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Optimal Sizing and Placement of Wind-Based Distributed Generation to Minimize Losses Using Flower Pollination Algorithm

Dian Budhi Santoso[1], Sarjiya[2], Fredi Prima Sakti[3]
[1]Program Studi Teknik Elektro, Fakultas Teknik, Universitas Singaperbangsa Karawang, Indonesia
Jalan H.S. Ronggowaluyo, Telukjambe, Karawang, 41361
[2,3]Departemen Teknik Elektro dan Teknologi Informasi, Fakultas Teknik, Universitas Gadjah Mada, Indonesia
Jalan Grafika No. 2 Kampus UGM, Yogyakarta, 55281
dian.budhi@ft.unsika.ac.id

Abstrak

Penempatan DG dapat mempengaruhi aliran daya dan tegangan pada *bus* di sistem distribusi. Oleh karena itu, penempatan DG harus diperhitungkan dan direncanakan secara detail agar dapat bekerja secara optimal. Penempatan DG yang tidak optimal dapat meningkatkan *losses* pada sistem, sehingga berpengaruh terhadap profil tegangan yang akan menurun. Penempatan dan kapasitas DG yang optimal dapat berpengaruh kepada peningkatan profil tegangan, mengurangi *losses*, peningkatkan kapasitas distribusi, dan peningkatkan keandalan pada sistem. Beberapa metode optimisasi banyak yang bermunculan mulai dari optimisasi klasikal, pendekatan analitis, sampai yang terbaru yaitu metaheuristik. Salah satu metode optimisasi metaheuristik terbaru adalah *Flower Pollination Algorithm* (FPA) yang merupakan metode optimisasi yang terinspirasi dari proses penyerbukan bunga. FPA lebih efisien dengan menghasilkan hasil yang lebih baik dan memiliki kecepatan konvergen yang lebih tinggi jika dibandingakan dengan metode metaheuristik lainnya. Pada penelitian ini, FPA digunakan untuk menentukan lokasi dan kapasitas *wind-based* DG yang optimal dengan *single* DG dan *multi* DG untuk meminimalkan rugi-rugi daya pada sistem tes IEEE 33-bus dan meningkatkan profil tegangan. Untuk mengetahui kinerja dari FPA, akan dibandingkan dengan metode optimasi lain. Selain itu, jumlah dan kapasitas *wind-based* DG yang dipasang pada *bus* terpilih akan diperhitungkan. Hasil simulasi menunjukkan bahwa metode yang diusulkan telah berhasil dengan baik menentukan lokasi dan kapasitas DG.

Kata kunci: *Flower Pollination Algorithm*, pembangkitan tersebar, *losses*, profil tegangan, sistem distribusi

Abstract

DG placement can affect to powertrain and voltage on the bus in distributed system. Therefore, DG placement must be calculated and cultivated in detail in order to work optimally. Non-optimal DG placement can increase system losses, so bias against the voltage profile will decrease. The optimal placement and capacity of DG can affect the increase of voltage profile, decreasing losses, increase of capacity, and increase of system performance. Some optimization methods have been addressed such as classical optimization, analytical approach, and metaheuristic. One of the newest methods of metaheuristic optimization is the Flower Pollination Algorithm (FPA) which is an optimization method that inspired by the flower pollination process. FPA is more efficient with better results and has a higher convergence rate when compared to other metaheuristic methods. In this study, FPA is used to determine optimal DG-based location and capacity with single DG and multi DG for power used IEEE 33-bus and raise the voltage profile. To know the performance of FPA, it will be compared with other optimization methods. In addition, the number and capacity of wind-based DG that mounted on selected buses will be calculated. The simulation results show that the proposed method has been successful to determine the location and capacity of DG.

