Riny Sulistyowati [1], Hari Agus Sujono [1], and Yudha Cipta [1]

Institut Teknologi Adhi Tama Surabaya (1)

,

doi:10.15199/48.2022.11.16

Optimization Of Distributed Generation Placement Using Particle Swarm Optimization Method At Sampang Feeder

Abstract: *Placement of Distributed Generation in a distribution network has increased power losses due to improper DG connection. One technique to reduce power losses is to determine the exact location of the DG connection through optimization. Optimizing the placement of DG connection locations at the substation aims to minimize power losses in the distribution system of the substation. This research was conducted at the substation in Blegah Sampang Regency. The initial power flow obtained in the distribution system power losses of 1560 KW. To optimize the DG connection, the Particle Swarm Optimization (PSO) method is used. This PSO method was chosen because it can provide more stable results according to the inputted fitness. After applying the PSO method to the distribution network system of the substation in Sampang, the minimum power loss in the distribution system reaches 906 KW. The most optimal DG placement is on Bus 5 and the average power losses are reduced by 58%. Uses are duly drawn.*

Streszczenie. *Umieszczenie generacji rozproszonej w sieci dystrybucyjnej spowodowało wzrost strat mocy z powodu niewłaściwego połączenia DG. Jedną z technik zmniejszania strat mocy jest określenie dokładnej lokalizacji połączenia DG poprzez optymalizację. Optymalizacja rozmieszczenia lokalizacji przyłączy DG w podstacji ma na celu zminimalizowanie strat mocy w systemie dystrybucyjnym podstacji. Badania te przeprowadzono w podstacji w Blegah Sampang Regency. Początkowy przepływ mocy uzyskany w systemie rozdzielczym straty mocy 1560 KW. Aby zoptymalizować połączenie DG, stosuje się metodę optymalizacji roju cząstek (PSO). Ta metoda PSO została wybrana, ponieważ może zapewnić bardziej stabilne wyniki w zależności od wprowadzonej sprawności. Po zastosowaniu metody PSO w systemie sieci dystrybucyjnej stacji w Sampang minimalna strata mocy w systemie dystrybucyjnym sięga 906 KW. Najbardziej optymalne umieszczenie DG znajduje się na magistrali 5, a średnie straty mocy są zmniejszone o 58%. Zastosowania są należycie sporządzone.* (***Optymalizacja rozmieszczenia generacji rozproszonej za pomocą metody optymalizacji roju cząstek w podajniku Sampang***)

Keywords: Distributed Generation (DG), Particle Swarm Optimization (PSO), Drop Voltage, Power Loss
Słowa kluczowe: rozmieszczenie generatorów w sieci rozproszonej, optymalizacja rojowa.

Introduction

Distributed generation (DG) is an approach technique that uses small-scale power generation technology to generate electricity close to consumers who are connected to the electricity distribution network. In many cases, DG can provide lower electricity costs, reliability at high voltage power and safety against environmental threats when compared to current conventional systems [1]. In contrast to the use of several large-scale power plants whose centers are far from the load center, the DG system uses a lot of small power plans so that it does not depend too much on distribution and transmission networks. DG systems generate electricity in capacities ranging from 1W-100MW, differentiated by generation source rating classification.

Distributed Generation occurs at 2 levels, namely the local level and the endpoint. At the local level, power plants tend to focus more on renewable energy technologies such as wind power, geothermal power, solar cells and other renewable energy generation. Meanwhile, at the endpoint level, energy consumers at this level are more likely to use this system as a backup from the normal power grid. For example, this technology can also be used in remote islands [2,3].

DG placement in a distributed network can cause power losses due to improper DG placement. To minimize these power losses, the placement of the DG must be in the right location. For this reason, an optimization algorithm is needed for optimizing DG placement on a distributed network.

