Selection of Sensitive Buses using the Firefly Algorithm for Optimal Multiple Types of Distributed Generations Allocation

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***Abstract*—Power loss is one aspect of an electric power system performance indicator. Loss of power can have an impact on poor voltage performance at the receiving end. DG integration in the network has become one of the more powerful methods. To get the maximum benefit from synchronizing the system with DG, it is necessary to ascertain the size, location, and type of DG. This study aims to determine the capacity and location of DG connections for DG type I and type II. To address the aim of this paper, a metaheuristic solution based on a firefly algorithm is used. FA can cover up the lack of metaheuristic algorithms that require a long computational time. To ensure that the load bus location solution is selected as the best DG connection location, the input of the load bus candidate has been filtered based on stability sensitivity. The proposed method is tested on IEEE 30 buses. The optimization results show a decrease in power loss and an increase in bus voltage, which affects an increase in system stability by integrating three DG units. FA validation of the evolution-based algorithm shows a significant reduction in computational time.**

Keywords—Firefly algorithm; time computation; real power loss index; voltage profile index; multi-type DG

I. Introduction

The use of distributed generators (DG) on a scale of capacity and various types of innovation is becoming increasingly prevalent used in electric power systems. Technically, the benefits obtained from DG integration have been mentioned in previous studies, including reducing power losses, increasing reliability, improving stability, and improving the voltage profile [1]-[4].

However, the implementation of the addition of DG to the existing system will cause a new problem that is synchronizing the work between the old generating system and the new generating system. Therefore it is essential to do a thorough analysis of the technical factors related to the placement of DG, including the size, location of the connection, and the resulting impact. DG units can inject and absorb active and reactive power in the distribution network. They can maintain and enhance the voltage profile at different power factors. The power factor is a factor determining the type of DG that governs the type and size of the injected power. Based on the kind of power injected, DG is divided into four classes which are presented in Table I [5].

The maximum result of DG integration is achieved by the size and installed location of DG. Therefore, further analysis is needed regarding this matter. Previous research has examined various DG allocation techniques, precisely Analytical techniques developed by becoming techniques based on artificial intelligence.

Analytical technique is a form of mathematical settlement in the form of numerical equations that are expressed as objective functions. This analytical technique represents the target to be achieved after DG placement. Some goals that generally want to be performed are the minimization of power losses, and increasing the voltage profile, achieving system stability [6]-[8]. In [7], the DG optimization process uses a combination of genetic algorithms with analytical techniques. DG optimization is done to reduce power losses in the system. In line with research [7], reference [8] has proposed a method for determining the location and size of DG type combinations using the efficient analytical method (EA) integrated power flow study. The target function is only to prioritize the power loss function, which is described by the real power loss (RPL) formula without assessing the bus voltage value after DG placement.

Artificial intelligence techniques using metaheuristics now also dominate DG research [9]-[13]. This is due to metaheuristic success to resolve cases in an extensive system range. Metaheuristic algorithms mimic natural processes in matters such as biological systems and chemical processes. Met[[aheuristics can be divided into search points, namely one point search and population search. Population-based algorithms have the advantage of being able to explore effectively in the search space, making it suitable for global search. This is due to the ability of local exploitation and comprehensive exploration to avoid convergent locality. One approach using population metaheuristics is the firefly algorithm.

In this study, using techniques developed by Dr. Xin-She Yang named the firefly algorithm (FA)[14]. FA imitated the information of fireflies in solving problems where in previous studies have been proven to resolve technical issues by solving global solutions [15]-[16]. The flash produced by fireflies is formulated based on objective functions. The brightest firefly determined as the most optimal solution.

TABLE. I. CLASSIFICATION OF DG BASED POWER INJECTION

DG Type	Power Injecting DG	Power Factor (pf)
Tipe I (DG-1)	Real power (P+)	Unity (1)
Tipe II (DG-2)	Real power (P+) and reactive power (Q+)	leading
Tipe III (DG-3)	Real power (P) but absorbing reactive power (P+Q-)	lagging
Tipe IV (DG-4)	Reactive power (Q+)	Zero

In a generation, there will undoubtedly be losses along the transmission and distribution lines. With the integration of DG, learning is done to minimize losses that occur on a line by using voltage control in a system that has been assumed, as illustrated in Fig. 1.

