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OPTIMAL PLACEMENT OF INTERMITTENT DG RENEWABLE ENERGY AND CAPACITOR BANK FOR POWER LOSSES REDUCTION AND VOLTAGE PROFILE IMPROVEMENT IN MICROGRIDS SYSTEMS

FIRDAUS[1,2], UMAR[1],
RONY SETO WIBOWO[1], ONTOSENO PENANGSANG[1,*]

[1]Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Indonesia
[2]Department of Electrical Engineering Education, Universitas Negeri Makassar, Indonesia
[3]Department of Electrical Engineering, Universitas Khairun, Indonesia
[*]Corresponding Author: zenno_379@yahoo.com

Abstract

The use of renewable energy in recent years growing continuously. Power generation from renewable sources of energy is in the form of Distributed Generation (DGs). Intermittent DG renewable energy source is connected to the system of a microgrid. Problems found in the microgrid are power losses and voltage drop. Power losses and voltage drop will affect the quality of the electrical power distribution. In this paper, the application of a genetic algorithm is proposed for optimal placement of intermittent DG renewable energy source and capacitor bank for power losses reduction and voltage profile improvement in microgrids. Optimal placement of the DGs and capacitor bank in microgrid significantly reduces active and reactive power losses. Optimal placement of DGs also significantly improve voltage profile. Optimal Placement of Intermittent DG on the IEEE 69 Bus system using the GA method can reduce active power losses by 69.14 percent, while using the PSO method can only reduce active power losses by 69.09 percent.

Keywords: Losses, Microgrid, Renewable energy, Voltage profile.

1. Introduction

Energy needs cannot be separated from human needs. The need for electrical energy cannot be separated from human life as a resource in various activities. Every human activity requires energy. Until now, one of the most widely used types of human energy is electrical energy. Strategy is needed to support the supply of electrical energy optimally and affordably. The traditional electric power system generates electrical energy centrally by using fossil resources. Then, the power generated is distributed over the network.

This leads to great contamination of relationships and energy losses. Microgrid can be an alternative to replace the traditional centralized power system. This is done to reduce the above problems through energy generation that is distributed near the load and the use of renewable energy. Renewable energy is naturally intermittent and has several other challenges [1-3].

Microgrid is a small power system that can operate independently or connected with the main grid. Microgrid capacity from several kilowatts to several megawatts. This is actually a group of small capacity generating units with energy storage devices and controlled loads connected to low voltage networks and operated to supply electricity to the area for various purposes [4-6].

The microgrid concept is part of the evolution of electric power systems consisting of distributed generation. One of the advantages of the microgrid is that it can be operated as an autonomous islanded mode. This can improve supply reliability in case of errors in the upstream network. The microgrid can be synchronized back to the network after upstream network recovery [7-10].

Similar to a large system, the disturbance can also occur in the system microgrid. The disturbance can decrease power factor, voltage drops, and power losses. Those problems should be a concern to be resolved. Therefore, the system losses reduction and the increase of the voltage profile has an important benefit. The active and reactive power supply of the generator significantly reduces feeder losses. It increases the voltage profile, but for power utilization, voltage control, and reactive power are generally achieved by generating capacity at generating capacity cost [11-13].

Traditionally, the losses inflicted by the power transmission and distribution can be minimized by using reactive power control devices, the automatic voltage regulator (tap changing transformers), and the installation of shunt capacitor on low voltage bus [14]. Installation of DG on radial distribution network load flow can change from unidirectional to bidirectional, resulting the power loss [15].

Installation of units distributed generation (DG) sourced from renewable energy becomes more prominent in the microgrid systems because of their overall positive impact on the electricity network. Some of the advantages of the DGs with integrated power system are reducing losses, improving voltage profile, reducing emissions, and improving the power quality [16-18]. Integration of DGs power system will increase the percentage of electricity produced from renewable energy sources (RES). Such integration can enhance the sustainability of the electricity and ideally will also provide reliable, secure, flexible, affordable, and sustainable electricity [19]. The challenge of DGs RES is naturally intermittent [19-21].

In the installation or placement of DGs, several factors must be considered, such as the technology used, the number and capacity of the unit, the optimum location, and the type of network connection. However, to maximize the benefits of DGs, the optimal placement is carried out using the method of optimization. Installing the units of DGs in places that are not optimal and inappropriate size can lead to increased costs and loss of power system. In addition, the installation of DGs unit is not easy, and thus the placement and size of units of DGs should be handled with caution and proper method. In addition to the placement of the unit DGs, power losses and improved voltage profile can be reduced by installing a capacitor bank on microgrid system. Optimal placement of the unit DGs and capacitor bank uses GA [22, 23].

Therefore, this study uses a genetic algorithm [24] for optimal placement of DGs units and capacitor banks to reduce power losses and improve the voltage profile. Genetic algorithm is a search algorithm that relies on evolutionary techniques [25]. The advantage of using GA is that the algorithm is easy to understand without using complex mathematical equations [26].