Many optimization methods can be applied to produce optimal levels of power efficiency and placement, some of which are described below. Meta heuristic optimization approaches Genetic Algorithm (GA) and Particle Swarm Optimization have been widely used to prevent voltage collapse in the power grid [4] and are more productive than greedy heuristic algorithms [5]. The PSO algorithm has been successfully applied in the operation control of reactive power sources to the power grid in real-time [6]. An improved GA algorithm approach has been used to improve voltage stability. The proposed technique is based on minimizing the maximum L-index bus load. Generator volt age, switchable VAR source and transformer tap changer are used as optimization variables of this problem. The proposed algorithm has been tested on the IEEE 30-bus and IEEE 57-bus test systems and showed good results [7, 8]. In this research, using GA integration with taboo search and simulated annealing methods. Taboo search is used to generate new population members in the reproductive phase of the genetic algorithm and annealing simulation method is used to accelerate the convergence of genetic algorithms. The results show the superiority of the solution [9]. In this study, combining the Linear Integer and K-Means methods used to optimize the PMU placement. Applied to distribution network with 11 buses. The results showed that the Integer Linear K-means Clustering method could be used to determine the location and reduce PMU by 73% [10]. The use of the static var compensator (SVC) placement method in power systems, has shown effective results in reducing real and reactive power spot prices, generation costs, system real power losses and increasing system loading margins during normal and critical [11, 12].

The research in this article is a case review that occurred at the Sampang substation feeder which has a step-down transformer with a capacity of 60 MVA. Sampang is the name of a small town on the island of Madura, East Java province, Indonesia. The transformer supplies 11 feeders and has difficulty getting additional power supply from the generator when a voltage drop occurs at the feeder at the substation. For this reason, it is necessary to develop a medium distribution network using DG to improve the quality of service to electricity users who are charged to the Sampang substation feeder.

From the problems above, it is necessary to analyze the power flow at the load for the placement of DG. To analyze the power flow, the forward-backward sweep method is used. This method can be used for distributed system power flow analysis with a solution without many calculations and efficient at each iteration. This method uses Kirchhoff's law principles for current calculations. The first step is to calculate the amount of current flowing in the line from the beginning to the end of the bus. The second step calculates the value of the voltage drop on each line by multiplying the previously calculated current value by the line impedance value [12].

In this study, the placement of DG by utilizing wind energy. As for the purpose of minimizing power losses in the distribution network of the Sampang substation, an optimization algorithm is needed for DG placement using the PSO algorithm. The main advantage of the PSO algorithm is that it has a simple concept, easy to implement, and efficient in calculations when compared to mathematical algorithms and other heuristic optimization techniques.

Formulation of Measurement Unit In Distribution Network

For the purposes of analyzing the power flow and determining the placement of DG, a network topology with a single line diagram of the 11 bus Sampang substation feeder is required, as shown in Figure 1.

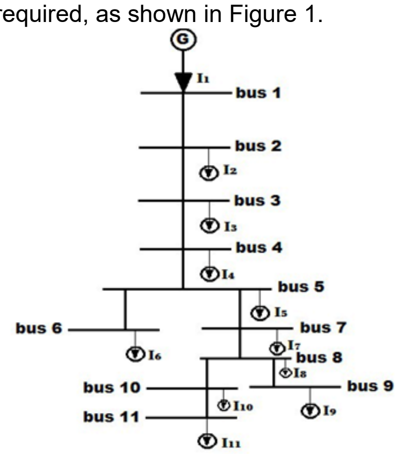

Fig. 1. Single line diagram of 11 bus Sampang substation feeder

The parameters that must be calculated are voltage, current, and power. The data used must be in units per unit or p.u. For simplification, the following equations (1), (2) and (3) are used [3].

(1) $$Base\_voltage(V) = \frac{BusVoltage}{\sqrt{3}}$$

(2) $$Base\_current(I) = \frac{KVAbase3\phi}{\sqrt{3}KVbase}$$

(3) $$Base\_impedance = \frac{(KVBase)^2}{MVAbase3\phi}$$

From the single line diagram, a K_matrik is made using the following path tracing rules:

- k_{ij} = 1, if branch i is on the path between bus j and reference bus and has the same direction.
- k_{ij} = -1, if branch i is on the path between bus j and reference bus and has opposite directions
- k_{ij} = 0, if branch i is not on the path between bus j and reference bus. The complete process of back forward calculation is shown in reference [9].

The composition of the BIBC (Bus Injection to Branch Current) matrix has components whose values are opposite to the values in the K_matrix. While the BCBV (Branch Current to Branch Voltage) matrix is formed from the transpose of the BIBC matrix components multiplied by the value of the impedance matrix, BCBV = -[K_matrik]' x [Channel Impedance]. So that the input data of voltage, current, resistance which is used to calculate the voltage drop $[\Delta V]$ uses the equation in the form of a matrix shown in equation (4).