There is a trend towards a reduction in power loss in line with the increase in DG capacity. But there is a point where the trend reverses to increase again. This indicates the need for proper techniques to obtain the optimal level of DG capacity.

DG applications at the distribution and transmission levels show that usage on DG-1 and DG-2 is quite high. Photovoltaics, microturbines, fuel cells assisted by converters, and inverters can be used as good examples for Type 1. Type 2 can be DG generating units based on synchronous engines such as cogeneration, gas turbines, and others. The utilization of DG-1 and DG-2 is increasingly widespread so that it becomes the reason for the choice of DG type.

This paper presents research results on the placement of DG-1 and DG-2 in varying units using FA approximations. FA, as a type of metaheuristic-based algorithm, has advantages in exploitation and exploitation in the search process and short computing time. This paper exists to address the shortcomings of using metaheuristic algorithms that require a long time in the execution process [9], [10]. Due to this reason, the FA election to resolve the DG case in this study.

The clustering of load buses based on the sensitivity level by bus stability level has been carried out to ensure the placement of DG buses as the best location. This indeed ensures that the selected bus is the best bus for DG placement that fulfills the objective function.

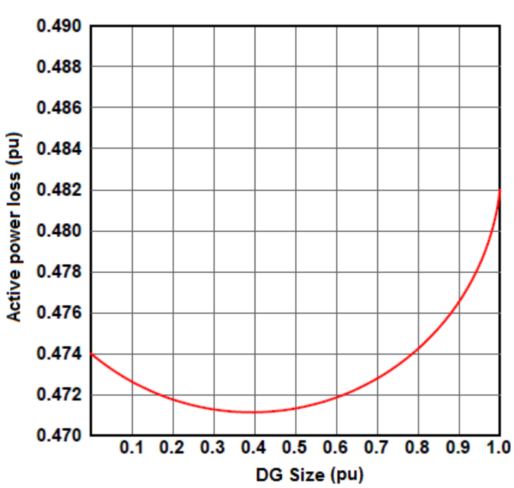

Fig. 1. Effect of DG Size on Active Power Loss [17].

The structure of the article is divided into five parts. Section 1 explains the background and linkages with previous research. Section 2 provides an analytical explanation of power flow studies for multi type DG placement. Section 3 describes the stages of solving optimization problems using FA. Sections 4 and 5 each explain the results of optimizing the placement of the both DG types and conclusions.

II. MULTI-TYPE DG OPTIMAL POWER FLOW

A. Objective Function

In this study, DG optimization consists of DG placement location and how much power is injected by DG. Calculation of DG power injection is determined based on power losses in the power system network, which are stated as objective functions. The objective function in this study is the minimization of the power loss function expressed by the exact loss formula [18] or written as (1).

$F_{objective} = \text{Min } P_L$

$$= Min \sum_{i=1}^{NB}\sum_{j=1}^{NB}[a_{ij}(P_iP_j + Q_iQ_{j})) + b_{ij}\,(Q_i\,P_j - P_i\,Q_j\,)] \qquad (1)$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\,\delta_i - \,\delta_j) \qquad \beta_{ij}\ \frac{(\,r_{ij}\,)}{V_iV_j}\sin(\delta_i - \delta_j);$$

V_i , δ_i = voltage and phase angle of bus-i ;

$r_{ij} + jx_{ij}$ = Zij are components of impedance Z bus matrix;

P_i and Q_i= real and reactive power injections of i^{th} bus

P_j and Q_j= real and reactive power injections of j^{th} bus

DG optimization strategies provide limits that must be met active power and reactive power of DG as shown in equations (2) and (3).

$$0.001 < P_{DGi} < 10 \text{ MW}, i = 1,2,....N_{DG} \qquad (2)$$

$$0.001 < Q_{DGi} < 2\text{MVAr}, i = 1,2,....N_{DG} \qquad (3)$$

where : N_{DG} is unit DG, P_{Dgi} and Q_{Dgi} are active power and reactive power of DG, respectively.

After DG integration, the voltage on bus-i (VDgi) must be controlled at the value specified in equation (4).

$$1.05\text{pu} < V_{DGi} < 0.95\text{MW}, i=1,2,....N_B \qquad (4)$$

The voltage limit refers to IEEE Std 45-2002 [19]. In this study, NB is limited to 30 according to the plant used, IEEE bus 30.

