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# Optimization of Distributed Generation Placement and Capacity Using Flower Pollination Algorithm Method

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**ABSTRACT**

The need for energy, especially electricity, is increasing along with the development of technology. An increase in electrical load and the location of the powerplant far causes voltage drops and causes power line losses. One solution can be chosen by adding a distributed generation (DG) to the distribution network. This study aims to enhance the voltage profile and reduce power losses according to DG-based photovoltaic (PV)'s optimal placement and capacity in the Bantul Feeder 05 distribution network. The flower pollination algorithm (FPA) method is used to determine the optimal DG placement and capacity. The study was conducted using three additional DG scenarios: scenario 1 with single DG and scenario 2 with multi-DG (2 DG and 3 DG). The results showed that the optimal placement and capacity of DG were on buses 9, 19, and 33 with DG sizes of 1.880 kW, 2.550 kW, and 2.300 kW, respectively. This placement can increase the voltage profile and reduce the active power loss from 439.8 kW to 77.5 kW. The research also considers the increase in the reliability of the distribution system in terms of the Energy not Supplied (ENS) and Cost of Energy not Supplied (CENS) index.



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## 1. INTRODUCTION

Photovoltaic (PV) generation is an excellent strategy and investment in overcoming problems in the energy and environment sectors [1]. The widespread technology in PV generation creates advantages; energy costs and emissions, costs of building transmission networks, and energy reduction from fossil fuels [2]. On the other side, additional placement of distributed generation (DG) to conventional systems will create new challenges such as overload, voltage stability, ampacity current in a conductor, and voltage profile on the distribution networks [3, 4].

Perusahaan Listrik Negara (PLN), as a business entity providing electricity in Indonesia, makes a 10-year electric power plan is an electricity supply business plan (RUPTL) to predict the load, power generation, and electricity transmission systems in the future. Electric power systems must be operated by optimally maintaining power systems and bus voltage to meet fluctuating load requirements.

Power losses cause less efficient an electric power system in sending from the powerplant to load or consumers. In contrast, a decrease in power will cause damage to electrical equipment that is available to consumers. One solution to this is to install DG on the distribution system. It was determined as a powerplant that is injected into the distribution network or on the consumer side. Interconnection, DG into the distribution network has a greater significance to improving the quality of the power distribution network that contains the power flow, increased voltage profile, increased reliability, and decreased power loss [2, 5-7]. In addition, DG also helps reduce operational costs during peak load, the ability to support the network, and increase security at critical loads [8-9].

Previous research related to reducing power losses and enhancing voltage profile through DG placement and capacity optimization has been carried out on these research, viz optimization of reactive power of distributed generation for voltage regulation of distribution systems; optimal capacity and placement of distributed generation using a metaheuristic optimization algorithm to reduce power losses in Bantul 05 feeder, Yogyakarta; and impact of high penetration of photovoltaic generation on voltage fluctuation of transmission and distribution systems have been investigated by [10-11]. Good planning is needed to support the benefits of DG in the power system, including determining the location of placement and a large number of power systems used by the optimization method [12-15]. Installation of capacity and location of enlargement that is not optimal on the distribution network will cause greater cost losses than installation at the location and optimal capacity. Therefore, it is necessary to study a method for determining the optimal location and capacity of distributions distributed in distribution networks [16]. Some optimization methods that have sprung up from classical optimization, from analytical to the most recent, are metaheuristic methods.

The metaheuristic method that is currently developing has reached a mature stage. FPA is a flower pollination algorithm created by Xin-She Yang. FPA is an efficient method with better results because it has a higher convergent speed than the genetic algorithm (GA) and particle swarm optimization (PSO) method [17-19]. The optimal placement and capacity of distributed generation are described in this study to obtain a good voltage profile and minimize power losses. This paper also considers the system reliability index, especially the Energy Not Supplied (ENS) and the cost of losses that must be replaced at the time of failure, Cost of Energy Not-Supplied (CENS).