(4) $$[\Delta V] = [\boldsymbol{BCBV}]\ [\boldsymbol{BIBC}]\ [I]$$

Furthermore, after getting the power loss, the optimization of the placement of DG on the Sampang feeder substation is carried out. In PSO multi-variable optimization, the swarm is assumed to have a certain size and random position for each particle in a multidimensional space. Each particle in PSO is considered to have 2 characters, namely: position and velocity. Each particle will remember the best position that has been passed before [3].

The following are the Particle Swarm Optimization (PSO) steps:

1. Determine the swarm size, and random particle velocity

Initial variables and input data are required to start the PSO algorithm. The data that must be defined include [3]:

a. Initialization in the form of the number of particles will be used in PSO, initialization and number of iterations (k), acceleration-coefficient values (c1 and c2), maximum load (W_{max}) and minimum particle load (W_{min}).

b. The initial position of the particle (X_{ij}^{o}) is a random value according to the dimensions of each particle.

c. The initial velocity of the particle (V_{ij}^{o}) is zero.

2. Evaluate the value of the objective function on each particle.

Particle position data (X_{ij}^{t}) is a matrix that has dimensions. The particle position matrix has dimensions that are formed from the numbers of data for each particle (m) and the number of particles in the swarm (n). The data value of each particle is obtained randomly according to the dimensions. The matrix will be shown in equation (5):

(5) $$X_{ij}^{t}\begin{bmatrix} X_{11}^{k} & X_{12}^{k} & \dots & X_{1m}^{k} \\ X_{21}^{k} & \dots & \dots & X_{2m}^{k} \\ \dots & \dots & \dots & \dots \\ X_{n1}^{k} & \dots & \dots & X_{nm}^{k} \end{bmatrix}$$

The value of the position of the particle is updated at each iteration by being influenced by the velocity value (V_i^{k+1}). Velocity value is obtained from particle experience (X_i^k) and experiences gained by other particles in the group ($P_{best,t}^{k}$ $G_{best,t}^{k}$).

3. Determine the value P*best* and G*best* early.

The personal best value ($P_{best,j}^{k}$) is obtained by finding the minimum value for the sensor placement that has a fairly accurate measurement error in each iteration. The particle with the minimum number of sensors becomes the personal best value according to the calculation of equations (6) and (7).

(6) $$f(X_j^k) = sum(X_j^k)$$

(7) $$P_{best,j}^{k+1} = \begin{cases} P_{bestj}^{k} & if\ f(X_j^{k+1}) > f_{Pbestj}^{k} \\ X_j^{k+1} & if\ f(X_j^{k+1}) < f_{Pbestj}^{k} \end{cases}$$

4. The equation to calculate the speed in the next iteration using equation (8).

(8) $$V_j(i) = \theta i(i-1) + c_1 r_1 (P_{bestj} - x_j(t-1)) + c_2 r_2 (G_{bestj} - x_j(i-1))$$

where,: *t* = iteration to-*t* ; *i* = particle index, r_1 and r_2 = random number

5. Each iteration change, the new particle position (X_j^{k+1}) is obtained by adding up the particle position in the previous iteration (X_j^k) with velocity (V_j^{k+1}). The position value in each iteration is updated by equation (9).

(9) $X_j(i) = X_j(i-1) + V_j(i)$
(10)
where, Xi= particle posisition ; Vi = particle speed

6. Evaluate the value of the objective function in the next iteration.

The value of inertia (W^k) will always change in each iteration. Changes in value will be affected by the number of iterations and the maximum and minimum inertia load values (W_{max} dan W_{min}). The inertial load has an interval equal to the difference between the maximum inertia load and the minimum inertial load. The value of the inertia load for each iteration is obtained by equation (10).