B. Determining Size of DG

Based on Table I, the DG type indicates the type of power injected into the system. Active power and reactive power that is injected must be following the needs to function optimally. The proposed power loss is the elaboration of the exact loss formula given in (1).

Since active and reactive power injected by DG on the bus i^{th} are:

$$P_i = P_{DG\,i} - P_{D\,i} \qquad (5)$$

$$Q_i = Q_{DG_i} \text{-} Q_{D_i} \quad (6)$$

From equations (1), (5), and (6), active power losses are expressed by:

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\begin{array}{l}\alpha_{ij}\,[(P_{DG_i} - P_{D_i})P_j + (\,a\,P_{DG_i} - Q_{D_i}) \quad Q_j] + \\ + \beta_{ij}\,[\,(a\,P_{DG\,i} - Q_{D_i})P_j - (P_{DG_i} - P_{D_i}) \quad Q_j\end{array}\right] \quad (7)$$

differentiating (7) w.r.t to get minimum value : $\frac{\partial P_L}{\partial P_{DG_i}} = 0$

$$\frac{\partial P_L}{\partial P_{DG_i}} = 2\sum_{j=1}^{N}[\,\alpha_{ij}\,(P_j + aQ_j) + \beta_{ij}(aP_j - Q_j) \quad (8)$$

By solving (8) in a matrix (7), a solution (9) is obtained as the optimal value of DG size on the bus i:

$P_{DG1}=(\alpha_{ii}(P_{D1}+\alpha Q_{D1})+\beta_{ii}(P_{D1}\text{-}\alpha Q_{D1})\text{-}X_i\text{-}\alpha Y_i)/\alpha^2\alpha_{ii}+\alpha_{ii}$

$$P_{DG_1} = \frac{\alpha_{ii}(P_{D_1}+aQ_{D_1})+\beta_{ii}(aP_{D_i}\text{-}Q_{D_i})\text{-}X_i\text{-}aY_i}{a^2\alpha_{ii}+\alpha_{ii}} \quad (9)$$

Assume a = (*sign*) tan ($\cos^{-1}$ (pfDG))$\cos^{-1}$ (pf_{DG}),

DG reactive power can be defined as given (10)

$$Q_{DGi} = a\,P_{Dgi} \quad (10)$$

where

Sign = +1: DG reactive power injection;

Sign = +1: DG absorbs reactive power;

pf DG is the DG power factor

The relationship between power factor (pfDG) and variable a_1 on the bus i th is expressed by (11):

$$pf_{DG} = \cos(\tan^{-1}(\frac{\alpha_{ij}Q_{Di}\text{-}Y_i}{\alpha_{ij}P_{Di}\text{-}X_i})) \quad (11)$$

where

$$X_i = \sum_{\substack{j=1 \\ j\neq i}}^{n} \alpha_{ij}P_j\text{-}\beta_{ij}Q_j \quad \text{and} \quad Y_i = \sum_{\substack{j=1 \\ j\neq i}}^{n} \alpha_{ij}Q_j\text{-}\beta_{ij}P_j$$

The DG types used in this research simulation are DG-1 and DG-2. In DG-1, the value (pfDG = 1, a = 0) so that the optimal DG-1 on each bus is expressed in (12):

$$P_{DG_1} = P_{D_1} - \frac{1}{\alpha_{ii}}\,[\beta_{ii}\,Q_{D_1} + \sum_{\substack{j=1 \\ j\neq i}}^{N}(\alpha_{ij}\,P_j - \beta_{ij}Q_j)] \quad (12)$$

For DG-2, the PF is in the range of values 0 <pfDG <1, the sign is '+', and 'a' is constant.

III. Implementation of the FA OPF in Determining Optimal DG

As discussed in the introduction, that the working principle of the FA's work follows the principle of fireflies in dealing with mating partners and potential prey. The working principle of the OPF FA algorithm embraces three social behaviors of fireflies.

1) All fireflies are unisex.

2) The movement of fireflies always looking for fireflies that have a higher brightness than their flocks.

3) The movements of the fireflies are always random until they find brighter fireflies.

