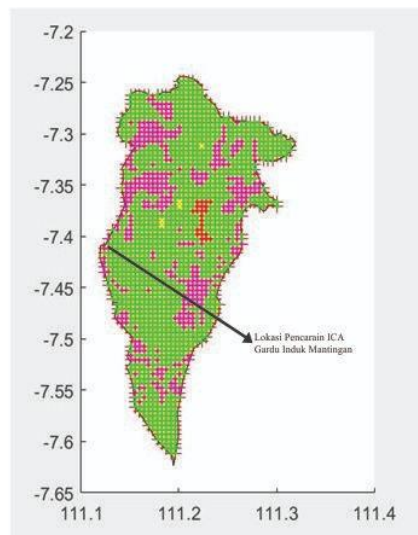

Figure 4. Location of calculation results using imperialist competitive algorithm

With the respective values of:

a. CCNS   = 74.96 billion rupiah
b. CALS   = 7.627 billion rupiah
c. CLL   = 2.954 billion rupiah
Total cost   = 85.541 billion rupiah

The optimal location from the calculation results using ICA is located at coordinates -7.4027, 111.1282. Based on satellite images from google maps, as shown in Figure 5. the location is in the form of land so that it is geographically possible to carry out the construction of the SS, but at that location, there are several buildings so that if the construction is carried out right at the prearranged location, it is necessary to evict the house. Alternatively, at a distance of 600m to the east of the optimal location, as shown in Figure 6. there is vacant land that is possible to build the SS. The difference in distance of 500m will not have too much influence on channel losses.
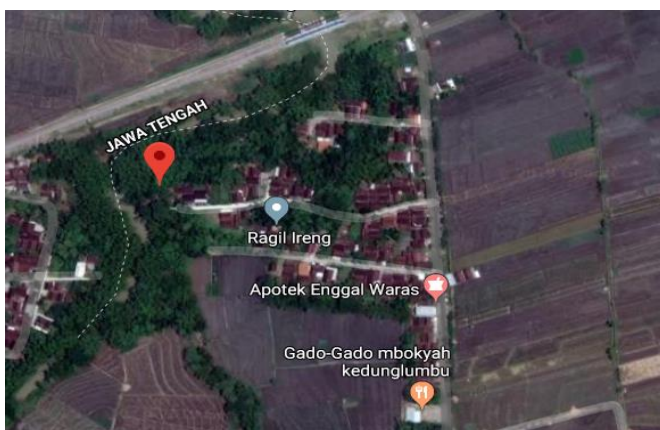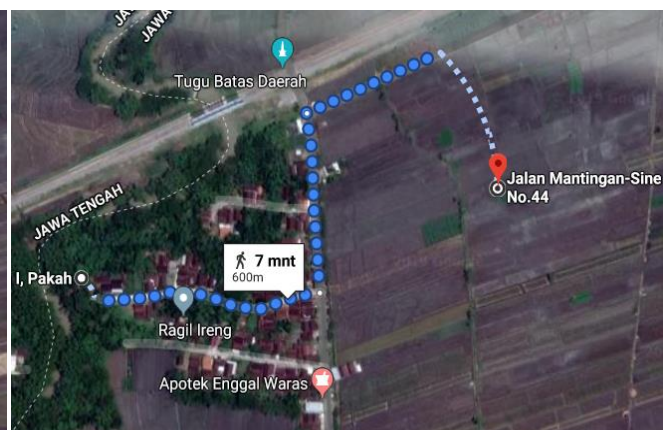

Figure 5. Location of substation construction

Figure 6. Alternative location for substation construction

3.3. Effect of ICA Parameters

The effect of method parameter values on calculation results and execution speed can be tested using seven scenarios with different parameter values according to Table 1. The data used as testing material is favorable conditions. Scenario 1 will be used as a reference for testing other scenarios. The average execution time for scenario-1 is 107.170611 seconds, with the final CLL calculation result is Rp. 2,954,598,491,-.

The comparison of the minimum value of each iteration in each scenario can be seen in Figure 8. From Figure 8, it can be seen that all scenarios can approach the best value after the 86th iteration. The final value obtained by each scenario can be said to be the same, but some scenarios take a long time to reach the best value, for example, scenario 4. The difference in parameter values in the ICA method does not significantly affect the value of the calculation results, causing all scenarios to show the same final result. However, the population size parameter significantly affects the speed of execution of calculations. It can be seen in Table 4.
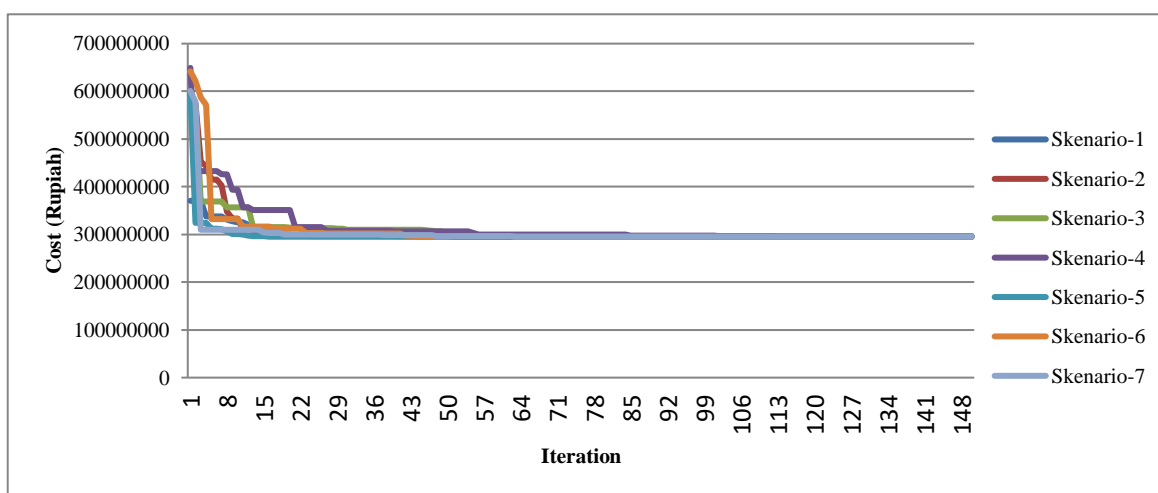
Figure 8. Comparison of the minimum values of imperialist competitive algorithm

Table 4. ICA execution time

Scenario	Time (Second)
Scenario-1	107.170611
Scenario-2	108.068675
Scenario-3	72.623432
Scenario-4	113.885197
Scenario-5	111.759239
Scenario-6	107.205792
Scenario-7	109.769802

4. Conclusions

Based on density mapping in 5 sub-districts of the Mantingan SS service area using MATLAB simulation and google maps imaging, the highest load density is found around the Widodaren sub-district area. Therefore, the best alternative to determining the optimal placement of the Mantingan substation is to build a substation at coordinates -7.4027, 111.1282, which is in the west of the Kidodaren sub-district. Calculation of investment and operating costs for eight years obtained amounted to 85.541 billion rupiahs. In addition, a comparison of the seven scenarios is also carried out in obtaining significant and constant calculation results with the conclusion that the parameters do not have much effect on the final calculation result (total final cost) but have an effect on execution time.

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