(10) $W^k = W_{max} - \frac{W_{max} - W_{min}}{W_{max}}$

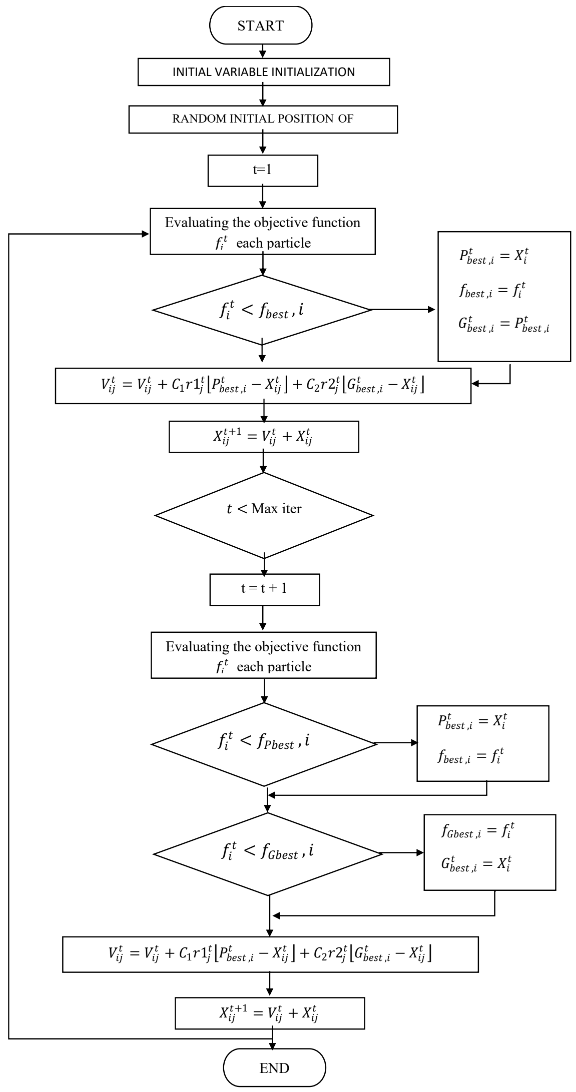

Fig. 2. PSO Algorithm System Flow Chart

7. New Value P*best* dan G*best*.

Global best Value $Gbestjk$ obtained by finding the minimum sensor placement between the kth iteration Pbest and the global best iteration k-1. $Gbestjk$ replaced with a new global best when the Pbest result function in each iteration is more minimal than the Initial Variable Initialization, Data Input and PSO Iteration Process. Gbest previous iteration. The Gbest value is formulated in equation (11).

(11) $G_{bestj}^k = \min\{P_{best}^t\}$

8. Checking whether the solution is optimal or not. If you get optimal results, then the algorithm process will stop, but if the results are not optimal then the process will be repeated in step number 4.

The flowchart for the PSO algorithm is shown in Figure 2.

Parameters used in DG using wind energy

A wind turbine generator is a system that converts wind energy into electrical energy. The blowing wind will drive a fan coupled to a generator, thus producing electrical energy. In wind turbine modeling, there are two important things that must be considered, namely the availability of wind and the power curve of the wind turbine itself. The power output of a wind turbine generator is a function of wind speed. To model the wind turbine performance, the current power curve is obtained [1].

In this study, the AIR403 wind turbine was used. The power curve of this wind turbine is shown in Figure 3.

The research methodology in this study is shown by the flowchart in Figure 4, with the following steps:
1. Initialize input data (bus, impedance, line, voltage and current)
2. Calculate the K matrix by determining BIBC, BCBV to determine the voltage drop.
3. PSO optimization (*see PSO step*)
4. After convergence, the DG placement is considered appropriate.

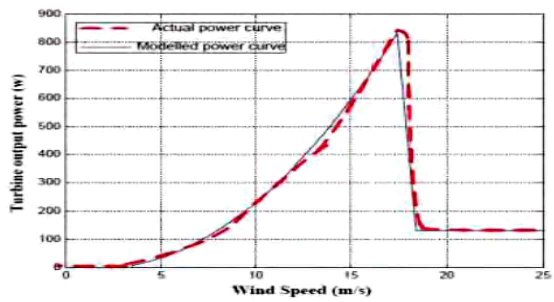

Fig 3. Actual power curve and its model form AIR403 [1]