In the FA OPF process, mathematical calculations follow the social behavior of fireflies, including distance calculation, brightness level calculation, and attraction calculation. These calculations are shown in (13), (14), and (15), respectively [14].

$$A(d) = A_0 * \exp(-\gamma\, d^m) \quad \text{with } m>>1 \quad (13)$$

where d= distance between firefly

A_0 = attractiveness of firefly at d=0

γ= coefficient of absorption

As distance increases, the attraction of fireflies will decrease due to absorption factors. The process of calculating the brightest firefly distance from the first firefly (i-firefly) is formulated in (13).

$$d_{ij} = \sqrt{\left(\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2\right)} \quad (14)$$

The distance and attractiveness of fireflies determine the process of moving fireflies in a brighter direction. It is given by (14).

$$x_i^{k+1} = x_i^k + A_0 * \exp(-d^2) * (x_i^k - x_i^k + a * rand_i^k) \quad (15)$$

where x^i_k = base position of firefly i

$a*rand^i_k$= random movement of fireflies i^{th}

The fireflies move randomly and will continue to repeat until the convergence criteria are reached. This process called safe iteration; the last iteration is called the optimal solution. The brightest position of the fireflies is predicted as the location and the optimal size of DG. The procedure above is shown through the power flow picture in Fig. 2.

The FA approach to this problem used the parameters that have been used in the calculation of power flow as follows number of firefly=40, α=0.5, β_0=1, β_{min}=0.2, γ=1, $Iter_{max}$ =100 [16].

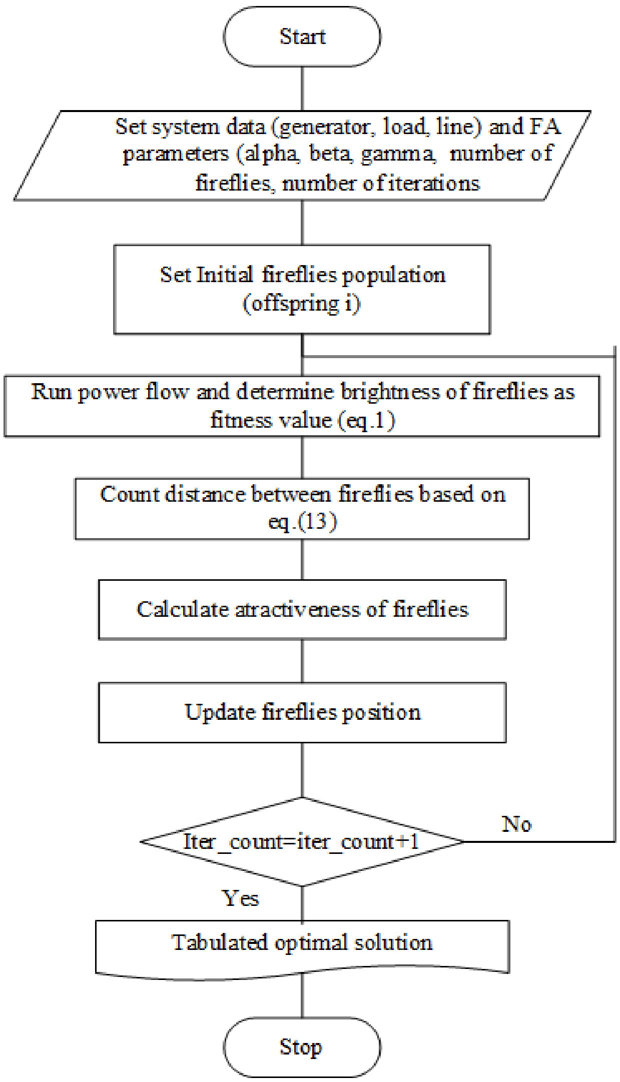

Fig. 2. Flowchart of FA OPF DG.

The proposed algorithm has been tested in Matlab 2016a. As a comparison validation, the computational time indicator and the power loss indicator are used as a fitness function.

IV. Result and Discussion

Implementation of FA on the problem of DG placement optimally performed on IEEE 30 bus system. The IEEE 30 bus system consists of six generator bus, and 41transmission lines that serve a total load 283.4 MW + j 126.2 MVAr load spread over 24 load bus. IEEE 30 bus system load and line data refer to previous research [20].

