Available online on: http://ejournal.undip.ac.id/index.php/teknik

TEKNIK, 46 (3), 2025, 232-243

Optimal Placement of Renewable Distributed Generation for Power Losses and Emissions Reduction Using the Multi Verse Optimization Algorithm in Distribution System

Firdaus

Department of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Makassar
Jl. A.P. Pettarani, Makassar, Indonesia 90222

Submitted: May 15th, 2025; Revised: June 30th, 2025; Accepted: July 17th, 2025; Available online: July 18th, 2025
DOI: 10.14710/teknik.v46i3.67453

Abstract

Distributed Generation (DG) from Renewable Energy Sources (RES) is widely applied in distribution systems or small-scale electric power networks. DG RES utilizes renewable energy sources such as PV and wind turbines. However, the intermittent and uncertain nature of renewable energy sources requires a mechanism to select and utilize them optimally. The aim of this research is to develop an optimization model for the use of renewable energy sources by determining the placement and size of optimal DG units sourced from renewable energy. Optimal placement and size decisions are obtained by considering emissions or pollution, power losses and voltage profiles in the electric power system. This research uses the Multi Verse Optimization (MVO) method, which is the development of multiverse theory and the big bang theory. The simulation in this research was carried out on the IEEE 33 bus distribution system. Simulation results using Matlab software show that the optimal placement and size of distributed generators from renewable energy sources can significantly improve the voltage profile and reduce electrical power losses. The optimal placement and sizing result for 1 DG injection is on bus 6, while when 3 DG injection, the optimal placement is on Bus 13, 24 and 30. This placement location is the same as the research results with other methods or algorithms. Optimizing the installation of three DG renewable energy sources using MVO by considering environmental factors was able to reduce emissions by 71.62 percent. Thus, there is a reduction in costs as environmental compensation of 71.60 percent in the IEEE 33 Bus system.

Keywords: *DG; RES; optimal placement; MVO algorithm; emissions*

1. Introduction

Electrical energy has become a primary need today. Electricity is generally generated from fossil fuels. As fossil energy decreases, it is necessary to look for alternative energy from renewable sources. This has triggered many things such as massive research and development of alternative energy sources. In addition to the limitations of fossil energy reserves, decarbonization is being driven to reduce greenhouse gas emissions caused by thermal power generation. The use of thermal power plants will threaten global climate change (Hlalele et al., 2020). Renewable energy sources are used to meet load needs in a sustainable and environmentally friendly manner (Liaquat et al., 2020).

The acceleration of the application of technology to produce electrical energy from renewable energy is getting faster due to environmental factors. The effects of global warming due to fossil fuel power plants are increasingly widespread, causing poor air and water quality in urban and industrial areas (Binini et al., 2024).

Global concerns about environmental impacts have driven technological advances to connect renewable energy sources to the grid and deregulation of the electricity market has shifted the attention of distribution system planners to grids connected to distributed generation. Reducing power losses and improving the voltage profile index in the delivery of electricity are also considerations in power system planning. Planners have made breakthroughs by building small generators near the load that are sourced from renewable energy.

Renewable energy sources such as wind and solar have great potential to meet the world's electricity needs in a sustainable and environmentally friendly manner.

*) Corresponding Author:
E-mail: dauselektro@unm.ac.id

Wind turbines can convert wind power into electrical energy, while solar energy is obtained through photovoltaic panels that capture sunlight and convert it into electricity. Both energy sources have advantages in terms of abundant availability and very low carbon emissions. In addition, the use of wind and solar energy can reduce the use of fossil fuels and reduce gas emissions that contribute to the greenhouse effect and help overcome climate change. With technology continuing to develop, the efficiency and cost of energy production from these sources continue to increase, making them increasingly competitive with conventional energy sources. Wind and solar energy are stochastic phenomena that depend on several factors such as weather and climate conditions, wind speed, radiation intensity, and many other unpredictable factors (Binini et al., 2024).

Generation units that rely on renewable energy are usually smaller and spread across the grid, which then gave rise to the Distributed Generation (DG) paradigm. DG is a distributed generator that is the main means of integrating the source of electrical energy into the distribution system (Al-Jumaili & Yilmaz Azlan, 2021). DG penetration has several benefits, including reducing power losses, increasing the voltage index value and improving power quality in the distribution system (Ahmad et al., 2019). Penetration of DG renewable energy sources in the distribution system contributes to emission reduction.

Optimization techniques have been used for the placement of distributed generators on the power grid, thus allowing for the best allocation of DG. There are many approaches to decide the optimization of the location and size of DG units in small-scale power systems. Several factors that must be considered in the planning process for expanding the distribution system with renewable energy DG include the location, size, type of DG unit, and network technology, system capacity and protection (Hemeida et al., 2021). Optimization methods can be done using analytical or deterministic methods and metaheuristic methods. Analytical methods commonly used include the Lagrange Multipliers method, the Newton Raphson and Gauss Jacobi methods and other deterministic methods (Costa et al., 2019). The current trend is to use metaheuristic methods to maximize the utilization of renewable energy sources. Various types of methods and approaches used in DG optimization include the decision tree (DT) classification approach or decision tree, namely for the placement of several photovoltaic DG units using certain indices in an unbalanced distribution network. Bonobo Optimizer (BO) is used to find and locate and capacity of photovoltaic energy sources and capacitors in the distribution system (Pham et al., 2023).

The use of artificial intelligence is able to integrate networks from many resources and distributed loads. Several algorithms that have been carried out in previous studies include the Genetic Algorithm (GA) (Das et al., 2021), the firefly algorithm (FFA) combined with the crow search (CS) optimizer used to obtain the optimal DG size (Hlalele et al., 2020), phasor particle swarm optimization (PPSO) (R. Nasser et al., 2021), Salp Swarm Optimization (SSO), SSO is a modified GA to find profitable locations and sizes of distributed generation units (Kola Sampangi Sambaiah & T Jayabarathi, 2019), (Davoudkhani et al., 2023). Geometric Mean Optimization (GMO) algorithm combines the unique properties of geometric mean operator in mathematics with power loss sensitivity index to perform various optimizations on distribution networks such as reconfiguration optimization, DG unit allocation with optimal power factor (Kamel et al., 2023). Constriction Coefficient Particle Swarm Optimization (CPSO) (Rathore & Patidar, 2021), PSO-GWO Approach (Suman et al., 2021), Improved Gray Wolf Optimization (IGWO) (Khan et al., 2024), Flower Pollination Algorithm (Ramshanker et al., 2022).