Keywords: *Flower Pollination Algorithm, distributed generation, losses, voltage profile, distribution system*

I. INTRODUCTION

Distributed Generation (DG) is a small-scale electrical energy generation technology that generates electricity somewhere closer to the consumer than a power plant. This electrical power plant can be connected directly to the consumer or to the distribution or transmission system [1]. The

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purpose of DG is to supply active power without having to provide reactive power [2]. There are several types of DG based on the technology it uses, namely traditional combustion generators, and non-traditional combustion generators. One form of DG non-traditional combustion generators is a wind turbine. The wind turbine is not a new energy but has been used for decades. In wind turbine consists of a rotor, turbine blades, and generators. Wind turbines fall into the category of environmentally friendly power plants because they do not produce pollution like other types of plants [2]-[4].

DG placement can affect the flow of power and voltage on the bus in the distribution system. Therefore, DG placement must be calculated and planned in detail in order to work optimally. Non-optimal DG placement can increase the losses on the system, affecting the downward voltage profile [5]-[8]. In addition, DG capacity must be considered to provide a positive impact of DG installation known as “system support benefits”. Optimal DG placement and capacity can affect the increase of voltage profile, reduce losses, increase distribution capacity, and improve reliability in the system [9], [10]. In practice, the load patterns in the distribution network vary by time. Optimal DG placement and capacity in varying loads may not be optimal, as load demand is always different each time. Therefore, for planning purposes, placement and DG capacity are determined by considering the peak load, average or combination of two loading conditions to obtain maximum results [11].

Several methods of optimization are emerging from classical optimization, analytical approach, to the latest metaheuristic. One of the latest metaheuristic optimization methods is the flower pollination algorithm (FPA) which is an optimization method that is inspired by the pollination process of flowers. FPA is more efficient by producing better results and has a higher convergence rate when compared to other metaheuristic methods such as genetic algorithm (GA) and particle swarm optimization (PSO) [12].

Determining the location and capacity of DG is very important in order to reduce losses and improve the voltage profile of the distribution channel optimally. One way to determine the location and capacity of DG is to use FPA. This is because the FPA can be used to solve real optimization problems [13], [14] and produce better outputs, has higher convergence rates, and has a more optimal success rate when compared to other metaheuristic methods such as GA and PSO [12].

In this study, the FPA is used to determine optimal DG and DG wind-based locations and capacities with single DG and multi DG to minimize power losses on the 33-bus IEEE test system and increase the voltage profile. To know the performance of FPA, it will be compared with other optimization methods. In addition, the amount and capacity of DG wind-based installed on selected buses will be taken into account.

II. PROBLEM FORMULATION

A. Distribution System

Electricity distribution system is part of the electrical power system that drains power from the substation to the consumer. The electric voltage generated by the generating centers is generally raised to 70 kV, 150 kV, and 500 kV through the voltage rising transformer on the transmission line, before being lowered to a medium voltage or primary distribution voltage of 20 kV. The voltage on the primary distribution network is lowered in the distribution substation into a low voltage of 380/220 volts, then distributed to the consumer.

B. Wind Turbine (WT)

In practice, to prevent damage to wind turbines, wind turbines are designed to have a relatively large cut-out shown in Figure 1 to anticipate the great wind speed [12].

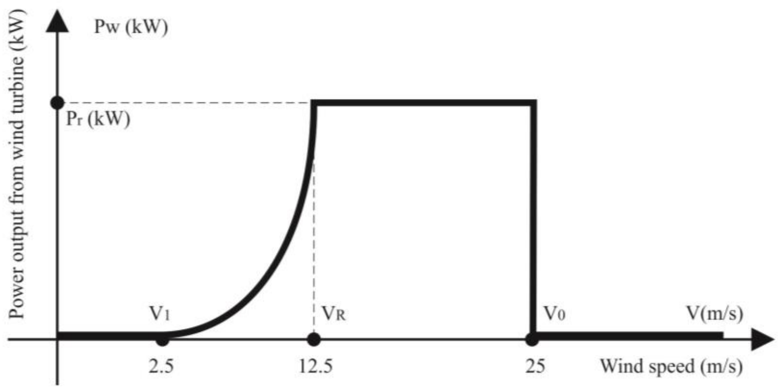

Figure 1. Limitation of Generator on Wind Turbine

$$P_w = \begin{cases} 0, & V \le V_I \\ \frac{V^n - V_I^n}{V_R^n - V_I^n} P_R, & V_I \le V \le V_R \\ P_R, & V_R \le V \le V_0 \\ 0, & V > V_0 \end{cases} \quad (1)$$

with
P_w: power output from the wind turbine (watt)
P_R: average wind power (kW)
V_I: wind speed at the beginning/*cut-in* (m/s)
V_R: average wind speed/*rated* (m/s)
V_0 : maximum speed/*cut-out* (m/s)

