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Low Voltage Network Reconfiguration at PLN ULP Rungkut as Load Optimization using the Ant Colony Optimization Method

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ABSTRACT

PLN (Persero) Ltd. Rungkut Customer Service Unit - The high load density and the length of the mangrove feeders, which are quite long, have caused several buses toward the end of the network to experience a voltage drop of 0.9421208 p.u. Therefore, it is necessary to reconfigure the network to overcome and improve the existing voltage conditions as well as optimize the loading on the feeders so that they can be evenly distributed. A comparative evaluation of the calculation of the ant chromosomes used is needed to ensure the disconnection point in reconfiguring the network. An ant colony optimization analysis on this mangrove feeder was simulated using ETAP software. The results of this drop voltage improvement analysis could be used to reconfigure the low-voltage network of mangrove feeders to 0.9933478 p.u. Consequently, it could be precise, reliable, and good at PLN Ltd. ULP Rungkut and obtain load optimization on mangrove feeders.

Kata kunci: *drop voltage; reconfiguration; existing; ant colony optimization; ETAP.*

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ABSTRAK

PLN (Persero) Unit Layanan Pelanggan Rungkut menghadapi permasalahan penurunan tegangan pada jaringan, khususnya pada feeder Mangrove yang memiliki densitas beban tinggi dan panjang saluran yang cukup jauh. Kondisi tersebut menyebabkan beberapa bus di ujung jaringan mengalami penurunan tegangan hingga 0,9421208 p.u. Oleh karena itu, diperlukan reconfigurasi jaringan untuk memperbaiki profil tegangan serta mengoptimalkan distribusi beban agar lebih merata pada seluruh feeder. Evaluasi komparatif terhadap perhitungan kromosom semut diperlukan guna memastikan titik pemutusan (switching) yang tepat dalam proses reconfigurasi. Analisis ant colony optimization (ACO) pada feeder Mangrove kemudian disimulasikan menggunakan perangkat lunak ETAP. Hasil analisis menunjukkan bahwa reconfigurasi menggunakan metode ACO mampu meningkatkan tegangan hingga 0,9933478 p.u. pada jaringan tegangan rendah feeder Mangrove. Dengan demikian, perbaikan ini dapat menjadi dasar bagi PLN ULP Rungkut untuk memperoleh profil tegangan yang lebih akurat, andal, serta mendukung optimalisasi beban pada feeder tersebut.

Kata kunci: *drop voltage; reconfiguration; existing; ant colony optimization; ETAP.*

INTRODUCTION

Electrical energy, as a fundamental necessity, has seen a significant increase in demand each year. This situation compels the State Electricity Company (Perusahaan Listrik Negara or PLN) to ensure that the availability and supply of electricity are optimal. According to SPLN No. 72 of 1987, the allowable voltage drop for a radial system is ±5% [1]. The Mangrove Feeder at PLN ULP

Rungkut, which spans a total length of 13.8 km, faces a high load density, particularly at the end of the network [2]. With 21 connected buses, the voltage at the network's endpoint measures only 0.9463 p.u., indicating a considerable voltage drop [3]. To address such issues, several studies have explored various methods to reduce voltage drops in distribution networks. Hidayat et al. [4] analyzed load balancing in low-voltage networks, specifically at the CD 33 substation, to optimize voltage levels. Sulistyowati et al. [5][6][7][16][17][18][20] worked on voltage drop improvements through load reconfiguration panel, highlighting the importance of network reconfiguration in maintaining voltage quality. The explored radial distribution network reconfiguration using BPSO, specifically focusing on the Suryagraha feeder, reinforcing the need for advanced optimization techniques in managing voltage drops. The Colony method is used to optimize reconfiguration to reduce voltage drop[19][21].

The voltage value measured at the 150 kV outgoing mangrove feeder substation is still good at the base of the network, namely 20 kV or 1,000 (p.u). The voltage value measured on the medium voltage equipment installed motorized in the final section shows a voltage value only in the range of 19.5 kV to 19.7 kV or 0.95000 to 0.97000 (p.u). BE 1059 transformer pole substation which supplies the Mount area Anyar Emas, Network reconfiguration is needed on the mangrove feeder network in order to optimize the load flowing to the substation so that it can work optimally from both sides. loading and in terms of service life time.