Optimal placement and sizing of PV considering PV inverter capability using Archimedes optimization algorithm (AOA) (Janamala & Radha Rani, 2022). Modified Harris Hawk optimization (MHHO) algorithm is used for location connection, source and location of energy storage system and optimal management of microgrid in smart distribution network (Poshtyafteh et al., 2024).

In this research, the authors optimize the placement and size of photovoltaic DG and wind turbine using Multi Verse Optimizer (MVO) algorithm method to reduce power losses, improve voltage profile and reduce emissions. The search process in the MVO algorithm consists of two main stages, namely the exploration stage and the exploitation stage. In the exploration stage, the MVO algorithm focuses on searching for the solution space widely to find various possible solutions that may not have been explored before. The purpose of this stage is to ensure that the algorithm does not get stuck in local solutions and has the opportunity to find the optimal global solution. Meanwhile, in the exploitation stage, the MVO algorithm focuses its search on improving the solutions that have been found during the exploration stage. At this stage, the algorithm tries to maximize the quality of the solution by conducting a deeper search around promising solutions. By dividing the search process into these two stages, the MVO algorithm can balance exploration and exploitation, thereby increasing the chances of finding the optimal solution (Karthikeyan & Dhal, 2017).

2. Materials and Methods

2.1. Materials

The data or input variables needed in this study include optimization data, MVO data, IEEE 33 bus

doi: 10.14710/teknik.v46i3.67453

system data, PV specification data, wind turbine specification data, and emission data. The simulation in this study uses Matlab software.

The IEEE 33 bus distribution system is one of the test systems that can be used to simulate and analyze electric power distribution systems. The IEEE 33 bus distribution system consists of 32 channels and 32 loads. The IEEE 33 bus distribution system used consists of an active power load of 3.715 MW and a reactive blood load of 2.3 MVAR. All loads are supplied from the main grid (bus 1), which is the only source in the system. The voltage of the IEEE 33 bus distribution system is 12.66 kV. Figure 1 shows a single line diagram of an IEEE 33 bus system as a representation of a radial distribution system.

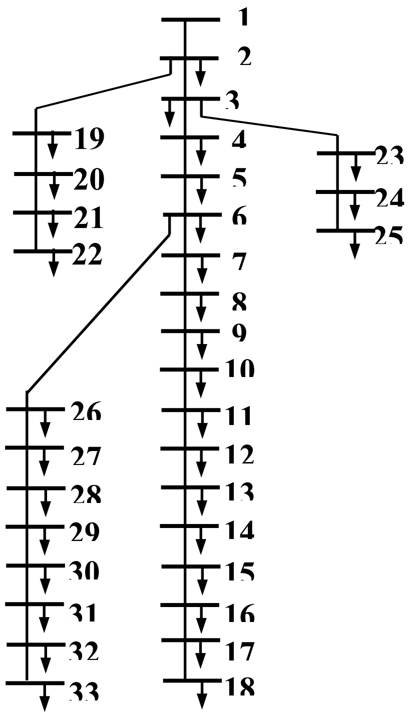

Figure 1. Single Line System IEEE 33 bus.

2.2. Methods

This research uses a simulation method using Matlab software with the following steps: (1) Modeling DG Renewable Energy, (2) conducting a power flow study, (3) conducting optimization using the Multi Verse Optimizer algorithm to determine the optimal placement and size of DG renewable energy sources in the IEEE 33 Bus distribution system with the objective function of power losses, voltage profile and Emission Reduction Benefit. Flowchart of proposed algorithm is shown in Figure 2.

In this paper, the multi-objective method uses weighted summation as Equation (1).

$$\text{Inflation}_{Best\_Universe} = A + B + C \tag{1}$$

where A is power loss weight, B is voltage profil weight and C is emission reduction benefit weight.

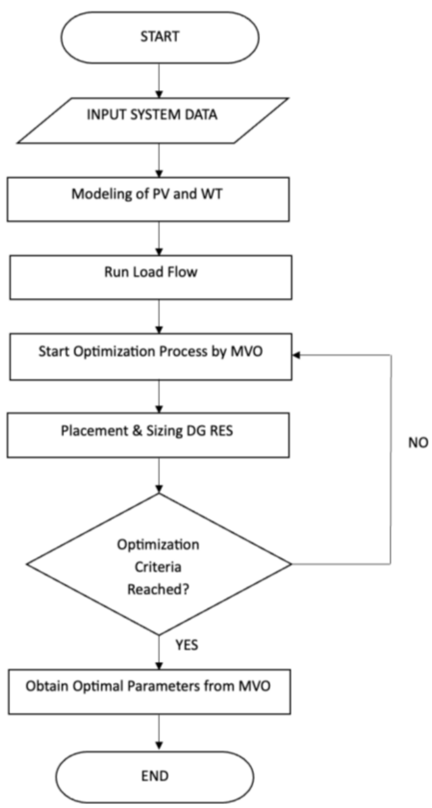

Figure 2. Flowchart of the proposed algorithm.

2.2.1. Modeling DG Renewable Energi

In this research, the output power probability model is used to extract the coefficients. These coefficients are calculated using mathematical expectations. These coefficients are a key aspect of the probability characteristics of the distribution. Mathematical expectations are the weighted average of the probabilities of all possible values. The procedure for calculating these coefficients can be done in the following steps: (1) Collecting the required measured historical data from a particular area such as wind speed, radiation intensity, and so on, (2) Fitting the known distribution function to the achieved data, (3) Obtaining the output power distribution function that matches the renewable DG characteristic data in the previous step, (4) Calculating the expected value, or capacity of the achieved output power distribution function. The computation and use of these coefficients enable planning to use the same renewable energy sources as non-

doi: 10.14710/teknik.v46i3.67453

renewable energy sources in power system planning (Taha et al., 2022).