A. Exploration and Exploitation of FA

The combination of DG size and location that has been raised has two dimensions, namely dimension -i and dimension -j. The number of dimensions -i is determined by the number of fireflies population, which is the number of desired candidate candidates (DG number) while the value of the candidate solutions determines the number of dimensions j. The population raised is an array to represent the size of the DG and the location of the DG.

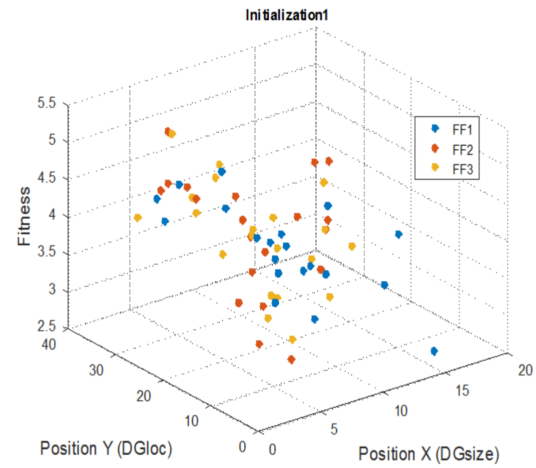

Fig. 3. Initialization Process.

Evaluate each component of DG size and location to position the first fireflies, as shown in Fig. 3. All processes in the FA stage are carried out in the form of functions that require different computational time.

As validation, the computational time of the proposed method is compared with the GA method that has been done in previous studies [10]. Comparison of the computational time of both methods are shown in Fig. 4. Compared to evolution-based search techniques, FA techniques have the advantage of faster computing time. The total execution time of FA is shorter 16.645 s compared to GA [10].

The time is due to the process of searching in the FA less starting from the process of generating population, evaluating, calculating the distance of fireflies, attractiveness, and movement. The function of FA affects the matrix operation formed. Compared to GA, matrix operations are built a lot because it matches the stages in the process of finding a solution. Self-time is the time spent in a function, not including the time spent in other sub-functions. In the process of optimizing the load flow sub-function, it is crucial to determine the solution obtained because the function produces an output of a power loss value and a voltage value. These parameters will be evaluated in the fitness function.

B. Optimal Multiple of Multi-Type DG

Performance of the firefly algorithm is measured using the Real Power Loss Index (RPLI) [21], Voltage Profile Index (VPI) [22], and Voltage Sensitivity Index (VSI) [23]. The equation of each index is shown in (16), (17), and (18).

$$RPLI = \mathbf{(}P_{loss} \text{ after DG}/P_{loss} \text{ without DG}) \quad (16)$$

where,

P_{loss} is active power loss of power system,

RPLI <1 shows DG integration is successful in reducing active power loss,

RPLI = 1 DG indicates that DG integration has no impact on the reduction in active power loss,

RPLI> 1 DG indicates that DG integration has not been successful in reducing power loss.

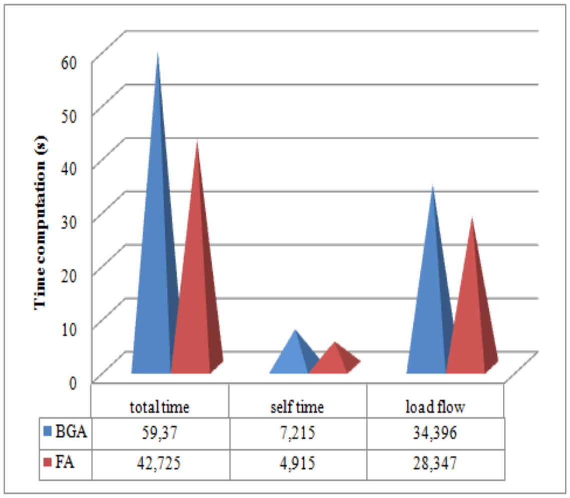

Fig. 4. Comparison of Time Computation.

$$VPI_{(i)} = (V_i - V_{min})*(V_{max} - V_i)/(V_{nom} - V_{min})*(V_{max} - V_{nom}) \quad (17)$$

where, $VP_{(i)}$ is the voltage profile of i^{th} bus, V_{min} and V_{max} are the minimum and maximum allowable voltages of the system and V_{nom} is the nominal bus voltage (1.0 pu).

$$VSI_{(i)} = \sqrt{\frac{\sum_{k=1}^{n}(1-V_k)^2}{n}} \quad (18)$$

where, V_i is voltage on i th bus and n is total number of bus.