2. Problem Formulation

2.1. Estimation of power losses and voltage drop

Modern power systems are designed to generate large power to be distributed to consumers. Thus, active and reactive power always flow from higher voltages to low voltage levels. With the penetration of DG, the flow of power becomes reversed. In addition, the distribution network is no longer a passive circuit that supplies the load but becomes an active circuit with power and voltage flow determined by the generator and load.

Changes in active and reactive power caused by micro generator sources are very important and have a technical and economic effect on the power system. Thus, when the generator changes power flow in the network, it will also change network losses.

If a small generator is located close to a large load, the network loss will be reduced. Both real and reactive power can be supplied to the load from an adjacent generator. However, if a large generation is located far from the load, it will increase the loss of the distribution system network.

In general, there is active power loss on the network. This loss depends on the currents in the circuit branches. This loss also depends on the voltage, and voltage analysis is the object of power flow calculation.

If a generator and network are chosen to operate on an integrated power factor, it needs to minimize electricity loss on the network. This can reduce the cost of reactive power consumption and improve the voltage profile.

Total complex power installation on the bus i was written with S_i, where $S_i = P_i + jQ_i = V_i.I_i^*$. The amount of power on all buses provides a system of total loss:

$$P_L + jQ_L = \sum_i^n V_i . I_i^* = V_{bus}^T . I_{bus}^* \qquad (1)$$

where P_L and Q_L are the loss of active power and reactive power on the system, V_{bus} is nodal voltage bus column vector, the vector is a column, I_{bus} current installation and n is the number of the bus [27].

The objective function related to voltage deviation index can be expressed in the following formula:

$$F = \sum_{i=1}^{n} \frac{|V_m - V_i|}{V_m} \quad (2)$$

where Vm is the slack bus voltage and Vi is the bus voltage to i

2.2. DGs Placement

Placement of DGs is the practice of placing small power plants in certain locations in the power system. This is an ideal solution because DGs units are easier to provide, easy to install and operate, easy to move, modular, and cost-effective. DG installations in power systems can obtain several advantages such as providing load-sensitive protection, reducing transmission and distribution network congestion, and improving overall system performance by reducing power losses and increasing voltage profiles [28-30].

The capacity of each DG varies according to the maximum size estimated for planning. Each DG must be maintained within the range [P_{DGmin}=50 P_{DGmax}=200], where P_{DGmin} is the minimum permissible Real Power value of each DG capacity and P_{DGmax} is the maximum permissible Real Power value of each DG capacity. This is a mandatory requirement because the type and associated DG costs must vary if the DG capacity is less than the specified minimum value. Similarly, the Power Factor (Pf) of each DG must be maintained as [pf_{min} pf_{max}], where pf_{min} is the minimum permissible Power Factor value of each DG capacity and pf_{max} is the maximum permissible Power Factor value of each DG capacity.

Mathematically, it can be seen as follows:

$$PDG_{DGmax_{DGmin}} \quad (3)$$

DG reactive power formula of Real Power is as follow:

$$Q_{DG} = P_{DG}.\, tan(\, cos^{-1}\, p\, f) \quad (4)$$

where Q_{DG} is the reactive power of DG in kVar, and pf is the power factor.

2.3. Capacitor placement

The longer an electrical conductor in the distribution network, the greater the inductance characteristic arising from the conductor. If a network does not have a reactive power source in the area around the load, the reactive current will flow to the network, which results in a decrease in the power factor, increase in network losses, and decrease in voltage, especially at the end of the network.

The alternative to reducing the consequences of increasing reactive current is to do reactive power compensation, which aims to transport reactive power to the power grid and keep the voltage profile always at the permitted limits. They can be achieved by installing capacitors.

The placement of the capacitor is determined based on the curve of the demand for electric power, meaning, and plot on the load versus time. In practice, the weights in the network distribution can vary with time and depends on various points on the feeder where the measurement is taken [31, 32].

Capacitor capacities are defined as [QC_{min}=50 KVAR, QC_{max}=2000 MVAR], where QC_{min} is the minimum Reactive Power value of each capacitor bank, and

QC_{max} is the maximum Reactive Power value of each capacitor bank for every 50 MVAR.

Mathematically, this can be described as follow:

$$QC_{Cmax_{Cmin}} \tag{5}$$

where Q_C is the reactive power of the capacitor in kVar.

2.4. Genetic algorithm (GA)

Genetic algorithms are computational algorithms to find solutions to a problem. This algorithm was inspired by the theory of evolution proposed by Charles Darwin. In the process of genetic algorithms, the population has n chromosomes representing candidate solutions. Each chromosome is the vector dimensions of real value m, where m is the number of optimal parameters.

In this study, the control variables are represented before optimizing using genetic algorithms. The control variable represents the integrated DG size as a percentage of the total distribution system load.