2.2.2 Power Flow Study

Before determining the location and size of DG, the first step that needs to be taken is to determine the power flow formula in the system. This step is very important in gaining a deep understanding of the distribution of voltage, current, and power losses throughout the electrical system. By knowing these values accurately, we can plan the placement and capacity of DG more effectively and efficiently. The power flow equation will provide a clear picture of how electrical energy flows through the network, as well as the points where significant power losses occur. This information is a crucial basis in the planning process, because determining the optimal size and location of Distributed Generation Renewable Energy Sources (DG RES) can reduce power losses, improve voltage quality, and ensure that renewable energy sources are used in the most efficient way. Thus, determining the power flow equation is an initial step that cannot be ignored in designing a distribution system that integrates DG.

In the process of installing DG RES in the electric power system, it is important to understand the power flow in the distribution system. The equations that appear in the power flow analysis are non-linear equations, which require an iteration method to solve. The data generated from the power flow calculation study includes the magnitude and phase angle values of the voltage at each bus, as well as the flow of active and reactive power. Electric power system. The data needed to perform power flow calculations includes channel data and bus data, which includes the type of bus, whether the bus is a generator bus or a load bus. If a bus has a generator or generator, then the bus is called a generator bus. Conversely, if the bus only has a load, then the bus is called a load bus.

Power flow studies provide a comprehensive picture of how electrical energy is distributed across the network, and enable the identification of critical points where power losses or voltage quality degradation occur. This information is essential for planning the optimal placement and capacity of DGs, with the aim of improving system efficiency and minimizing energy losses. With a deep understanding of power flows, we can ensure that DGs are integrated in the most effective way, supporting the stability and reliability of the power system (Al-Shamma'a et al., 2024).

2.2.3 Optimization using Multi Verse Optimizer

The optimization method used in this study is the Multi Verse Optimizer. Each universe in the Multi-Verse Optimizer (MVO) algorithm contains a unique inflation rate. This inflation rate serves as an important parameter that affects the performance and behaviour of the universe. Using this inflation rate, the fitness value of each universe can be calculated. This fitness value is then used to assess how well the solution represented by the universe is in solving the given problem. A universe with a higher fitness value indicates a better solution, while a universe with a lower fitness value indicates a less optimal solution. Thus, the inflation rate plays a crucial role in the evaluation and selection process of solutions in the MVO algorithm. The positions of the universes have been updated using wormhole existence probability (WEP) as in Equation (2) and travelling distance rate (TDR) as in Equation (3).

$$WEP = min + l_x \left(\frac{max - min}{L}\right) \tag{2}$$

$$TDR = 1 - \left(\frac{l^{1/p}}{L^{1/p}}\right) \tag{3}$$

where l is the current iteration, L is the maximum iteration. min, max are constants (min = 0.2, max = 1). p is the constant accuracy of exploitation. The best universe is one that contains more WEP values and less TDR values.

The optimization process using MVO begins with exploration, which consists of: First, initialize the universe data using random numbers (0-1) with the following universe element arrangement:

Universe: Element 1 – Element 2 – … n^{th} Element

Element 1 (Odd): Size of the 1st DG

Element 2 (Even): Location of the 1st DG

Element n (Odd): Size of the n^{th} DG

Element n (Even): Location of the n^{th} DG.

Second, convert the results of the power flow analysis before optimization into the best universe inflation data initialization using Equation 1.

The third and fourth stage are calculating the wormhole existence probability (WEP) and traveling distance rate (TDR) values using Equations (2) and (3).

Fifth stage, the results of the universe initialization are limited according to the input data of the upper limit (U_b) and lower limit (L_b) so that all the random results of the universe will always be between the values (U_b) and (L_b) using Equation (4).

$$U_b > Universe > L_b \tag{4}$$

Next, convert the universe values into new bus data using Equation (5) and (6).

$$DG_{size}(n) = n^{th} Universe\ Element\ (odd) \times DG_{max} \tag{5}$$

$$DG_{loc}(n) = n^{th} Universe\ Element\ (even) \times Bus_{max} \tag{6}$$

Using the above equations, the universe values can be converted into the n^{th} DG size and the n^{th} DG location. This results in a new data bus with the addition of DGs,

doi: 10.14710/teknik.v46i3.67453

corresponding to each universe value linearized using the above equation.

After the exploration phase is complete, each universe is exploited based on the inflation value generated during the exploration phase. The exploitation process in MVO consists of:

1) Sorting the inflation values from largest to smallest.
2) Normalizing the sorted inflation data.
3) Selecting and accumulating the ordered inflation values to obtain a new universe value. This is expected to find a universe value with a much smaller inflation output and lead to a convergent inflation value.
4) Next, the universe value is updated again by selecting using the (WEP) value combined with calculations using the (TDR) value.

In the exploitation phase, the universe value is updated twice, resulting in a new universe value for the next iteration, thus getting closer to the universe value that produces the most optimal output. If the mass value does not reach ≥ the iteration maximum, the process returns to exploration for the next iteration. Once the mass value is ≥ the iteration maximum, the new best universe is obtained, which serves as the MVO optimization planning recommendation.

After obtaining the best universe value resulting from the maximum number of iterations, the best universe value needs to be converted into bus data. From this bus data, the DG bus size and location values are derived, which are recommendations from artificial intelligence calculations using the MVO method.

2.2.4 Objectif Function

This study discusses multi-objective optimization of intermittent renewable energy sources. Optimization is carried out in the form of optimal size and optimal location. Power loss reduction, voltage profile index improvement and emission reduction are discussed in this study.