Placement of multiple DG-1 units is shown in Table II.

The clustering process is carried out by the FA to get candidates for DG placement locations. The resulting bus candidates are sensitive buses referring to (18), namely buses 7, 10, 23, 26, 29, and 30 with VSI values of 0.3857, 0.4476, 0.4253, 0.7978, 0.4322 and 0.4688, respectively. The most likely bus candidate as a DG placement location is the bus.

The results of this cluster become a reference for applying the combination process with DG size as specified in (2), (3), and (4). In this test case, the best solutions for placing multiple DG-1 units are shown in Table II.

The placement of one DG-1 unit of 9 MW on bus 30 generates RPLI 0.914. The placement of DG-1 has an impact on reducing power loss by 8.64% so that the system power loss becomes 16.657 MW. The installation of the two DG-1 units on bus 26 and bus 30 was 8.4 MW and 9.4 MW, respectively, resulting in a real power loss reduction of 15.87%.

In addition to reducing power loss, DG-1 integration also has an impact on improving the voltage profile. The addition of one DG-1 unit reduces the voltage deviation from 4.1% to 1.4% or 0.986 pu while the addition of two DG-1 units decreases the minimum voltage deviation by 4.1% to 1.3% or the minimum voltage by 0.987 pu. Concerning the RPLI with a minimum value of 0.78259, the optimal location of DG-1 is on buses 7, 30, and 26, with sizes of 8.9 MW, 8.9 MW, and 9.4 MW, respectively.

TABLE. II. RESULT OF OPTIMAL MULTIPLE DG-1 PLACEMENT

DG Unit	Optimal DG	Index	
		RPLI	***VPI*** ***($VP_{with\ DG}/VP_{withoutDG}$)***
1	Bus 30 (9 MW)	0.9136	1.223
2	Bus 26 (8.4 MW)	0.8412	1.312
	Bus 30 (9.4 MW)		
3	Bus 7 (8.9 MW)	0.7825	1.334
	Bus 30 (8.9 MW)		
	Bus 26 (9.4 MW)		

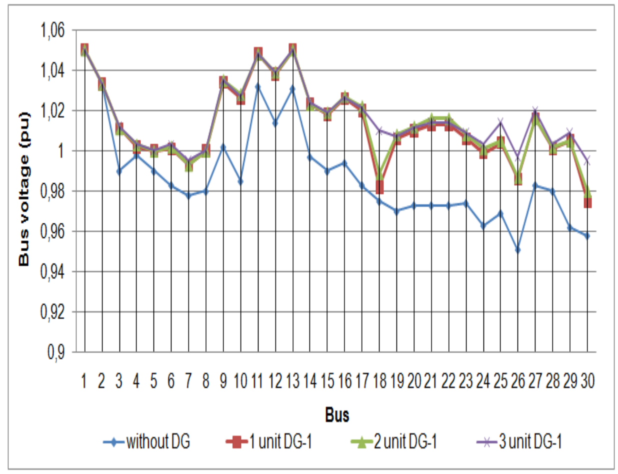

Fig. 5. Voltage Profile after DG-1 Placement.

The real power loss for this solution decreased by 22.37% of the power loss before the DG-1 placement or 14.402 MW. Integration of the DG units into the network improved the voltage profile of the system. Placement of three DG-1 units gives the best results by adjusting the voltage profile from a deviation of 4.1% to 0.3% or a minimum voltage of 0.997 pu on bus 26. Comparison of the DG-1 placement voltage profile with the number of units one, two, and three can be seen in Fig. 5. From the results of the power flow shows that the addition of three DG units causes the voltage magnitude of all buses not to violate the voltage limit function. However, when the number of DG units increases to four DG units, voltage limit function violations will occur.

Multiple DG-2 placements is shown in Table III.