The research being developed is the application of network reconfiguration using the ant colony optimization method with a voltage drop problem that occurs on the side of the low voltage network which is expected to speed up finding the correct disconnection point and in accordance with standards and/or in accordance with predetermined tolerance limits. So it is hoped that research using the An Colony method can be another alternative in determining the connection point with excess search time effectiveness in accordance with the conditions that support this method as a whole.

RESEARCH METHOD

This study employs a combination of manual calculations and ETAP simulation software to analyze the voltage drop and load distribution on the Mangrove feeder. The power flow analysis in this study is conducted using the Backward/Forward Sweep method, which is widely applied for radial distribution systems due to its computational efficiency and reliable convergence characteristics.

The research begins with the collection of load and line data from the Mangrove feeder, as recorded in the September 2022 LTB report by PLN ULP Rungkut. The load data, presented in Table 1, detail the active power (P) and reactive power (Q) at each bus, while the line data in Table 2 include the resistance (R), reactance (X), and network segment lengths.

Based on the collected data, a single line diagram of the Mangrove feeder is constructed as shown in Figure 1(b). The feeder is operated under a radial configuration during normal conditions. Several switching points in the network are defined as normally open (NO) switches to avoid loop operation. These normally open switches provide alternative paths that can be utilized during network reconfiguration.

Referring to the single line diagram, the normally open switches are located at the connection between Bus 10–Bus 12 and Bus 16–Bus 17. If all normally open switches were closed, the system would form two loops. However, during normal operation, these loops are kept open to maintain radial operation and simplify protection coordination. The stages of the ACO algorithm optimization process are as follows:

1. Determine the number of ants n and the discrete value p. The value of the variable sought is expressed in equa:

$$X_i = X_{i1}, X_{i2}, X_{i3}, \dots, X_{ip} \; ; (i = 1,2,3, \dots, n) \quad (1)$$

Where n is the number of variables. Then determine the initial pheromone, set iteration, iter = 1.

2. Calculating the probability () of segment selection by the ant:

$$P_{ij} = \frac{\tau_{ij}}{\sum_{j \in N_i^k} \tau_{ij}} \quad (2)$$

A certain segment will be chosen by ant k based on a random number generated in the range (0,1). The selection of this segment is determined using a lottery circle (roulette-wheel selection).

3. Generate N random numbers in the range (0,1) for each ant. Then determine the discrete value that represents the edge for ant k in variable i using the random numbers from stage 2 and the cumulative probability area in the lottery circle.
4. Repeat stage 3(a) for each variable i = 1,2,3,…,n.

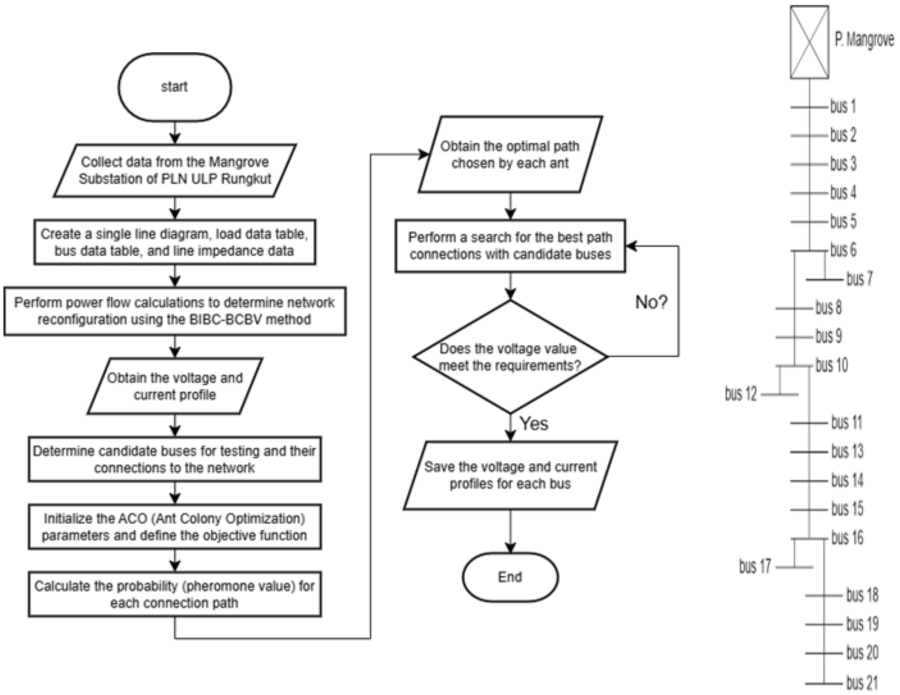
Evaluate the value of the objective function by entering the selected values for all variables I = 1,2,3,…,n by ant k, k = 1,2,3,…,N; k = 1,2,3,…,N. Then determine the best and worst paths among N segments or paths that have been chosen by different ants.