2.2.4.1 Power Losses

An important aspect of the distribution system is low power losses. One of the objectives of using DG in the distribution system is to reduce power losses along the distribution network. Active power losses in the radial distribution system can be obtained using Equation (7). (Umar et al., 2020).

$$P_{loss} = \sum P_i - P_{load} = \sum_{k=1}^{Ni} g_k \left[(t_k V_i^2) + V_j^2 - 2 t_k V_i V_j cos(\theta_1 - \theta_2) \right] \quad (7)$$

where P_{loss} is the amount of power loss, P_i is the power on the generation side, P_{load} is the power on the load side, V_i is the voltage at bus point i, V_j is the voltage at bus point j, N_i indicates the number of branches, g_k is the conductance on branch k and θ_i is the voltage angle at bus point i, θ_j is the voltage angle at bus point j.

The objective function relating to power losses is expressed in Equation (8).

$$F_1 = min \sum_{k=1}^{Ni} g_k \left[(t_k V_i^2) + V_j^2 - 2 t_k V_i V_j cos(\theta_1 - \theta_2) \right] \quad (8)$$

2.2.4.2 Voltage profile

The integration of DG RES units into the electric power system is carried out to increase the voltage profile index on all buses. The magnitude of the voltage on each bus is expected to optimally reach 1 *pu*. The voltage profile is written as Equation (9) (Umar et al., 2020):

$$V_p = V_{ref} - V_{\pi} \quad (9)$$

where V_p is the voltage profile index and V_{ref} is the reference voltage. The objective function related to the voltage profile at each bus is found using Equation (10).

$$F_2 = min(V_p) \quad (10)$$

2.2.4.3 Emission Reduction Benefits

Compared with traditional DG, the installation of renewable energy DG is cleaner and pollution-free, thus reducing the system cost in terms of environmental protection throughout the life cycle. This cost reduction is the cost that can be avoided to utilize the environment after utilizing the output power of renewable energy DG instead of burning fossil fuels called Emission Reduction Benefit (ERB) as expressed in Equation (11). (Deng et al., 2023).

$$C_{ERB} = \sum_{i=1}^{4} (P_{DRB}.Emi_i.Env_i) \quad (11)$$

where P_{DRB} is the annual power output of renewable DG in the distribution system; Emi_i is the emission of four different pollutants in generating 1 kWh of electricity with fossil fuels and Env_i is the associated environmental cost required to exploit the environmental damage caused by 1 kg of each pollutant.

3. Results and Discussion

In this research, the optimization of DG RES unit placement and sizing to obtain power loss reduction, emission reduction and voltage profile index improvement is done using the MVO algorithm method. The advantage of the MVO algorithm is that it can

doi: 10.14710/teknik.v46i3.67453

converge in a small number of iterations. The simulation results shown in Figure 3 show that this MVO converges in the 2nd iteration with the best inflation of 0.526.

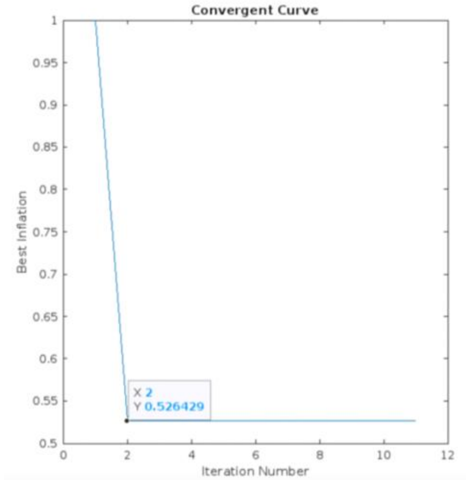

Figure 3. Convergent curve of MVO.

3.1. Case Study Without DG

Base case (initial condition without DG) is the initial condition of the simulation on the IEEE 33 bus distribution system before conditioning/optimization is carried out, especially for DG placement optimization. This study serves as a comparative case after conditioning/optimization. The initial condition of the system before the DG RES is installed is the running load flow to obtain the voltage index value on each bus, reduce power losses in the system and the amount of power that should be supplied to the main grid.

The power flow simulation carried out in the case study before the installation of DG RES, resulted in the amount of active power loss in the IEEE 33 Bus distribution system reaching 211 kW and the amount of reactive power loss reaching 143 kVAr. These data indicate the level of network efficiency before the integration of renewable energy sources. Power flow simulation is important to understand the basic conditions of the system before changes or additions of new energy sources are made. Based on the simulation data before the installation of DG renewable energy sources shown in Figure 4, it can be seen that the active and reactive power losses are quite significant, indicating great potential for increasing efficiency through the use of renewable energy. Reducing these power losses will not only increase network efficiency but will also contribute to reducing operational costs and increasing the stability of the electric power system as well as reducing environmental impacts in the form of reduced emissions. The simulation results without DG RES integration in Figure 4 below show that there are 21 buses or 63.6 percent experiencing undervoltage or voltage below 0.95 pu.

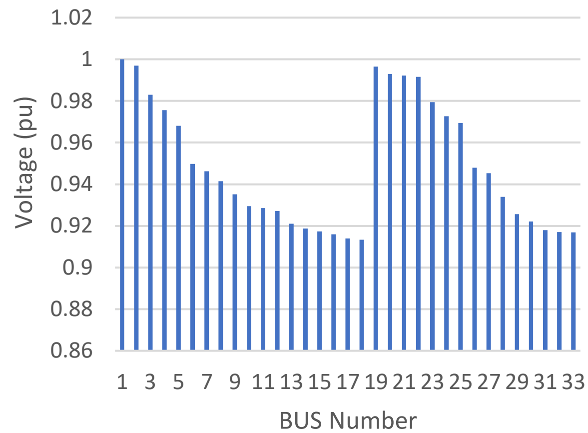

Figure 4. Voltage Profile IEEE 33 Bus Distribution System before DG RES addition.

Figure 4 shows the condition of the voltage profile in the IEEE 33 Bus distribution system. The bus with the lowest voltage index is obtained at bus 18, which is 0.903810 pu, and the highest voltage index is seen at the slack bus or at the source bus, namely bus 1, which reaches a voltage profile of 1 pu.