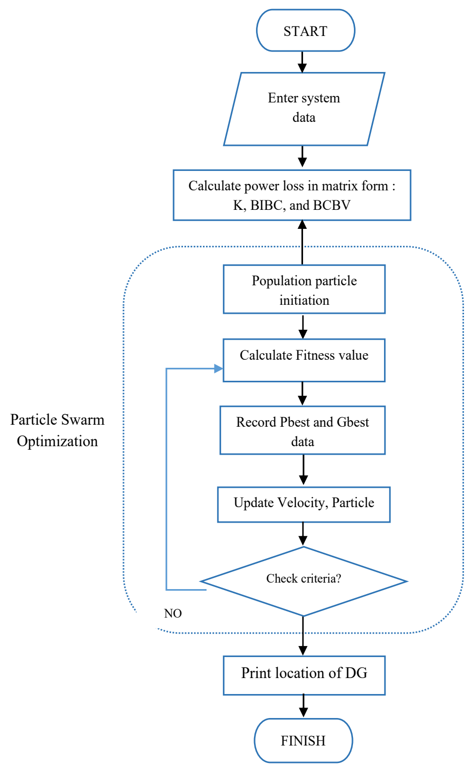

Fig. 4. Research methodology

Results and Discussions

The load data for each bus at the Sampang Substation feeder can be seen in Table 1, this data is used for calculating the flow of active power and reactive power to determine the voltage drop.

Table 1. Sampang feeder load data

Bus	V (kV)	T (kVA)	S (kVA)	P (kW)	Q (kVAR)	PF
Torjun	20	630	498.4	290	288.4	0.85
Payudan	20	630	423.1	291.55	181.55	0.78
Ketapang	20	400	62.8	31.4	81.4	0.92
Bireun	20	315	93.7	46.85	96.85	0.84
Blegah	20	400	338.4	169.2	219.2	0.84
Wijaya Kusuma	20	400	381	190.5	240.5	0.88
Banyumas	20	250	172.4	86.2	136.2	0.72
Kemuning	20	630	347.4	173.7	223.7	0.86
Kedundung	20	400	312.4	156.2	206.2	0.85
Aeng Sareh	20	250	121.8	60.9	110.9	0.85
Omben	20	400	93.9	46.95	96.95	0.84

Information: V = Voltage; T=Travo; S=Apparent Power; P=Active Power; Q=Reactive Power; PF=Power Factor

The impedance and resistance data for each bus can be seen in Table 2.

Table 2. Impedance, line data and power

Channel		Impedance		Power	
Bus to Bus		R	X	P (kW)	Q (kVAR)
1	2	0.051	0.057	290	288.4
2	3	0.032	0.185	291.55	181.55
3	4	0.022	0.173	31.4	81.4
4	5	0.042	0.037	46.85	96.85
5	6	0.061	0.198	169.2	219.2
5	7	0.058	0.176	190.5	240.5
7	8	0.011	0.041	86.2	136.2
8	9	0.046	0.116	173.7	223.7
9	10	0.026	0.082	156.2	206.2
10	11	0.012	0.042	60.9	110.9

Table 3. Load Flow without DG

Bus	Voltage		Voltage Drop	Ploss
	kV	Deg	kV	
1	20	0	0	182.77
2	19.88	-0,010723	0.02	183.55
3	19.87	-0.015797	0.03	123
4	19.64	-0.110629	0.26	123
5	19.63	-0.118723	0.26	1560
6	19.48	-0.380723	0.53	158
7	19.34	-0.410723	0.53	178
8	19.25	-0.430756	0.63	199
9	19.25	-0.430756	0.63	200
10	19.23	-0.441923	0.74	590
11	19.23	-0.441923	0.74	350

Calculation of power losses using Matlab (PSO simulation)

The load data for each bus is shown in Table 1. Table 2 shows the impedance and resistance data between buses. The data in both tables are used for power flow calculations. The value of the current and voltage drop flowing in each branch will be calculated using the elements of the K_matrix. By calculating using Matlab, the voltage drop and Ploss values without DG are so for the PSO simulation using 1 DG wind energy placed on bus 5. The results are shown in Table 4. obtained, the results of which are shown in Table 3.

The graph of the voltage angle of each bus calculated by Matlab can be seen in Figure 5 where the x-axis is the bus and y-axis is the voltage angle.

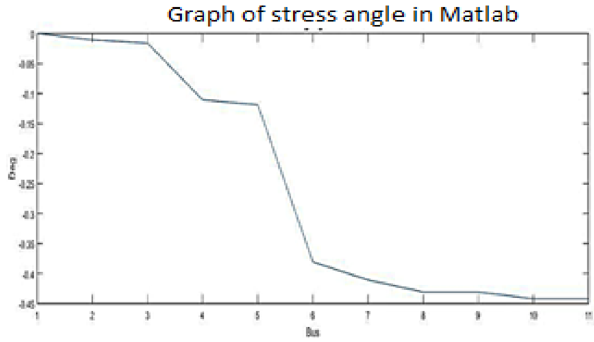

Fig. 5. Graph of Input Voltage Angle without DG

Based on the results of power losses in Table 3. the placement of DG will be more optimal if it is placed on the bus with the largest PLoss. namely on Bus 5 as a feeder for the distribution network in Blegah Regency of 1560 kW.