## 2. RESEARCH METHOD

### 2.1. Flower Pollination Algorithm (FPA)

A flower pollination algorithm is an algorithm inspired by nature, especially in flowering plants (Fig. 1). In 2012, Xin-She Yang, a DPhil student from the University of Oxford, gave an idea of this localization. Flowers are used for reproduction in species through the process of pollination. There are four rules of pollination, which are then compiled as the basis of the FPA. Some of the phenomena of pollinating flowers are as follows [17]:

a. Biotic pollination and cross-pollination for global pollination with pollinators.
b. Abiotic pollination and pollination are considered local pollination.
c. The interest constant considers the opportunity for returns that are proportional to the interest agreement involved.
d. Local and global pollination are referred to as a switching opportunity called the probability of displacement.

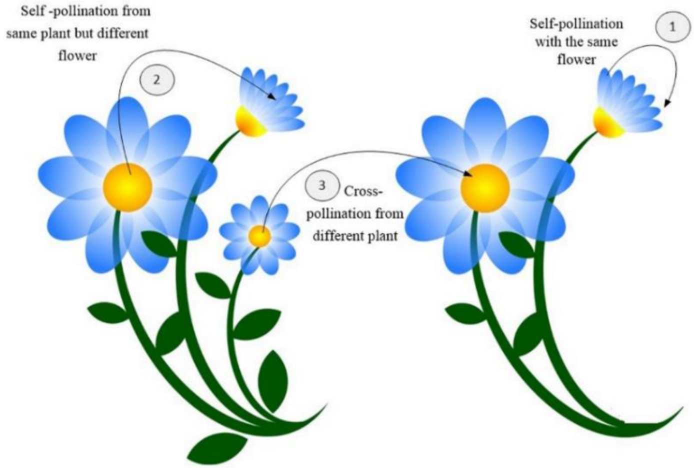


**Fig. 1.** Flower Pollination

At the FPA Fig. 1, there are two key steps: global and local pollination. In global pollination, the first and third rules are used together to find solutions in the next step $(x_i^{t+1})$ using the values from the previous step $(x_i^t)$. Global pollination is formulated as

$$(x_i^{t+1}) = x_i^t + L(x_i^t - g^*) \tag{1}$$

The subscript $i$ shows $i$ (or flower) powder, equation (1) is applied to powder on flowers, $g^*$ is the best solution at that time. $L$ is the flying distance obtained from Levy distribution, whereas, in local pollination, the third rule of flower constancy is shown as

$$(x_i^{t+1}) = x_i^t + \varepsilon(x_j^t - x_k^t) \tag{2}$$

Where $x_j^t$ and $x_k^t$ is a solution from a different plant. ε is a random number between 0 and 1. Based on these four rules, switch probability ($p$) is used to select the type of pollination that will control the optimization process in iteration [17].

### 2.1.1. Levy's Motion Operator

The Levy motion operator applies global pollination with (4). The next step is to select j and k between all solutions randomly, then do local pollination with (5), if done, then calculate the fitness of the new solution. If the fitness of the new solution is better than the old solution, then replace the old fitness solution with a new solution [12]. Levy's motion of flower pollination algorithm is shown in Fig. 2.

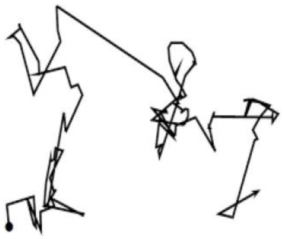

**Fig. 2.** Levy's motion

### 2.1.2. Determination of DG Capacity

Determination of DG capacity is assumed $a = (sign)\tan\left(cos^{-1}(PF_{DG})\right)$ , then the DG reactive power output can be expressed with

$$Q_{DGi} = aP_{DGi} \tag{3}$$

where $sign = +1$ is DG injects reactive power, $sign = -1$ is DG takes reactive power and $PF_{DG}$ is power factor from DG.