$$\tau_{ij}^{k(iter)} = \tau_{ij}^{old} + \sum k\Delta\tau^{k} \quad (3)$$

5. Carry out a convergence test, on ACO which means if all ants take the same best path. If it has not converged, the ant colony will return to the nest and start searching for food again. Set iteration, iter = iter + 1, and update the pheromone for each segment with the equation:

$$\tau_{ij}^{old} = (1-\rho)\tau_{ij}^{iter-1} \quad (4)$$

The research process is illustrated in Figure 1(a), which outlines the steps taken from data collection to simulation and analysis. The single line diagram of the Mangrove feeder is depicted in Figure 1(b), showing the connections between buses, normally open switches, and the distribution of loads along the feeder.



(a) (b)

Figure 1. (a). Flowchart of the research process, illustrating the sequence of activities undertaken in this study, (b). Single Line Diagram of the Mangrove Feeder, depicting the electrical connections and load distribution across the feeder's network

RESULTS AND DISCUSSION

The analysis of the Mangrove feeder involves two primary approaches: manual calculations and simulation using ETAP software. The manual calculations focus on determining voltage drops across various segments of the feeder, employing the load data and line parameters outlined in Tables 1 and 2. These calculations aim to evaluate the performance of the feeder under the given load conditions and to identify any potential issues related to voltage drop. The ETAP simulation provides a more comprehensive analysis by modeling the entire network in a virtual environment, allowing for the assessment of various operational scenarios and their impacts on the voltage profile. The results from both methods are compared to verify consistency and accuracy. The combination of manual and simulation approaches ensures a robust analysis of the feeder's performance, facilitating accurate assessments and recommendations for any necessary improvements or adjustments

Table 1. Databus , Resistance and Distance

Early Bus	End Bus	R (Ohm)	X (Ohm)	Network Length (m)
1	2	0	0	0
2	3	0,125	0,097	300
3	4	0,2162	0,3305	1000
4	5	0,206	0,104	1500
5	6	0,2162	0,3305	500
6	7	0,2162	0,3305	500
6	8	0,2162	0,3305	500
8	9	0,2162	0,3305	500
9	10	0,2162	0,3305	1000
10	11	0,2162	0,3305	500
10	12	0,2162	0,3305	500
11	13	0,2162	0,3305	1000
13	14	0,2162	0,3305	1000
14	15	0,2162	0,3305	500

Power Flow Analysis and Ant Colony Optimization for Network Reconfiguration can be seen figure 3. The initial power flow analysis was conducted to obtain key parameters such as voltage, current, and voltage drop across the network can be seen table 1 and 2. The results are presented in Table 4 which compares the voltage values at each bus in the Mangrove feeder system as obtained through MATLAB and ETAP simulations. The error percentage between the two methods is also provided, indicating the accuracy of the simulation tools used.

Table 2. Voltage at Each Bus in the Mangrove Feeder System

Bus	Voltage $(p.u)$		
	MATLAB	ETAP	ERROR (%)
1	1,0000000	1,0000000	0,000000%
2	0,9998821	0,9994809	0,000401%
3	0,9992212	0,9968000	0,002421%
4	0,9886101	0,9858000	0,002810%
5	0,9871125	0,9820000	0,005112%
6	0,9816719	0,9819000	0,000228%
7	0,9733428	0,9783000	0,004957%
8	0,9703198	0,9750000	0,004680%
9	0,9697091	0,9688000	0,000909%
10	0,9653407	0,9657000	0,000359%
11	0,9658716	0,9687000	0,002828%
12	0,9599341	0,9602000	0,000266%
13	0,9511308	0,9552000	0,004069%
14	0,9501299	0,9531000	0,002970%
15	0,9489705	0,9498000	0,000829%
16	0,9491141	0,9490000	0,000114%
17	0,9457138	0,9490000	0,003286%
18	0,9465123	0,9479000	0,001388%
19	0,9465123	0,9479000	0,001388%
20	0,9451333	0,9467000	0,001567%
21	0,9421208	0,9463000	0,004179%

The voltage values obtained from MATLAB and ETAP show slight differences, with the error percentages indicating a high level of consistency between the two methods. This validation is essential for ensuring the reliability of the simulation results before proceeding with further analyses.