The turbine parameters used are as follows: $V_I = 2.5\ m/s$, $V_R = 12.5\ m/s$, $V_0 = 25\ m/s$, and $P_R = 100\ kW$.

C. Objective Function

The objective function is to minimize active power loss on the channel with the main equation as follows:

$$f(x) = min\left(\sum_{i=1}^{N} P_{Li}\right) \quad (2)$$

The first approach is done with an analytical approach. The total losses of active power on the power system are represented by the above equation, or popularly called “exact loss formula” [14], [15].

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (3)$$

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}cos\left(\delta_i - \delta_j\right) \quad (4)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}sin\left(\delta_i - \delta_j\right) \quad (5)$$

with
$V_i < \delta_i$: The complex voltage on the *i*-bus
$r_{ij} + jx_{ij} = Z_{ij}$: The *ij* element of the impedance matrix
P_i, P_j: Active power injection on the *i* and *j*-bus
Q_i, Q_j: Reactive power injection on the *i* and *j*-bus
N: Number of buses

Assume $a = (sign)\ tan(cos^{-1}(PF_{DG}))$ [14][15], then the reactive power output DG can be expressed by the following equation:

$$\boldsymbol{Q_{DGi} = aP_{DGi}} \quad (6)$$

with
$sign = +1$: DG supplies reactive power
$sign = -1$: DG requests reactive power
PF_{DG}: the power factor of DG

The active power and reactive power injected at bus *i*, where DG is located, are expressed by the following equation:

$$\boldsymbol{P_i = P_{DGi} - P_{Di}} \quad (7)$$

$$\boldsymbol{Q_i = Q_{DGi} - Q_{Di} = aP_{DGi} - Q_{Di}} \quad (8)$$

From equations (3), (7), and (8), the active power loss can be written as follows:

$$\boldsymbol{P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\{\alpha_{ij}\left[(P_{DGi} - P_{Di})P_j + (aP_{DGi} - Q_{Di})Q_j\right] + \beta_{ij}\left[(aP_{DGi} - Q_{Di})P_j - (P_{DGi} - P_{Di})Q_j\right]\}} \quad (9)$$

The total active power losses on the system will be minimum if the partial derivatives of equation(9) to active power injection from DG to bus *i* become 0. After simplification and rearrangement, equation (9) can be written as follows:

$$\boldsymbol{\frac{\partial P_L}{\partial P_{DGi}} = 2\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_j + aQ_j\right) + \beta_{ij}(aP_j - Q_j)\right] = 0} \quad (10)$$

Equation (8) can be written as follows:

$$\boldsymbol{\alpha_{ii}(P_i + aQ_i) + \beta_{ii}(aP_i - Q_i) + \sum_{j=1,j\neq i}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) + a\sum_{j=1,j\neq i}^{N}(\alpha_{ij}Q_j - \beta_{ij}p_j) = 0} \quad (11)$$

$$\boldsymbol{set\begin{cases} X_i = \sum_{j=1,j\neq i}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \\ Y_i = \sum_{j=1,j\neq i}^{N}\left(\alpha_{ij}Q_j - \beta_{ij}p_j\right) \end{cases}} \quad (12)$$

From equations (7), (8), (11), and (12), equations can be developed (13),

$$\boldsymbol{\alpha_{ii}\left(P_{DGi} - P_{Di} + a^2P_{DGi} - aQ_{Di}\right) + \beta_{ii}(Q_{Di} - aP_{Di}) + X_i + aY_i = 0} \quad (13)$$