Active power and reactive power injected on the bus $i$, where DG is located, are expressed with

$$P_i = P_{DGi} - P_{Di} \tag{4}$$

$$Q_i = Q_{DGi} - Q_{Di} = aP_{DGi} - Q_{Di} \tag{5}$$

The active power loss can be written as

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\{\alpha_{ij}[(P_{DGi} - P_{Di})P_j + (aP_{DGi} - Q_{Di})Q_j] + \beta_{ij}\begin{bmatrix}(aP_{DGi} - Q_{Di})P_j - \\ (P_{DGi} - P_{Di})Q_j\end{bmatrix}\} \tag{6}$$

The total active power losses in the system will be minimum if the partial derivative of (6) of the injection of active power from DG to bus $i$ becomes 0. After simplification and rearrangement, equation (6) can be written as

$$\frac{\partial P_L}{\partial P_{DGi}} = 2\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_j + aQ_j\right) + \beta_{ij}\left(aP_j - Q_j\right)\right] = 0 \tag{7}$$

Equation (3) can be written as

$$\alpha_{ij}\left(P_j + aQ_j\right) + \beta_{ij}\left(aP_j - Q_j\right) + \sum_{j=1,j\neq i}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) + a\sum_{j=1,j\neq i}^{N}(\alpha_{ij}Q_j - \beta_{ij}P_j) = 0 \tag{8}$$

From equations (4), (5), (7), and (8), equality (9) can be developed as

$$\alpha_{ii}(P_{DGi} - P_{Di} + a^2P_{DGi} - aQ_{Di}) + \beta_{ii}(Q_{Di} - aP_{Di}) + X_i + aY_i = 0 \tag{9}$$

From equation (9), the optimal DG capacity value in each bus $i$ to minimize active power loss can be written as

$$P_{DGi} = \frac{\alpha_{ii}(P_{Di} + aQ_{Di}) + \beta_{ii}(Q_{Di} - aP_{Di}) - X_i - aY_i}{a^2\alpha_{ii} - \alpha_{ii}} \quad (10)$$

### 2.1.3. Calculation of ENS index

Energy not supplied (ENS) index calculation is done by using the following equation:

$$ENS = L_{avg} - U_i \quad (11)$$

Fig. 3 shows a flowchart of the entire study to explain what will be done in this study in general. The research was conducted by analyzing the power flow in Bantul 05 feeders before the addition of distributed generation. Additional distributed generation schemes are carried out in 3 scenarios; Scenario 1, Scenario 2, and Scenario 3. The flower pollination algorithm will determine the optimal placement and capacity of DG in improving the voltage profile and power loss in distribution systems.