Ant Colony Optimization for Network Reconfiguration

To address the imbalance between the research methodology and the implementation of the Ant Colony Optimization (ACO) algorithm, this section explicitly describes the application of ACO in the network reconfiguration process of the Mangrove feeder.

The ACO algorithm is initialized by defining the candidate buses as the initial positions of the ants. Each ant represents a potential reconfiguration path formed by opening and closing specific switches at the candidate buses, as illustrated in Figure 2. The candidate buses are selected based on voltage drop severity and network topology constraints obtained from the power flow analysis.

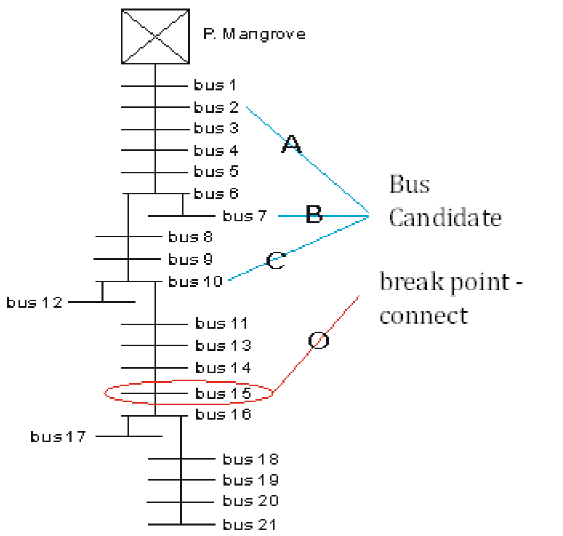


Figure 2. Candidate Buses and Tested Paths.

At the initialization stage, the following parameters are defined:

1. Number of ants (N), representing the number of candidate reconfiguration paths,
2. Initial pheromone value (τ_0)for each candidate connection,
3. Objective function based on voltage deviation minimization and current reduction,
4. Radial topology constraint to prevent loop formation.

Each ant explores a feasible reconfiguration path by performing a break point–connect operation on the normally open switches shown in Figure 2. For each selected path, power flow analysis is performed to calculate the voltage magnitude (p.u) and current (A) at every bus along the feeder.

The voltage and current profiles obtained from the reconfiguration paths selected by Ant 1, Ant 2, and Ant 3 are evaluated and compared. Table 3 presents the voltage (p.u) and current (A) values for each bus along the path selected by Ant 1, which demonstrated the most optimal performance among all tested ants.

Table 3. Voltage (p.u) and Current (A) on Ant 1's Path

Bus	**Voltage (p.u)**	**Current (A)**
1	1.000	58.11
2	1.008	431.5
3	1.007	159.7
4	1.004	155.8
5	1.000	144.8
6	0.9993	131
7	0.9992	9

8	0.9982	122
9	0.9975	72.01
10	0.9963	62.45
11	0.9952	56.55
12	0.9963	5.896
13	0.9952	31.97
14	1.003	271.8
15	1.000	239.3
16	0.9971	179.4
17	0.9962	90.27
18	0.9962	89.09
19	0.995	86.76
20	0.9937	67.66
21	0.9934	38.57

Based on the simulation results using MATLAB for ACO computation and ETAP for power flow validation, the final voltage profile of the Mangrove feeder after reconfiguration is summarized in Table 4. The comparison between MATLAB and ETAP results shows very small percentage errors, indicating high consistency and validation accuracy of the proposed method.