From equation (13), the optimal DG capacity value in each bus *i* to minimize the active power losses can be written as follows:

$$\boldsymbol{P_{DGi} = \frac{\alpha_{ii}(P_{Di} + aQ_{Di}) + \beta_{ii}(aP_{Di} - Q_{Di}) - X_i - aY_i}{a^2\alpha_{ii} + \alpha_{ii}}} \quad (14)$$

III. FLOWER POLLINATION ALGORITHM

In real life, every plant can have several flowers, and each flower releases thousands and even millions of pollen gametes. In the FPA, for simplicity, it is assumed that each plant has only one flower, and each one produces only one pollen gamete. This simplification means one solution x_i is equivalent to one flower and/or one pollen gamete. Two key steps in this algorithm are global pollination and local pollination. In the global pollination step, pollen is carried by the pollinator and can move over long distances. This ensures the most optimal pollination and reproduction (the best fitness value) and the fitness value is represented as g*. The first rule, as well as the specific relationship of interest, can be represented mathematically as follows.

$$x_i^{t+1} = x_i^t + L(x_i^t - g^*) \tag{15}$$

where x_i^{t+1} is the pollen i or the solution vector x_i On the t iteration and g^* Is the latest best solution of all solutions on the latest generation or iteration. The parameter of L is the power of the pollination, which is essentially the step size. Since the insect as a pollinator may move at a great distance by various step measures, levy motion is used to represent this characteristic. The equation L > 0 is taken from the levy distribution,

$$L = Z \frac{R\left(\frac{\Gamma(1+\beta)sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right)\beta^{\frac{\beta-1}{2}}}\right)}{|R|^{\frac{1}{\beta}}} \tag{16}$$

with $\Gamma(\lambda)$ Is a standard gamma function, R is a normal random number, β Is the factor of levy step scaling which in this research is valuable 3/2, and Z is levy step constant which in this research is valued 0.01.

At the local pollination or second rule, the specific relationship of interest is represented

$$x_i^{t+1} = x_i^t + \in (x_j^t - x_k^t) \tag{17}$$

where x_k^t and x_j^t is pollen from another flower on the same type. Mathematically, if x_k^t and x_j^t Coming from the same type or selected from the same population, will be a local random step if the value ϵ is a uniform distribution of 0 to 1. To start, we can use p = 0.5 as the initial value, and it has been observed that for the simulation, p = 0.8 works better in most applications [6].

IV. SYSTEM MODEL

The data required for carrying out this research are resistance data (R), reactance (X), active load point (P) and reactive (Q), point dot data, channel length used to define IEEE 33-bus test system Computing [17]-[19]. The voltage level on the test system uses a base voltage level of 12.66 kV [20] with 33 buses, 32 branches, and total loads of (3,655+j2,260) kVA. The proposed method has been tested on the IEEE 33 radius distribution system bus shown in Figure 2 with branch data and loads connected in the destination bus shown in Table 1 [16]-[19].

The results of the optimization will be accepted when the voltage at any point restraints meet the standard voltage bus as equation (18).

$$V_{min} < V_{bus} < V_{max} \tag{18}$$

The results of the optimization must also meet the availability DG capacity limits that are sold in the market as equation (19).

$$P_{min} < P_{DG} < P_{max} \tag{19}$$

The type of DG used in this study is wind-based DG. This is because wind-based DG is more flexible to be used and installed in some locations with low, medium or high wind speeds. In this study, it is assumed that each bus test system used can be installed wind-based DG with the specified wind characteristics on each bus as shown in Table 2.