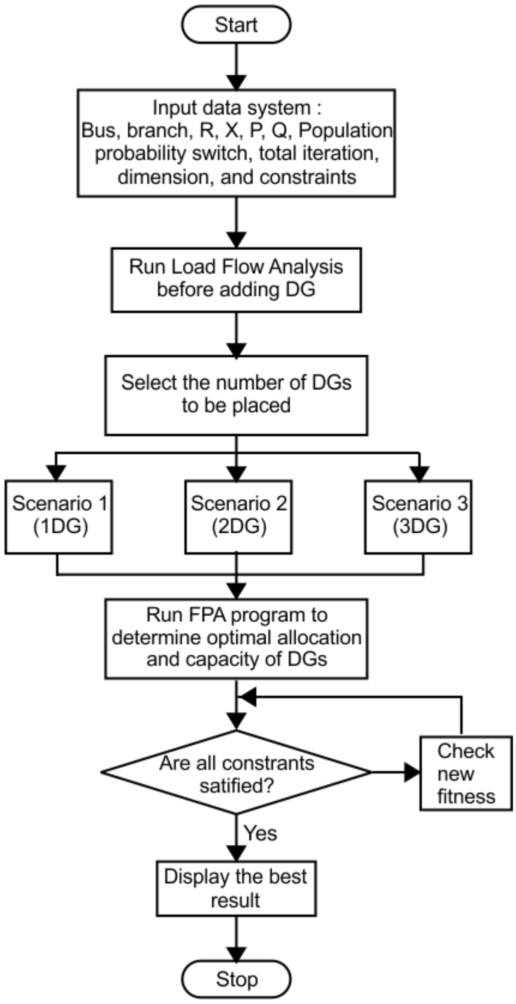


**Fig. 3**. Research flowchart

## 3. RESULTS AND DISCUSSION

In the DG optimization study, it was carried out using the FPA method with the data used was distribution network data from one feeder at the Bantul substation, namely Bantul Feeder 05. The voltage level in the distribution system uses a 20 kV voltage level. Fig. 4 shows the distribution system of Bantul feeder 05, which has been simplified and used in this study.

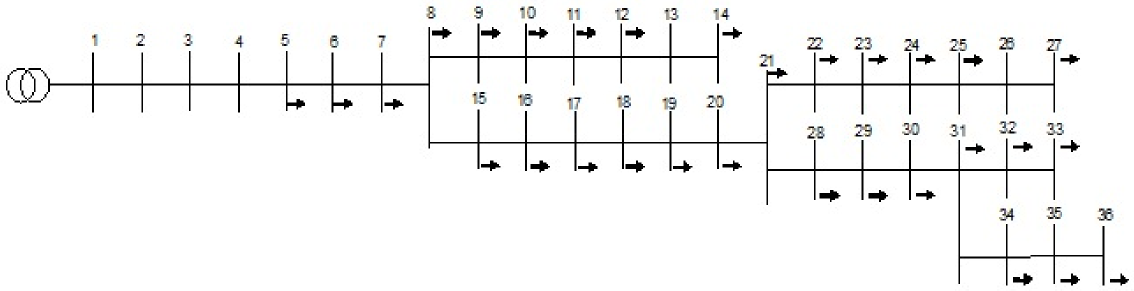


**Fig. 4**. Single line diagram feeder 05 Bantul

Before the addition of DG, the system had active power losses of 439.9 kW with the lowest voltage profile value of 0.86 p.u. This value is outside the constraints of the standard voltage profile restraints SPLN 1: 1978, so it is necessary to improve the voltage profile and minimize active channel power losses. The voltage at each bus point meets the standard restraints of 0.95-1.05 p.u.

There are 3 DG installation scenarios in the form of photovoltaic, using single DG and multi-DG (2 DG and 3 DG). With a fluctuating load in the form of a real load on Bantul 05 feeders for one day (24 hours), the following results are obtained.

### 3.1. Scenario 1

In the first scenario, the number of iterations given is 500 iterations with 20 populations in each iteration. Simulations were carried out ten times to find out the differences produced. Table 1 shows the results that are convergent to the optimal bus that is on bus 29 and has a capacity of 3000 kW so that the value of active power losses becomes 117.68 kW, and the voltage profile improves as shown in Fig. 5. The graph interpreted that the voltage profile after the integration of a single DG had a significant increase in each bus. The voltage profile is at the standard set by the Standard of PLN (0.95-1.05 p.u). Meanwhile, the ENS value is still relatively high due to DG's small capacity.

**Table 1.** The results of objective function optimization with the FPA method on a single DG

| Simulation to- | The number of iterations to converge | Optimal bus | Optimal capacity (kW) | Total load power (kW) | Losses | | ENS (kWh) | CENS ($) |
|---|---|---|---|---|---|---|---|---|
| | | | | | kW | % | | |
| 1 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 2 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 3 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 4 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 5 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 6 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 7 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 8 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 9 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| 10 | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| Mean | 10 | 29 | 3,000 | 5,271.5 | 117.7 | 1.94 | 3,543.5 | 2,232,578.2 |
| Std. Dev | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.9085 |

### 3.2. Scenario 2

In the second scenario, the number of iterations given is 1,000 iterations with 20 populations in each iteration. Simulations were carried out ten times to find out the differences produced. Table 2 shows the convergent results under 300 iterations. The bus values and capacities vary due to the type of metaheuristic method. By comparing the value of losses in each simulation, the optimal bus placement for 2 DGs is on buses 17 and 33 with a capacity of 2836 kW and 2435 kW, respectively, so the value of active power losses becomes 82.9 kW and the voltage profile improves as shown in Fig. 6. In this case, for the cost of using a single DG with multiple DG (2 DG), it is more profitable to use multi-DG, this is because the same parameters and cases as single DG produce a greater total cost than multi-DG.