Table 4. Mangrove Feeder System Stress Profile Final Condition

Bus	**Voltage (p.u)**		
	MATLAB	**ETAP**	**Error (%)**
1	1,0000000	1,000	0,007900%
2	1,0000000	1,008	0,007400%
3	1,0000000	1,007	0,007400%
4	1,0000000	1,004	0,004000%
5	1,0000000	1,000	0,000000%
6	0,9999765	0,9993	0,000677%
7	0,9997758	0,9992	0,000576%
8	0,9991605	0,9982	0,000961%
9	0,9983371	0,9975	0,000837%
10	0,9971101	0,9963	0,000810%
11	0,9965475	0,9952	0,000748%
12	0,9961322	0,9963	0,000168%
13	0,9952131	0,9952	0,000013%
14	1,0000000	1,003	0,005000%
15	1,0000000	1,000	0,005000%
16	0,9977751	0,9971	0,000675%
17	0,9967810	0,9962	0,000581%
18	0,9963305	0,9962	0,000131%
19	0,9954435	0,995	0,000444%
20	0,9941377	0,9937	0,000438%
21	0,9933478	0,9934	0,000052%

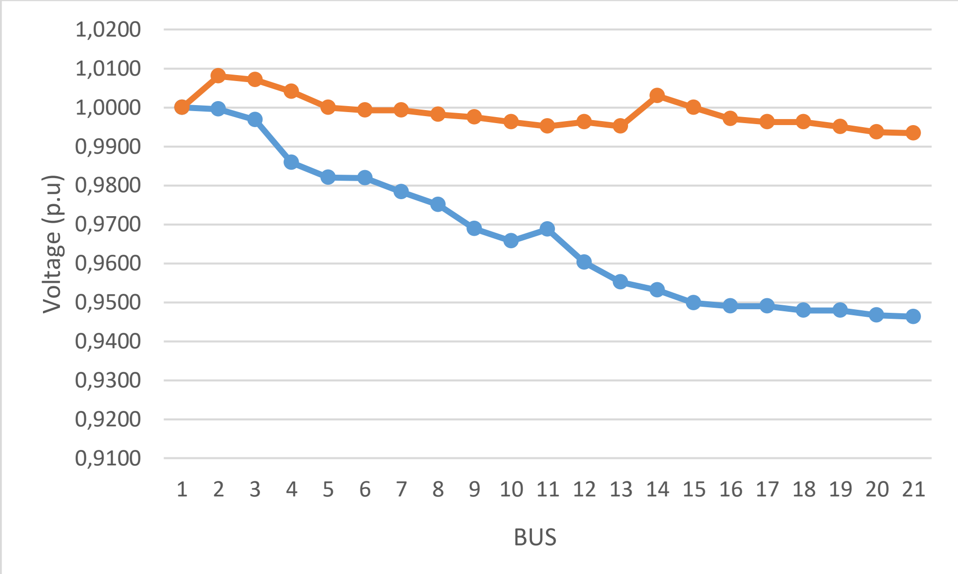


Figure 3. Voltage Profile Before and After Reconfiguration

The voltage profiles before and after reconfiguration are illustrated in Figure 3. Prior to reconfiguration, a significant voltage drop was observed starting at Bus 15, where the voltage reached 0.9489705 p.u, and further decreased to 0.9421208 p.u at Bus 21.

After applying the ACO-based reconfiguration, the voltage at Bus 15 improved to 1.000000 p.u, while the voltage at Bus 21 increased to 0.9933478 p.u. This improvement confirms that the reconfiguration strategy effectively mitigated voltage drop issues along the feeder.

CONCLUSION

The reconfiguration process of the 20 kV distribution network was conducted by rearranging the network's structure to enhance its efficiency and stability. Initially, buses 15, 16, 17, 18, 19, 20, and 21 were branches connected to bus 14. After reconfiguring the network using the Ant Colony Optimization (ACO) method, a new network structure was achieved, whereby buses 15, 16, 17, 18, 19, 20, and 21 became branches of bus 2. This structural reconfiguration had a significant impact on improving the voltage levels across the Mangrove feeder.

From a technical perspective, the ACO-based reconfiguration significantly improved the voltage profile of the system. The minimum voltage increased from 0.9421208 p.u. at Bus 21 to 0.9933478 p.u. after reconfiguration, while the voltage at Bus 15 improved from 0.9489705 p.u. to 1.000000 p.u. This improvement also reduced line current magnitudes, leading to lower I^2Rpower losses and more efficient power distribution. The close agreement between MATLAB and ETAP results further confirms the reliability of the proposed method.

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