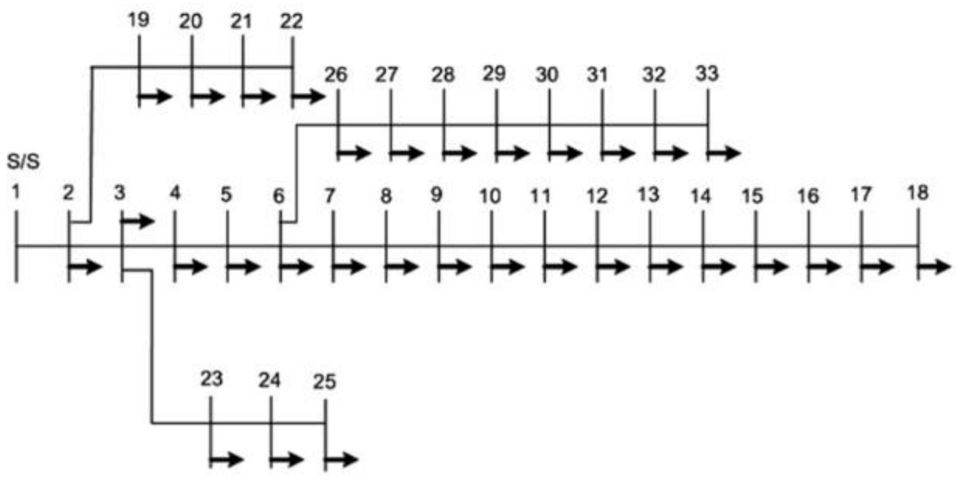

Figure 2. One Line Diagram Test System IEEE 33 bus

Table 1. Line data and Load of System IEEE 33 bus

Branch No.	From bus	To bus	R (Ω)	X (Ω)	Load at to bus	
					P (kW)	Q (kW)
1	1	2	0.0922	0.0477	0	0
2	2	3	0.4930	0.2511	100	60
3	3	4	0.3660	0.1864	90	40
4	4	5	0.3811	0.1941	120	80
5	5	6	0.8190	0.7070	60	30
6	6	7	0.1872	0.6188	60	20
7	7	8	1.7114	1.2351	200	100
8	8	9	1.0300	0.7400	200	100
9	9	10	1.0400	0.7400	60	20
10	10	11	0.1966	0.0650	60	20
11	11	12	0.3744	0.1238	45	30
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	60	35
14	14	15	0.5910	0.5260	120	80
15	15	16	0.7463	0.5450	60	10
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	60	20
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	40
23	23	24	0.8980	0.7091	90	50
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	420	200
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	25
28	28	29	0.8042	0.7006	60	20
29	29	30	0.5075	0.2585	120	70
30	30	31	0.9744	0.9630	200	600
31	31	32	0.3105	0.3619	150	70
32	32	33	0.3410	0.5302	210	100

*R: resistance *X: reactance

Table 2. Data Speed of Test System IEEE 33 bus

No. Bus	VI (m/s)	VR (m/s)	Vo (m/s)	PR (kW)	Vwind
1	2.5	12.5	25	100	2
2	2.5	12.5	25	100	4
3	2.5	12.5	25	100	3
4	2.5	12.5	25	100	5
5	2.5	12.5	25	100	10
6	2.5	12.5	25	100	12
7	2.5	12.5	25	100	12
8	2.5	12.5	25	100	12
9	2.5	12.5	25	100	9
10	2.5	12.5	25	100	6
11	2.5	12.5	25	100	8
12	2.5	12.5	25	100	12
13	2.5	12.5	25	100	10
14	2.5	12.5	25	100	11
15	2.5	12.5	25	100	9
16	2.5	12.5	25	100	12
17	2.5	12.5	25	100	11
18	2.5	12.5	25	100	10
19	2.5	12.5	25	100	9
20	2.5	12.5	25	100	8
21	2.5	12.5	25	100	7
22	2.5	12.5	25	100	6
23	2.5	12.5	25	100	5
24	2.5	12.5	25	100	11
25	2.5	12.5	25	100	3
26	2.5	12.5	25	100	9
27	2.5	12.5	25	100	12
28	2.5	12.5	25	100	11
29	2.5	12.5	25	100	10
30	2.5	12.5	25	100	12
31	2.5	12.5	25	100	12
32	2.5	12.5	25	100	5
33	2.5	12.5	25	100	6

V. Result And Discussion

A. *Scenario 1 (with 1 DG)*

The simulation results show that the fastest convergent value using the FPA method occurs at the 87th iteration with the total loss of power of 111.046 kW on the IEEE 33-bus test system shown in Figure 3. Figure 4 indicates that the minimum voltage value before DG is installed is 0.91 p.u, while the minimum voltage value after DG installation becomes 0.97 p.u.