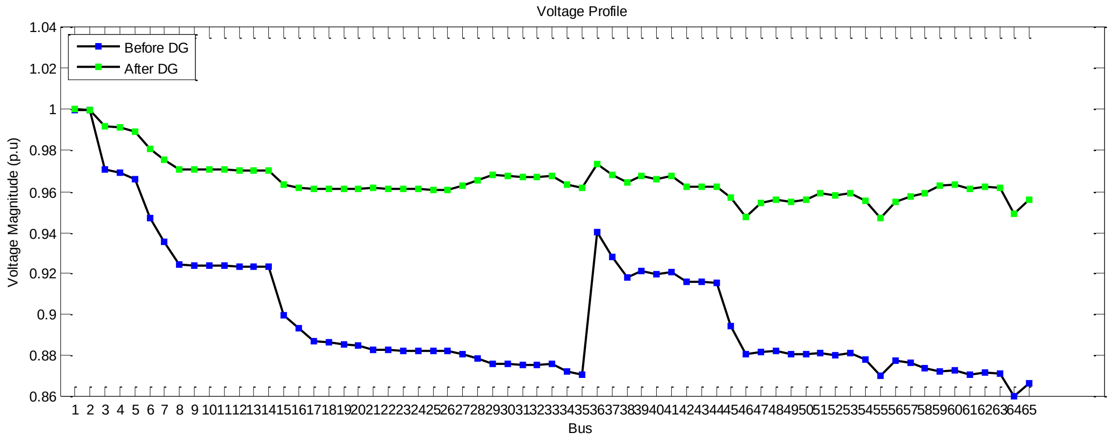


**Fig. 5**. Results of comparison of voltage profiles with single DG

**Table 2**. The results of objective function optimization using the FPA method with 2 DG

| Simulation to- | The number of iterations to converge | Optimal bus | Optimal capacity (kW) | Total load power (kW) | Losses kW | Losses % | ENS (kWh) | CENS ($) |
|---|---|---|---|---|---|---|---|---|
| 1 | 100 | 20 | 2,867 | 5,271.5 | 88.3 | 1.45 | 0.00496 | 37.8864 |
| | | 29 | 2,404 | | | | | |
| 2 | 300 | 17 | 2,604 | 5,271.5 | 85.0 | 1.4 | 0.00280 | 39.1641 |
| | | 33 | 2,668 | | | | | |
| 3 | 180 | 18 | 2,780 | 5,271.5 | 84.6 | 1.39 | 0.00594 | 41.1995 |
| | | 33 | 2,491 | | | | | |
| 4 | 150 | 22 | 2,500 | 5,271.5 | 98.3 | 1.62 | 0.00068 | 29.0375 |
| | | 30 | 2,772 | | | | | |
| 5 | 110 | 23 | 2,279 | 5,271.5 | 101.5 | 1.67 | 0.00565 | 30.9766 |
| | | 33 | 2,992 | | | | | |
| 6 | 250 | 17 | 2,836 | 5,271.5 | 82.9 | 1.36 | 0.00751 | 44.1409 |
| | | 33 | 2,435 | | | | | |
| 7 | 180 | 20 | 2,868 | 5,271.5 | 88.3 | 1.45 | 0.00036 | 34.9959 |
| | | 29 | 2,403 | | | | | |
| 8 | 110 | 18 | 2,901 | 5,271.5 | 83.7 | 1.38 | 0.00305 | 40.4144 |
| | | 33 | 2,370 | | | | | |
| 9 | 120 | 18 | 2,437 | 5,271.5 | 87.7 | 1.44 | 0.00697 | 45.3651 |
| | | 28 | 2,835 | | | | | |
| 10 | 100 | 19 | 2,581 | 5,271.5 | 88.3 | 1.45 | 0.00010 | 34.6752 |
| | | 29 | 2,690 | | | | | |
| Mean | 161 | | | 5,271.5 | 88.9 | 1.46 | 0.00380 | 37.7855 |
| Std. Dev | 70.9381577 | | | 0 | 6.193 | 0.102 | 0.00278 | 5.36100 |