In the case study before the addition of DG, there was no emission reduction and emission compensation. The amount of emissions before the addition of DG is shown in Table 1.

Table 1. IEEE 33 Bus system emission and environmental values before DG addition.

Emission Value	Emission Type				Total
	SO_2	NOx	CO	CO_2	
Emission (Ton/Hour)	0,039	0,025	0,006	4,199	4,270
Environmental Cost (Rp-Million)	0,537	0,464	0,014	0,221	1,236

Table 1 shows that the type of emissions or pollutants produced in the IEEE 33 bus distribution system are carbon dioxide (CO2) which is 4.199 tons per hour. While the type of pollutant produced the lowest is carbon monoxide (CO). The total amount of emissions produced is 4.270 tons per hour. The environmental costs that must be incurred in the IEEE 33 Bus distribution system are Rp 1,236,000 per hour. The highest environmental

doi: 10.14710/teknik.v46i3.67453

expenditure costs are obtained from sulfur dioxide (SO2) pollutants which are Rp 537,000 per hour. The lowest environmental costs are carbon monoxide (CO) which is Rp 14,000 per hour.

3.2. Case study Addition of 1 DG RES

Based on the results of the power flow simulation after adding one DG RES unit, the reduction in real power losses in the IEEE 33 Bus distribution system reached 111 kW and the reduction in reactive power losses fell to 82 kVAr.

Figure 5 shows the voltage profile at each bus in the IEEE 33 bus distribution system under simulation conditions with the installation of one DG unit of renewable energy sources (DG RES). From the figure, it can be concluded that by adding one DG unit to the IEEE 33 Bus distribution system, the voltage profile of each bus experiences an improvement in the voltage profile, so that the lowest voltage previously only 0.903810 pu increased to 0.942428 pu. Thus, the addition of one DG unit can increase the voltage profile by 0.038558 pu. The installation of one DG RES unit to the IEEE 33 Bus distribution system has not been able to create a voltage profile on all buses in normal conditions. There are still 6 buses with undervoltage conditions below 0.95 pu, namely buses 13 to 18.

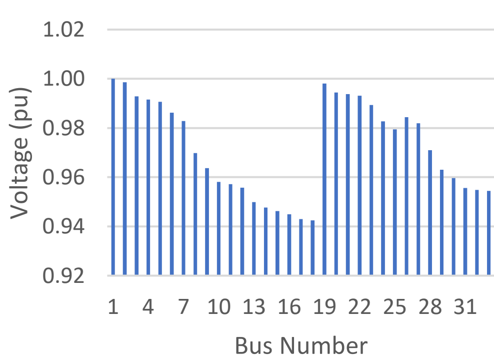

Figure 5. IEEE 33 Bus System Voltage Profile after addition of one DG.

However, the condition of the bus with the lowest voltage profile remains at bus 18 and the condition with the highest voltage profile at the source bus is bus 1 at 1 pu. The condition of the bus with the lowest voltage profile is because the bus is far from the source and the location of the DG unit installation, while on Bus 1 it always has a value of 1 pu because it functions as a slack bus or source bus and without load.

Figure 6. Showing a graph of the voltage index on each bus in the IEEE 33 Bus distribution system in the simulation of conditions without DG RES injection and conditions after the addition of one DG RES. Figure 4 below shows a significant increase in the voltage of each bus after the addition of one DG, especially on buses that are still undervoltage.

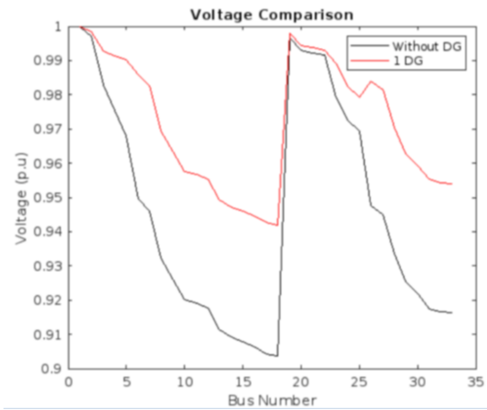

Figure 6. Voltage Profile Graph of IEEE 33 Bus Distribution System before adding DG and after adding 1 DG.

In the case study after the addition of one DG, there is a reduction in emissions and emission compensation. The amount of emissions after the addition of one DG RES unit is listed in Table 2.

Table 2. Emission and Environmental Values of IEEE 33 Bus Distribution System after adding 1 DG RES unit.

Emission Value	Emission Type				Total
	SO_2	NOx	CO	CO_2	
Emission (Ton/Hour)	0,013	0,008	0,002	1,375	1,398
Environmental Cost (Rp-Million)	0,176	0,152	0,005	0,072	0,405

Table 2 shows that the type of emission or pollutant produced in the IEEE 33 bus distribution system is the most carbon dioxide (CO2) which is 1.375 tons per hour. While the type of pollutant produced the lowest is carbon monoxide (CO) which is 0.002 tons per hour. The total amount of emissions produced is 1.398 tons per hour. The environmental costs that must be incurred in the IEEE 33 Bus distribution system are Rp 405,000 per hour. The highest environmental expenditure costs are obtained from sulfur dioxide (SO2) pollutants which are Rp 176,000 per hour. The lowest environmental costs are carbon monoxide (CO) which is Rp 5,000 per hour.

Reduction in emission value of 67.26% after the addition of one DG is shown in Table 3. So that the

doi: 10.14710/teknik.v46i3.67453

injection of one DG RES into the system can reduce environmental costs as emission compensation by 65.80%. The simulation results show that the addition of one unit of renewable energy DG to the IEEE 33 bus distribution system can reduce emissions by 2,872 tons/hour and save environmental costs of Rp 831,000 per hour.

Table 3. Percentage reduction of emissions and environmental costs after adding 1 DG RES to the IEEE 33 Bus Distribution System.