.

Table 4. Simulation PSO with 1 DG

Bus	Voltage		Voltage Drop	Ploss
	kV	Deg	kV	
1	20	0	0	32
2	19.98	0.0028	0.01	30
3	19.97	0.0026	0.01	25
4	19.74	0.0105	0.08	26
5	19.73	0.0240	0.1	906
6	19.58	0.0650	0.18	12
7	19.54	0.0756	0.2	34
8	19.35	0.1143	0.25	49
9	19.35	0.1143	0.25	13
10	19.33	0.1145	0.29	50
11	19.33	0.1145	0.29	13

So for the PSO simulation using 1 DG wind energy placed on bus 5. The results are shown in Table 4. The graph of the voltage angle of each bus with DG installed is Figure 6 where the x-axis is the bus and the y-axis is the voltage angle.

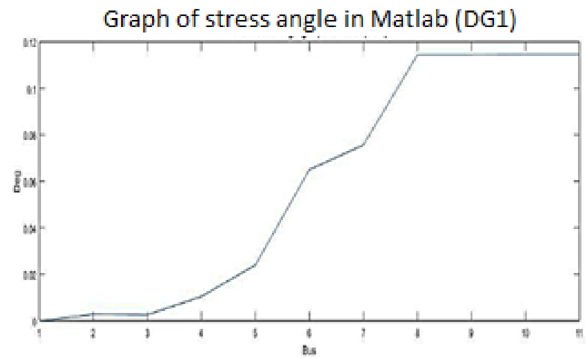

Fig. 6. Graph of Input Voltage Angle with DG

PSO application analysis for 1 DG

Based on the simulation results with the PSO algorithm after placing 1 DG of wind energy in the network system. it shows that it is able to reduce power losses in each bus with the smallest percentage level of 3.7% and the highest 58%. Table 5 which shows the decrease in Ploss for each bus.

Table 5. Results of Optimization of DG Placement

Bus	P-loss (kW)	P-loss 1 DG (kW)	Loss Reduction (%)
1	182	32	17.5
2	183	30	16.3
3	123	25	20.3
4	123	26	21.1
5	1560	906	58
6	158	12	7.5
7	178	34	19.1
8	199	49	24.6
9	200	13	6.5
10	590	50	8.4
11	350	13	3.7

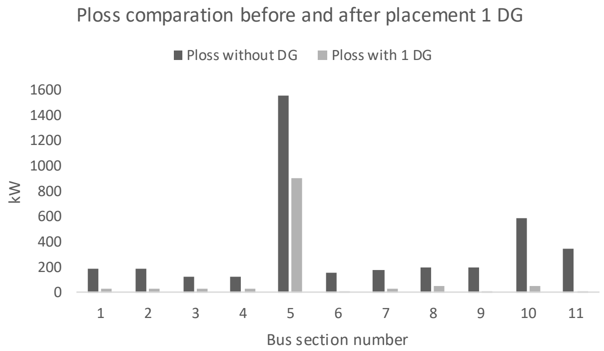

Fig. 7. Comparison of loss power before and after DG placement

Based on the results of power losses in Table 4 and the percentage of voltage drop in Table 5. the placement of DG will be more optimal if it is placed on the bus with the largest percentage of voltage drop and PLoss. namely on Bus 5. The feeder for bus 5 is located in the distribution network in the Regency. Blegah.

Figure 7 shows a comparison graph of Ploss before and after the placement of DG wind energy in the distribution network. Blue color indicates Ploss before DG placement and yellow color on the chart shows Ploss after DG placement. The x-axis is the number of bus interconnections and the y-axis is the nominal PLoss in kilo watts (kW).

Placement of wind energy DG in the distribution network is not the only alternative strategy to minimize the occurrence of power losses that occur in the city of Sampang. Based on the geographical location with the abundance of solar energy. it can be placed DG solar energy or a combination of DG with wind and solar energy.