B. *Scenario 2 (with 2 DG)*

The simulation results show that the fastest convergent value using the FPA method occurs at 641 iterations with the total power loss of 84.05 kW on the IEEE 33-bus test system shown in Figure 5. Figure 6 shows that the minimum voltage value before DG is installed is 0.91 p.u, while the minimum voltage value after DG installation becomes 0.97 p.u.

C. *Scenario 3 (with 3 DG)*

The simulation results show that the fastest convergent value using the FPA method occurs at the iteration to 1,214 with the total power loss of 70.64 kW shown in Figure 7.

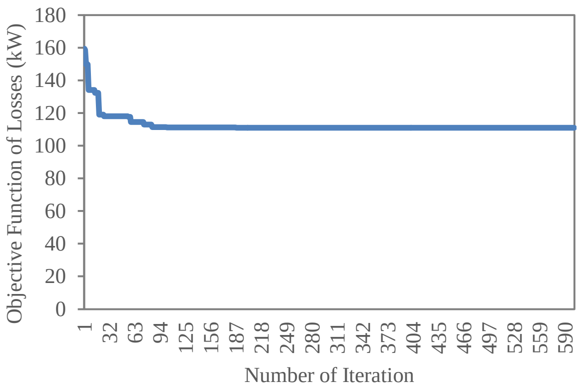

Figure 3. The best convergence graph of placement optimization and wind-based DG capacity to minimize power losses by the FPA method

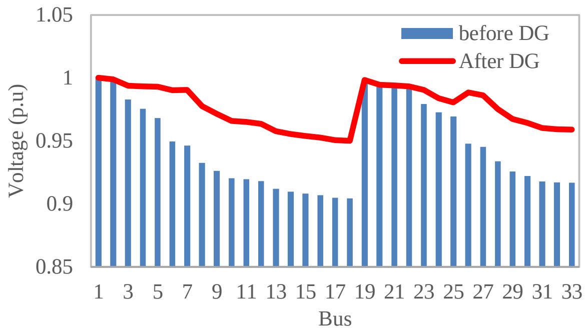

Figure 4. Voltage profile test system IEEE 33 bus

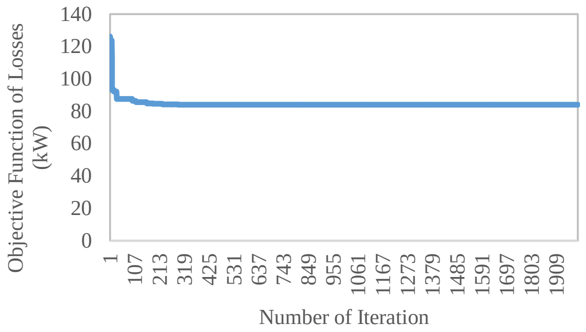

Figure 5. The best convergence graph of placement optimization and wind-based DG capacity to minimize power losses by the FPA method

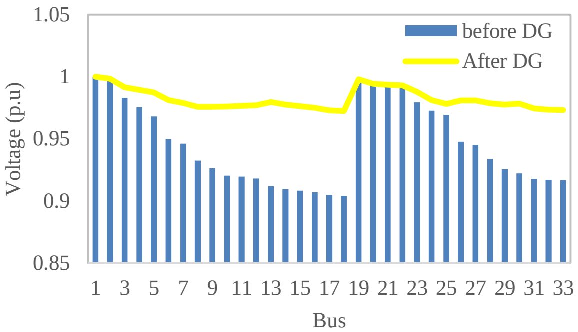

Figure 6. Voltage profile test system IEEE 33 bus

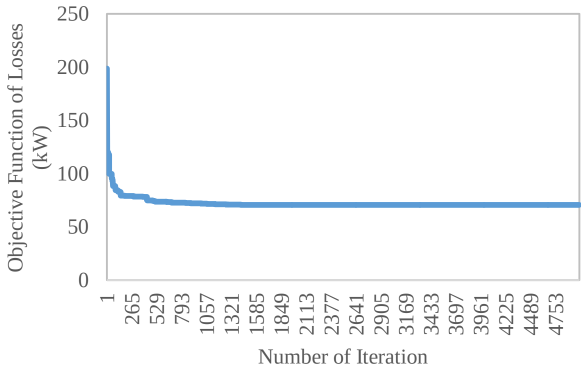

Figure 7. The best convergence graph of placement optimization and wind-based DG capacity to minimize power losses by the FPA method