### 3.3. Scenario 3

In the third scenario, the number of iterations given is 1,000 iterations with 20 populations in each iteration. Simulations were carried out ten times to find out the differences produced. Table 3 shows the convergent results under 330 iterations. The bus values and capacities vary due to the type of method used by the metaheuristic method. By comparing the value of losses in each simulation, the optimal bus placement for 3 DGs is on buses 16, 17, and 31 with capacities of 1060 kW, 2539 kW, and 1672 kW, so the value of active power losses will be 77.5 kW the voltage profile improves as shown in Fig. 7. The addition of multi DG (3

DG) is the best scenario than scenario 1 and scenario 2, with the lowest voltage profile of 1.00 p.u. and power losses of 77.5 kW or 1.27% of the total load power.

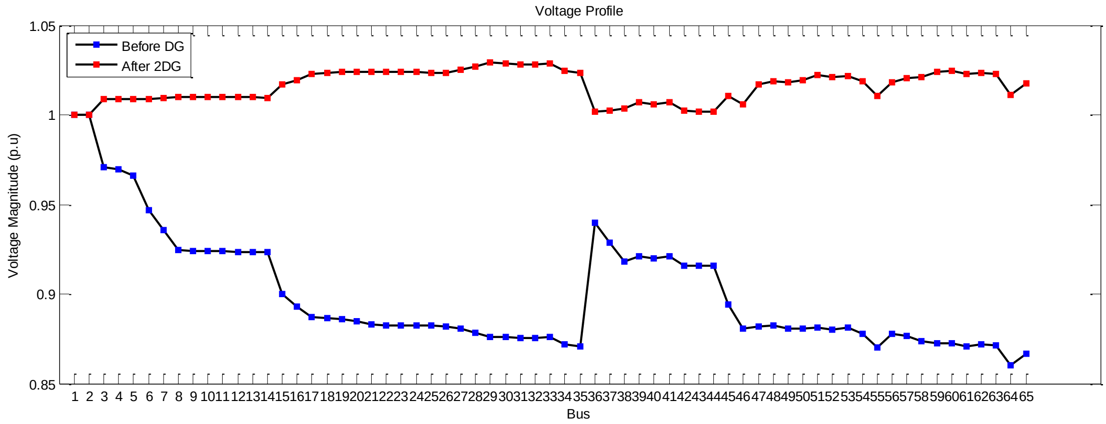


**Fig. 6**. Results of comparison of voltage profiles with multi-DG (2 DG)

**Table 3.** The results of objective function optimization using the FPA method with 3 DG.

| Simulation to- | The number of iterations to converge | Optimal bus | Optimal capacity (kW) | Total load power (kW) | Losses kW | Losses % | ENS (kWh) | CENS ($) |
|---|---|---|---|---|---|---|---|---|
| **1** | 330 | 18 | 2,732 | 5,271.5 | 83.4 | 1.37 | 0.0599 | 73.6113 |
| | | 29 | 1,445 | | | | | |
| | | 30 | 1,095 | | | | | |
| **2** | 185 | 16 | 1,060 | 5,271.5 | 77.5 | 1.27 | 0.0142 | 58.4614 |
| | | 17 | 2,539 | | | | | |
| | | 31 | 1,672 | | | | | |
| **3** | 170 | 24 | 2,326 | 5,271.5 | 98.5 | 1.62 | 0.0763 | 69.1912 |