Conclusion

A study has been produced with good results in order to find a solution to the voltage drop that occurs in the distribution network in the city of Sampang by simulating wind energy electricity injection (DG). using the PSO algorithm to determine the optimum location and the magnitude of PLoss reduction. The results show that the largest PLoss occurs on bus 5 in Blegah sub-district. After the DG placement. there was a 58% reduction in PLoss from the original PLoss before DG placement of 1560 kW to 906 kW after DG placement.

Conflict of Interest

The author declares no conflicts of interest in this paper.

Acknowledgments

We would like to thank you for following the instructions above very closely in advance. It will definitely save us a lot of time and expedite the process of your paper's publication. We express our gratitude and high appreciation to the PT PLN Persero JAWALI branch for supporting this research

Authors

Dr. Riny Sulistyowati. ST.. MT.. Department of Electrical Engineering Institut Teknologi Adhi Tama Surabaya. Indonesia. email: riny.971073@itats.ac.id

Dr. Ir. Hari Agus Sujono. M.Sc.. Department of Electrical Engineering Institut Teknologi Adhi Tama Surabaya. Indonesia. e-mail: hari.agus17@itats.ac.id

Yudha Cipta. Department of Electrical Engineering Institut Teknologi Adhi Tama Surabaya. Indonesia. e-mail: yudhacipta0401@gmail.com.

The correspondence e-mail: riny.971073@itats.ac.id

REFERENCES

[1] Y. M. Atwa and E. F. El-Saadany. "Optimal allocation of ESS in distribution systems with a high penetration of wind energy". IEEE Trans PowerSyst.. vol 25. no. 4. pp. 1815-1822. Nov. 2010.

[2] Aguero. J.R.. dan Steffel. S.J.. "Integration Challenges of Photovoltaic Distributed Generation on Power distribution Systems". IEEE Power and Energy Society General Meeting. ISSN: 1944-9925. pp. 1-6.. San Diego. CA. 2011

[3] C Hiyan and C Jinfu. "Power Flow study and Voltage stability and Analysis for Distribution System with Distributed Generation". in proceding.IEEE. 2008

[4] Verayiah R.. Mohamed A.. Shareef H.. Abidin I. Z.. "Under Voltage Load Shedding Scheme Using Meta-heuristic Optimization Methods". *Przeglad Elektrotechniczny* 90 (2014). nr. 11. 162-168.

[5] Zhu Y. Tang X.. "Overview of swarm intelligence. *Computer Application and System Modeling"*. 9(2010). pp. 400-409.doi: 10.1109/ICCASM.2010.5623005

[6] Manusov. V.. Matrenin. P.. Kokin. S.. "Swarm intelligence algorithms for the problem of the optimal placement and operation control of reactive power sources into power grids". *International Journal of Design & Nature and Ecodynamics*. 12 (2017). No. 1. 101-112. doi: 10.1109/EPE.2017.7967231.

[7] Der Vani D.. Roselyn J.P.. Genetic algorithm based reactive power dispatch for voltage stability improvement. *International Journal of Electrical Power & Energy Systems*. 32(2010). No. 10. 1151-1156.

[8] R. Sulistyowati. M. Ashari. D. Candra. "Clustering Based Optimal Sizing and Placement of PV-DG Using Neural Network". Advanced Science Letters 23 (3). 2373-2375.2017.

[9] Mantawy A.H.. Abdel-Magid Y. L.. Selim S.Z.. "Integrating Genetic Algorithms. Tabu Search. and Simulated Annealing for the Unit Commitment Problem". *IEEE Transactions on Power Systems*. 14 (1999). No. 3. 829-836.

[10] R. Sulistyowati. D. Candra . R. Seto. M. Ashari. Optimum Placement of Measurement Devices on Distribution Networks using Integer Linear K-Means Clustering Method. *Przeglad Elektrotechniczny. 2020.* Doi:10.15199/48.2020.10.23

[11] Minguez R.. Milano F.. Zarate-Minano R.. Conejo A.. Optimal Network Placement of SVC Devices. IEEE Trans. Power Syst. 22 No. 4.1851-1861. 2007

[12] Singh J.G.. Singh S. N.. Srivastava S. C.. An Approach for Optimal Placement of Static VAR Compensators Based on Reactive Power Spot Price. IEEE Trans. Power Syst.22 (2007). No.4. 2021-2029.