The placement of one DG-2 unit on bus 30 with a capacity of 9.70 MW + j1.30 MVAr gives an RPLI value of 0.898. The installation of DG-2 has the effect of reducing active and reactive power losses by 10.16% and 35.86%, respectively.

The integration of two DG-2 units on bus 23 with a capacity of 9.90MW + j0.9 MVAr and on bus 30 with a capacity of 9.80MW + j1.5 MVAr were able to reduce real power losses by 17.4% from 18.403 MW (without DG) to 15.207 MW. RPLI of 0.8263 indicates these benefits.

The reactive power loss was also reduced by 56.53% so that the system's reactive power loss was 12.66 MVAr. In addition to reducing power loss, DG-2 integration also has an impact on improving the voltage profile. The addition of one DG-2 unit decreases the voltage deviation from 4.1% to 1% or equal to 0.990 pu on bus 26.

TABLE. III. RESULT OF OPTIMAL MULTIPLE DG-2 PLACEMENT

DG Unit	Optimal DG	Index	
		RPLI	*VPI* (*$VP_{with\ DG}/VP_{withoutDG}$*)
1	Bus 30 (9.70 MW+j 1.30MVAr)	0.898	1.218
2	Bus 30 (9.80 MW + j1.5 MVAr)	0.8263	1.268
	Bus 23 (9.80MW+j0.9MVAr)		
3	Bus 30 (8.6 MW +j0.7 MVAr)	0.76521	1.320
	Bus 7 (9.6 MW +j0.05 MVAr)		
	Bus 10 (9.1 MW +j1.9 MVAr)		

While the addition of two DG-2 units reduces the minimum voltage deviation by 3.3% so that the minimum system voltage is maintained at 0.994 pu on bus 7.

Concerning the RPLI, the minimum value of 0.765201 refers to the DG-2 optimal location on three buses 7, 30 and 10, with a total size of 27.3MW + j2.65 MVar. The actual power loss and reactive power for this solution decreased by 23.48% and 69.9% of the power loss before DG-2 or 14.082MW - j8.753 MVar, respectively. The integration of DG-2 on three different buses also had a positive impact on decreasing the minimum voltage deviation of 2.9%. Where the minimum system voltage is maintained at 0.998 pu on bus 7. Overall, from the DG2 placement scenario, it can be concluded that the placement of three DG-2 units gives better results on the voltage improvement, as shown in Fig. 6.

After the addition of DG-1 and DG-2 into the power system, line loss reduced. Because of DG has supplied the current flowing in the small line due to part of the load. DG acts as a negative load which causes the load on the system to be reduced so that the current flowing is diminished.

In this study, the test system is in a balanced condition scenario, so it needs further analysis for unbalanced conditions with variable load, bearing in mind that this is the main problem in the distribution system. For further studies, implementation in a real plant needs to be considered where there is a study that is in sync with the geographical conditions of natural resources in the form of geographic information systems (GIS).

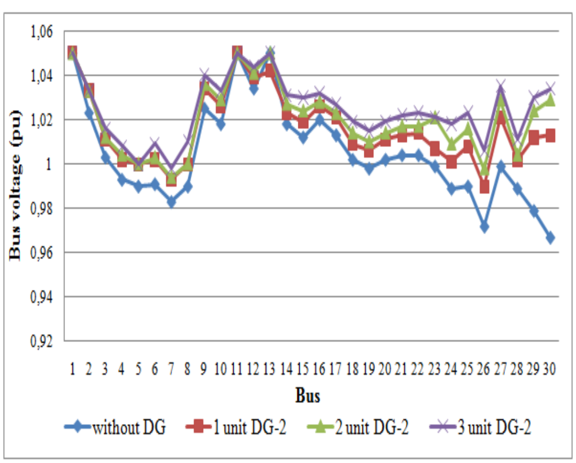

Fig. 6. Voltage Profile after DG-2 Placement.

V. CONCLUSION

The FA optimization method succeeded in solving locating the location of the generator deployed faster than searching using an evolution-based algorithm. The FA's clustering process based on the bus sensitivity factor results in a combination of location and DG size, which effectively reduces power loss and improves the voltage profile. The effectivity measured through the smaller RPLI indicator and the increasing VPI after integrated DG.The power loss and voltage profile obtained when DG-2 penetration is smaller than DG-1.

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