Emission value	Without DG	1 DG	Percentage Reduction (%)
Emission (Ton/Hour)	4,270	1,398	67,26
Environmental Cost (Rp-Million)	1,236	0,405	65,80

3.3. Case Study of Addition of 3 DG

In the case study of adding three DG RES units to the IEEE 33 Bus distribution system, optimization was carried out specifically to obtain the optimal location and size of the DG. There are three main parameters measured in this case, consisting of electric power quality, economy and environment. Based on the results of the three DG simulation, the location of the DG placement is on Bus 13 with a capacity of 1.12 MW and Bus 24 with a capacity of 1.228 Bus 30 with a capacity of 1.408 MW so that the total capacity of the three DGs is 3.756 MW. Based on the results of the power flow simulation carried out after installing three DG RES units, there was a change in active power losses in the IEEE 33 Bus distribution system to 73 kW and a change in reactive power losses to 51 kVAr.

Figure 7 shows the voltage profile graph of each bus in the IEEE 33 bus distribution system under simulation conditions with the injection of three DG renewable energy (DG RES). Based on Figure 7 above, it can be concluded that with the addition of three DG units in the IEEE 33 Bus distribution system, the voltage profile of each bus experiences an improvement in the voltage profile, so that the lowest voltage previously only 0.903810 pu increased to 0.973116 pu. Thus, the addition of three DG units can increase the voltage profile by 0.069306 pu. The injection of three DG RES units in the IEEE 33 Bus distribution system produces voltage profile conditions at all buses in normal conditions or not buses with undervoltage conditions below 0.95 pu. However, the condition of the bus with the lowest voltage profile remains at bus 18 and the condition with the highest or best voltage profile at the source bus, namely bus 1, is 1 pu. The condition of the bus with the lowest voltage profile is caused because the bus is far from the source and DG injection location, while on Bus 1 it always has a value of 1 pu because it functions as a slack bus or source bus and has no load.

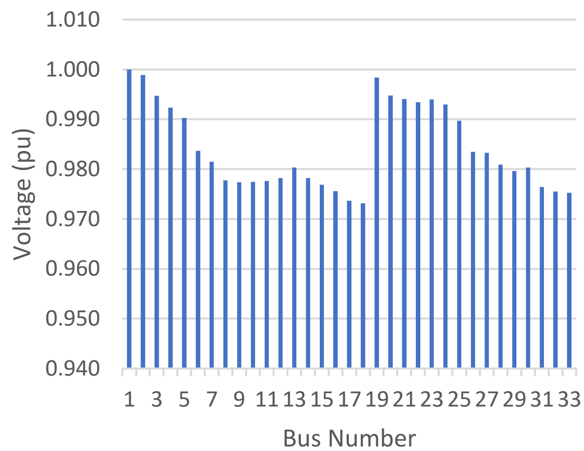

Figure 7. Voltage Profile of IEEE 33 Bus Distribution System after addition of 3 DG RES.

Figure 8 shows the voltage index graph on each bus in the IEEE 33 Bus distribution system with simulations in the first condition, without DG RES injection, the second condition with one DG RES injection, the third condition with two DG RES injections and the third condition with simulations on three DG RES injections.

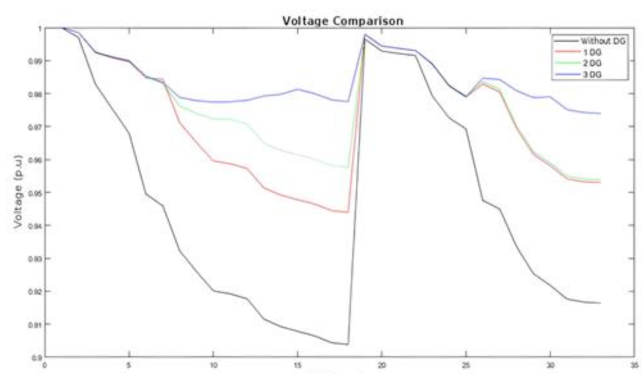

Figure 8. Voltage Profile Graph of IEEE 33 Bus Distribution System before adding DG and after adding 1, 2, and 3 DG.

doi: 10.14710/teknik.v46i3.67453

Table 4. Emission and environmental values of IEEE 33 Bus Distribution System after addition of 3 DGs.

Emission Value	Emission Type				Total
	SO_2	NOx	CO	CO_2	
Emission (Ton/Hour)	0,011	0,007	0,002	1,192	1,212
Environmental Cost (Rp-Million)	0,152	0,132	0,004	0,063	0,351

The simulation results show a significant increase in the voltage of each bus after the addition of 3 DGs, especially on bus 18 and bus 33. The simulation results also show no decrease in the voltage profile on the bus after the addition of DGs.

In the case study after the addition of three DGs, there is a reduction in emissions and emission compensation. The amount of emissions after the addition of three DGs is shown in Table 4.

Table 4 shows that the type of emission or pollutant produced the most in the IEEE 33 bus distribution system is carbon dioxide (CO_2) which is 1.192 tons per hour. While the type of pollutant produced the least is carbon monoxide (CO) which is 0.002 tons per hour. The total amount of emissions produced is 1.212 tons per hour. The environmental costs that must be incurred in the IEEE 33 Bus distribution system are Rp 351,000 per hour. The highest environmental expenditure costs are obtained from sulfur dioxide (SO_2) pollutants which are Rp 152,000 per hour. The lowest environmental costs are carbon monoxide (CO) which is Rp 4,000 per hour.

Table 5 shows that there is a reduction in emission value of 3,058 tons per hour or 71.62 percent after the addition of three DGs. So that there is a reduction in environmental costs of Rp 885,000 per hour. So that the injection of three DG RES into the system can reduce environmental costs as emission compensation by 71.60 percent.

3.4 Method Validation and Comparison of Simulation Results

Validation of the MVO method on the IEEE 33 Bus distribution system was validated by comparing it with other methods that have been carried out by researchers and other researchers. The comparative methods include PSO, IA, Hybrid, SOS, NeSOS, and GA (Umar et al., 2020). For comparison and validation, Table 6 shows the optimal location and size of DG using the MVO method and other methods.