| | | 33 | 1,722 | | | | | |
| | | 34 | 1,223 | | | | | |
| **4** | 170 | 24 | 2,326 | 5,271.5 | 98.5 | 1.62 | 0.0763 | 69.1912 |
| | | 33 | 1,722 | | | | | |
| | | 34 | 1,223 | | | | | |
| **5** | 170 | 24 | 2,326 | 5,271.5 | 98.5 | 1.62 | 0.0763 | 69.1912 |
| | | 33 | 1,722 | | | | | |
| | | 34 | 1,223 | | | | | |
| 6 | 170 | 24 | 2,326 | 5,271.5 | 98.5 | 1.62 | 0.0763 | 69.1912 |
| | | 33 | 1,722 | | | | | |
| | | 34 | 1,223 | | | | | |
| **7** | 270 | 21 | 2,773 | 5,271.5 | 90.2 | 1.48 | 0.0021 | 36.8095 |
| | | 22 | 1,300 | | | | | |
| | | 30 | 1,199 | | | | | |
| **8** | 140 | 18 | 2,098 | 5,271.5 | 81.5 | 1.34 | 0.0417 | 57.4566 |
| | | 27 | 1,716 | | | | | |
| | | 34 | 1,457 | | | | | |
| **9** | 230 | 18 | 1,556 | 5,271.5 | 86.5 | 1.42 | 0.0021 | 40.6429 |
| | | 23 | 2,594 | | | | | |
| | | 32 | 1,121 | | | | | |
| **10** | 140 | 17 | 1,037 | 5,271.5 | 79.4 | 1.31 | 0.0020 | 40.6209 |
| | | 18 | 2,102 | | | | | |
| | | 30 | 2,132 | | | | | |
| **Mean** | 194 | | | 5,271.5 | 88.28 | 1.45 | 0.0454 | 65.6009 |
| **Std. Dev** | 62.9285308 | | | 0 | 10.539 | 0.17 | 0.0328 | 26.7051 |

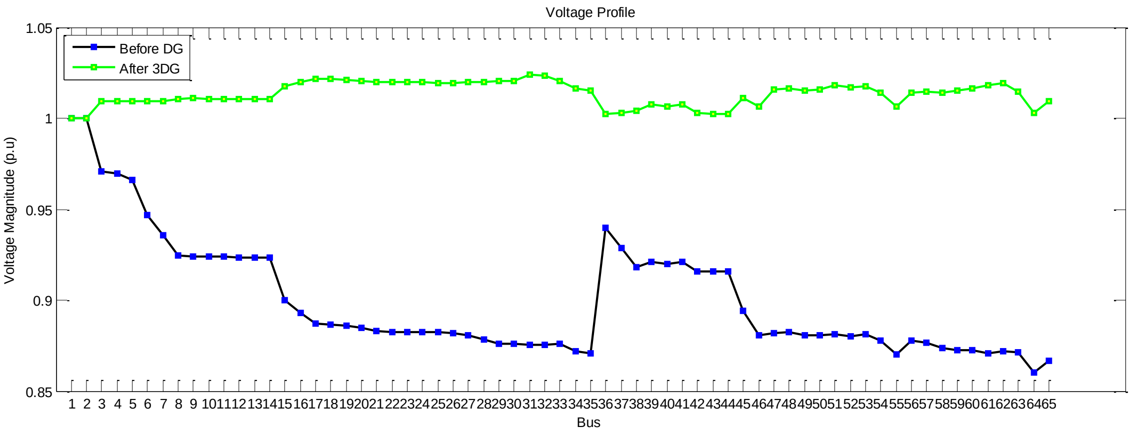


**Fig. 7.** The results of the comparison of voltage profiles with multi-DG (3 DG)

For the cost of using multi-DG (2 DG) with multi-DG (3 DG), it is more profitable to use 2 DG. This is because the same parameters and cases with 3 DG generate greater total cost than 2 DG. Table 4 shows the comparison before DG and after DG was installed against the voltage profile, active power losses, and ENS costs.