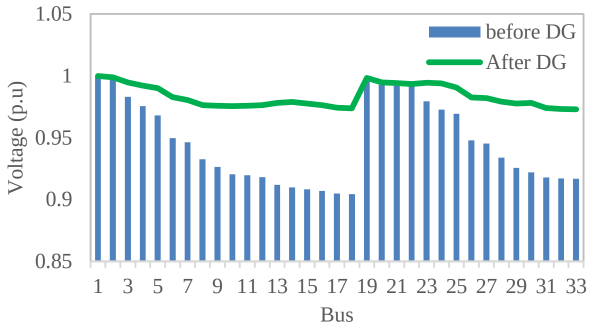

Figure 8. Voltage profile test system IEEE 33 bus

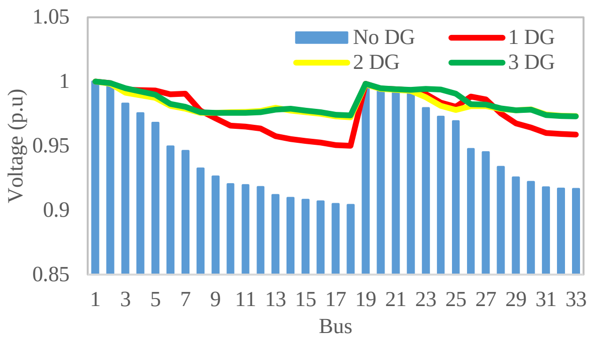

Figure 9. Comparison of the voltage profile of each scenario on IEEE 33-bus test system

Table 3. Comparison of The Optimization of System IEEE 33 bus

Method	1 *wind-based* DG			2 *wind-based* DG		
	Bus	Sizing (kW)	LR (%)	Bus	Sizing (kW)	LR (%)
FPA	7	2,755	47.14	13 30	859.54 1,187	59.99
Analytical [44]	6	2,600	47.85	12 30	1,020 1,020	58.51
BSOA [43]	6	2,460	47.30	13 31	880 924	57.62
PSO [43]	6	2,567	47.40	13 30	849 1,152	58.68

Figure 8 shows that the minimum voltage value before DG is installed is 0.91 p.u, while the minimum voltage value after DG installation becomes 0.98 p.u. Figure 9 shows that the more wind-based DGs installed on selected buses, it will have a positive impact on the improvement of the voltage profile on all buses. This is due to a decrease in the supply of current from the source to the load which in turn has a positive impact on the loss of power losses in each branch.

Based on Table 3 of optimization result, the optimal bus location in bus 7 with 2,756 kW, wind DG 32 units, and losses 47.14% in the first scenario. In the second scenario, an optimal bus location on bus 13 and bus 30 with the capacity of DG 859.55 kW and 1,187.86 kW, total wind DG 17 units and 14 units, and a decrease in losses of 59.99%. In the third scenario, the optimal bus location in bus 30, bus 14, and bus 24 with the capacity of DG 1,091,72 kW, 779.74 kW and 1,067.45 kW, wind DG 13 units, 12 units, and 16 units, as well as a decrease in losses of 66.37%.

VI. CONCLUSION

The simulation results show that the proposed method has succeeded well determine the location and capacity of DG. DG placement and capacity optimization on the distribution network has the benefit of improving the voltage profile and active power losses. Optimization methods with FPA provide better results in case of DG placement when compared with previous research results. This research still has limitations that are not yet able to estimate cost requirement for installation of DG and not yet tested in data in the real system. This limitation will be able to open further research ground.

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