Table 5. Percentage reduction of emissions and environmental costs after adding 3 DGs to the IEEE 33 Bus Distribution System.

Emission value	Without DG	3 DG	Percentage Reduction (%)
Emission (Ton/Hour)	4,270	1,212	71,62
Environmental Cost (Rp-Million)	1,236	0,351	71,60

In addition to location and size, the percentage of power loss reduction with various methods is presented in Table 6. Table 6 shows the optimal location and size of DG in the IEEE 33 Bus system. The simulation was carried out with three conditions, namely simulation without DG, simulation of one DG, and simulation of three DG.

In the simulation of the installation of one DG RES unit on the IEEE 33 bus distribution system, the MVO algorithm searches to get the most appropriate location and size of DG in order to obtain the smallest power losses and emission as well as an increase in the good voltage profile index. Based on the simulation results with the installation of one DG unit, it shows that the optimal DG placement using the MVO method is on Bus 6 with a reduction in power losses from 211 MW to 111 MW or a reduction in power losses reaching 47.39 percent. The optimal placement in the MVO method is the same as the placement of the PSO, Hybrid, IA, SOS, and NeSOS methods, namely both located on Bus 6. In the simulation of the placement of 3 DGs using the MVO method on the IEEE 33 Bus distribution system, it was able to reduce power losses by 65.40 percent.

This percentage is lower when using the PSO method, IA method, SOS method, and NeSOS, but higher than the Hybrid method and GA method, Based on the comparison in Table 6, it can be seen that the highest percentage of power loss is with the IA method, which is 61.62 percent. Based on the simulation results with the addition of several DG RES on the IEEE 33 bus distribution system using the MVO algorithm method, it can be concluded that the use of the MVO method in the condition of adding one DG obtained a higher percentage of power loss reduction than other methods. However, in the condition of three DGs, the MVO algorithm method is lower than the Hybrid and PSO methods but higher than the IA and GA methods. The percentage of power loss reduction using MVO can be greater if the number of universes is increased

doi: 10.14710/teknik.v46i3.67453

Table 6. Optimal Location and Size of DG Additions in IEEE 33 Bus Distribution Systems Using MVO and Various Methods

Condition	Methods	Bus Location	Size (MW)	Capacity (MW)	Power loss (kW)	Reduction of Power Loss (%)
Without DG					211	
1 DG	PSO	6	2,59	2,59	111, 03	47,38
	IA	6	2,60	2,60	111,10	47,34
	Hybrid	6	2,49	2,49	111,17	47,31
	SOS	6	2,59	2,59	111,02	47,38
	NeSOS	6	2,59	2,59	111,02	47,38
	MVO	**6**	**3,64**	**3,64**	**111,00**	**47,39**
3 DG	PSO	13	0,770	2,93	72,79	65,50
		24	1,090			
		30	1,070			
	IA	6	0,900	2,52	81,05	61,62
		12	0,900			
		31	0,720			
	Hybrid	13	0,790	2,87	72,89	65,45
		24	0,070			
		30	1,010			
	SOS	13	0,802	2,947	72,78	65,51
		24	1,091			
		30	1,054			
	NeSOS	13	0,802	2,947	72,78	65,51
		24	1,091			
		30	1,054			
	GA	13	0,801	2,947	73,80	65,02
		24	1,091			
		30	1,055			
	MVO	**13**	**1,120**	**3,756**	**73,00**	**65,40**
		24	**1,228**			
		30	**1,408**			

4. Conclusion

Optimal placement of renewable energy source DG units based on MVO algorithm simulation on IEEE 33 bus distribution system with one DG unit scheme located on bus 6 with a size of 3.64MW, three DG unit scheme located on bus 13, bus 24 and bus 30 with sizes of 1.228 MW and 1.408 MW respectively. The highest percentage of power loss reduction using MVO compared to other methods was obtained in the one DG unit allocation scheme, which was 47.39 percent each. The reduction in emission value after the addition of three DGs was 71.62 percent. Thus, there was a reduction in environmental costs of 71.60 percent. The advantage of the MVO algorithm is that it can converge in a small number of iterations

References

Ahmad, I., Fandi, G., Muller, Z., & Tlusty, J. (2019). Voltage Quality and Power Factor Improvement in Smart Grids Using Controlled DG Units. *Energies*, *12*(18), 3433. https://doi.org/10.3390/en12183433

Al-Jumaili, A. M., & Yilmaz Azlan. (2021). Optimal Allocation and Sizing of Distributed Generation in Radial Distribution Systems using Geolocation-Aware Heuristic Optimization. *International Journal of Computer Applications*, *183*(16), 26–34.

Al-Shamma'a, A. A., Hussein Farh, H. M., & Alsharabi, K. (2024). Integrating Firefly and Crow Algorithms for the Resilient Sizing and Siting of Renewable Distributed Generation Systems under Faulty Scenarios. *Sustainability*, *16*(4), 1521. https://doi.org/10.3390/su16041521

doi: 10.14710/teknik.v46i3.67453

Binini, G. M., Munda, J. L., & Popoola, O. M. (2024). Optimal location, sizing and scheduling of distributed energy storage in a radial distribution network. *Journal of Energy Storage*, *94*, 112499. https://doi.org/10.1016/j.est.2024.112499

Costa, J. A. D., Castelo Branco, D. A., Pimentel Filho, M. C., Medeiros Júnior, M. F. D., & Silva, N. F. D. (2019). Optimal Sizing of Photovoltaic Generation in Radial Distribution Systems Using Lagrange Multipliers. *Energies*, *12*(9), 1728. https://doi.org/10.3390/en12091728

Das, B. K., Hassan, R., Tushar, M. S. H. K., Zaman, F., Hasan, M., & Das, P. (2021). Techno-economic and environmental assessment of a hybrid renewable energy system using multi-objective genetic algorithm: A case study for remote Island in Bangladesh. *Energy Conversion and Management*, *230*, 113823. https://doi.org/10.1016/j.enconman.2020.113823