**Table 4.** Overall comparison results without DG, single DG, and multiple DG

| Measured parameters | Feeder Distribution System BNL05 | | | |
|---|---|---|---|---|
| | Without DG | With 1 DG | With 2 DG | With 3 DG |
| $V_{max}$ (p.u) | 1.00 | 1.00 | 1.026 | 1.024 |
| $V_{min}$ (p.u) | 0.86 | 0.947 | 1.00 | 1.00 |
| $\sum Total\ loss$ (%) | 8.34 | 1.94 | 1.36 | 1.27 |
| $\sum Total\ loss$ (kW) | 439.8 | 117.7 | 82.9 | 77.5 |
| *Line Loss* (kW) | 419.8 | 90.4 | 55.3 | 52.3 |
| *Transform Loss* (kW) | 20 | 27.3 | 27.7 | 25.2 |
| CENS ($) | >3500000 | 2232578.2 | 44.1409 | 58.4614 |

The active power losses are then shown in Fig. 8**,** which consists of line losses and transformer losses. Based on the graph, in general, the value of active power losses has decreased with the increasing number of DG installed. The effect of DG addition on Bantul 05 feeders with three scenarios is as follows; the addition of a single DG can reduce total power losses of 117.7 kW or 1.94% of the total load power, the addition of multiple DG (2 DG) can reduce power losses of 82.9 kW or 1.36% of the total load power, and the addition of multi DG (3 DG) is the best scenario with reducing power losses of 77.5 kW or 1.27% of the total load power.

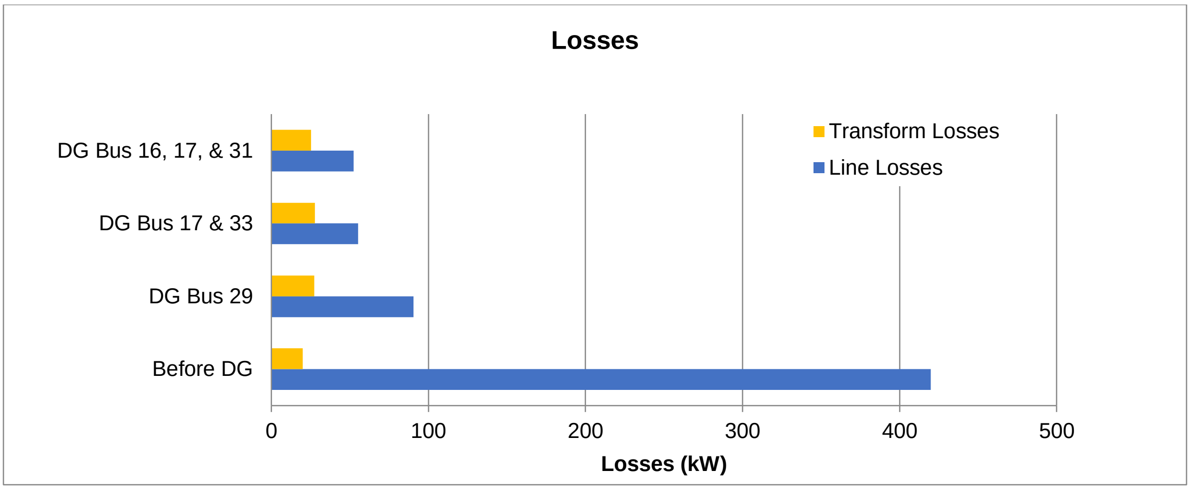


**Fig. 8.** Comparison of losses

## 4. CONCLUSION

In this paper, determining the placement and capacity of distributed generation using the flower pollination algorithm method has been presented. Several scenarios for determining the placement and capacity of distributed generation have been considered. The performance of these scenarios has been compared based on system power loss and voltage profile. From this comparative study, it has been found that scenario 3 (multi-DG), integration on buses 16, 17, and 31 with capacities of 1.060 kW, 2.539 kW, and 1.672 kW, respectively, were the best strategies with the lowest voltage profile of 1.00 p.u. and power losses of 77.5 kW or 1.27% of the total load power. Meanwhile, as DG capacity increases, the ENS value decreases so that CENS also decreases.

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