Davoudkhani, I., Zishan, F., Mansouri, S., Abdollahpour, F., Grisales-Noreña, L., & Montoya, O. (2023). Allocation of Renewable Energy Resources in Distribution Systems While Considering the Uncertainty of Wind and Solar Resources via the Multi-Objective Salp Swarm Algorithm. *Energies*, *16*(1), 474. https://doi.org/10.3390/en16010474

Deng, Y., Wu, J., Yang, Q., Chen, W., Li, P., Huang, C., Deng, J., Ji, B., & Xie, L. (2023). Life Cycle-Based Carbon Emission Reduction Benefit Assessment of Centralized Photovoltaic Power Plants in China. *Sustainability*, *15*(23), 16323. https://doi.org/10.3390/su152316323

Hemeida, M. G., Ibrahim, A. A., Mohamed, A.-A. A., Alkhalaf, S., & El-Dine, A. M. B. (2021). Optimal allocation of distributed generators DG based Manta Ray Foraging Optimization algorithm (MRFO). *Ain Shams Engineering Journal*, *12*(1), 609–619. https://doi.org/10.1016/j.asej.2020.07.009

Hlalele, T. G., Naidoo, R. M., Zhang, J., & Bansal, R. C. (2020). Dynamic Economic Dispatch With Maximal Renewable Penetration Under Renewable Obligation. *IEEE Access*, *8*, 38794–38808. https://doi.org/10.1109/ACCESS.2020.2975674

Janamala, V., & Radha Rani, K. (2022). Optimal allocation of solar photovoltaic distributed generation in electrical distribution networks using Archimedes optimization algorithm. *Clean Energy*, *6*(2), 271–287. https://doi.org/10.1093/ce/zkac010

Kamel, S., Khasanov, M., Jurado, F., Kurbanov, A., Zawbaa, H. M., & Alathbah, M. A. (2023). Simultaneously Distributed Generation Allocation and Network Reconfiguration in Distribution Network Considering Different Loading Levels. *IEEE Access*, *11*, 105916–105934. https://doi.org/10.1109/ACCESS.2023.3319456

Karthikeyan, K., & Dhal, P. K. (2017). Multi verse optimization (MVO) technique based voltage stability analysis through continuation power flow in IEEE 57 bus. *Energy Procedia*, *117*, 583–591. https://doi.org/10.1016/j.egypro.2017.05.153

Khan, M. S., Waheed, D., Shahzad, S., Afzal, S., & Killic, H. (2024). Optimal allocation of distributed generation in meshed power networks: A metaheuristic approach. *IET Renewable Power Generation*, *18*(8), 1570–1595. https://doi.org/10.1049/rpg2.13004

Kola Sampangi Sambaiah & T Jayabarathi. (2019). Optimal Allocation of Renewable Distributed Generation and Capacitor Banks in Distribution Systems using Salp Swarm Algorithm. *International Journal of Renewable Energy Research*, *9*(1), 97–107. https://doi.org/10.20508/ijrer.v9i1.8581.g7567

Liaquat, S., Fakhar, M. S., Kashif, S. A. R., Rasool, A., Saleem, O., & Padmanaban, S. (2020). Performance Analysis of APSO and Firefly Algorithm for Short Term Optimal Scheduling of Multi-Generation Hybrid Energy System. *IEEE Access*, *8*, 177549–177569. https://doi.org/10.1109/ACCESS.2020.3027436

Pham, T. D., Nguyen, H. D., & Nguyen, T. T. (2023). Reduction of Emission Cost, Loss Cost and Energy Purchase Cost for Distribution Systems With Capacitors, Photovoltaic Distributed Generators, and Harmonics. *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, *11*(1), 36–49. https://doi.org/10.52549/ijeei.v11i1.4103

Poshtyafteh, M., Barati, H., & Falehi, A. D. (2024). Optimal placement of distribution network-connected microgrids on multi-objective energy management with uncertainty using the modified Harris Hawk optimization algorithm. *IET Generation, Transmission & Distribution*, gtd2.13116. https://doi.org/10.1049/gtd2.13116

R. Nasser, M., I. Ali, I., & H. Alkhafaji, M. (2021). Optimal Placement and Size of Distributed Generators Based on Autoadd and PSO to Improve Voltage Profile and Minimize Power

Losses. *Engineering and Technology Journal*, *39*(3A), 453–464. https://doi.org/10.30684/etj.v39i3A.1781

Ramshanker, A., Isaac, J. R., Jeyeraj, B. E., Swaminathan, J., & Kuppan, R. (2022). Optimal DG Placement in Power Systems Using a Modified Flower Pollination Algorithm. *Energies*, *15*(22), 8516. https://doi.org/10.3390/en15228516

Rathore, A., & Patidar, N. P. (2021). Optimal sizing and allocation of renewable based distribution generation with gravity energy storage considering stochastic nature using particle swarm optimization in radial distribution network. *Journal of Energy Storage*, *35*, 102282. https://doi.org/10.1016/j.est.2021.102282

Suman, G. K., Guerrero, J. M., & Roy, O. P. (2021). Optimisation of solar/wind/bio-generator/diesel/battery based microgrids for rural areas: A PSO-GWO approach. *Sustainable Cities and Society*, *67*, 102723. https://doi.org/10.1016/j.scs.2021.102723

Taha, H. A., Alham, M. H., & Youssef, H. K. M. (2022). Multi-Objective Optimization for Optimal Allocation and Coordination of Wind and Solar DGs, BESSs and Capacitors in Presence of Demand Response. *IEEE Access*, *10*, 16225–16241. https://doi.org/10.1109/ACCESS.2022.3149135

Umar, U., Setyawan, G., Faanzir, F., Firdaus, F., U.P, D., Soeprijanto, A., & Penangsang, O. (2020). New Enhanced Symbiotic Organisms Search for Optimal Location and Sizing of Distributed Generation in Radial Distribution System. *International Journal of Intelligent Engineering and Systems*, *13*(5), 170–180. https://doi.org/10.22266/ijies2020.1031.16

doi: 10.14710/teknik.v46i3.67453