The fitness function is formulated based on a multi-objective function to estimate the quality and performance of individuals in a population. The fitness function is formulated as follow:

$$Min\,F = P_{loss} + (V_r - V_{ref}) \tag{6}$$

where P_{loss} is the power loss in MW, V_r is the voltage on the bus r, and V_{ref} is the reference voltage.

Therefore, any parameter represents the optimized dimensions of space problems. The followings are description of the steps in the approach of the GA.

Step 1: Generating the population of random strings.

Step 2: Calculating the fitness value for each of the population of a string and selecting the strongest members of the population.

Step 3: Reproducing the probabilistic method.

Step 4: Creating the pool after the election.

Step 5: Creating the offspring through the crossover and mutation operations.

Step 6: Evaluating the offspring and calculating the fitness value for each solution.

Step 7: If the destination is reached, looking for a generation allowed to be achieved. Backing in the chromosome is the best solution; or going to step 4 [33].

The production process for the new generation of GA can be seen in Fig. 1, and the GA optimization process for the plant can be seen in Fig. 2.

3. Case Study

In this paper, simulation and test use IEEE system with 15 bus, 33 bus, and 69 bus distribution network, 11 kV, and Single line diagram as illustrated in Fig. 3. For simulation, DG type 2 uses sources Photovoltaic (PV), DG type 3 using sources Gas Turbine (GT), and type DG 4 uses source Wind Turbine (WT).

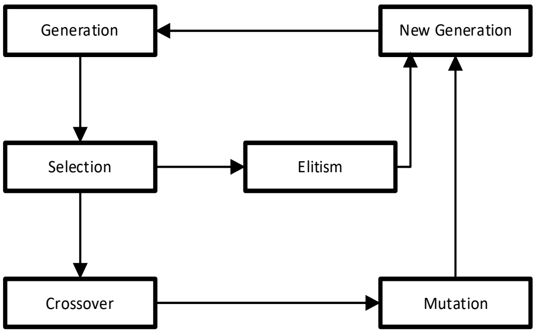

Fig. 1. The production process of the new generation.

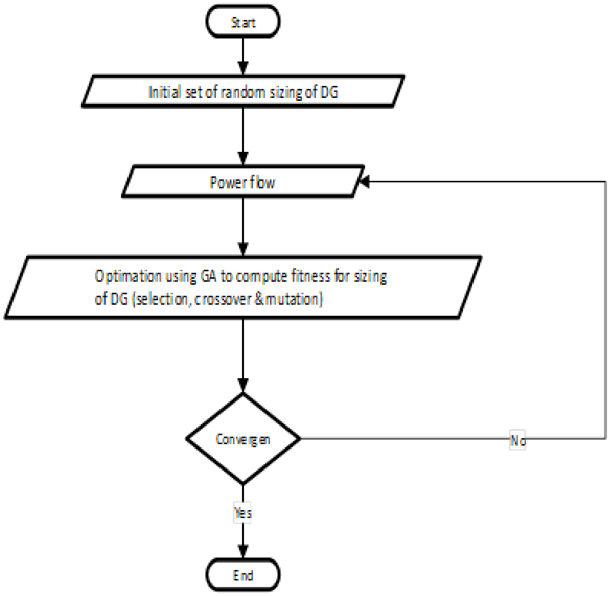

Fig. 2. Flowchart of optimization using GA.

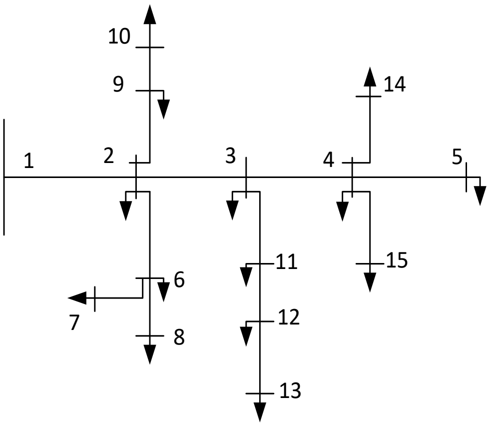

Fig. 3. Single line diagram of IEEE 15 bus system.

4. Results and Discussion

Simulations are carried out to obtain the optimal placement of intermittent DG renewable energy sources and Capacitor banks. Simulations were carried out on the IEEE 15 bus, 33 bus, and 69 bus systems. Simulation scheme is done by installing a capacitor bank inject Q(kVAr), DG type 2 using sources Photovoltaic (PV) inject P(kW), DG type 3 using Gas Turbine (GT) inject P, absorb Q, and type DG 4 using Wind Turbine (WT) inject P and Q.

Figure 4 shows the results of the optimization of DGs and Capacitor bank placement. Optimal placement obtained DGs type 3 on bus 15, bus 7, bus 12 and capacitor bank on bus 11 in IEEE 15 bus system. The best fitness is 0.0254 and converges on iterations above 100.

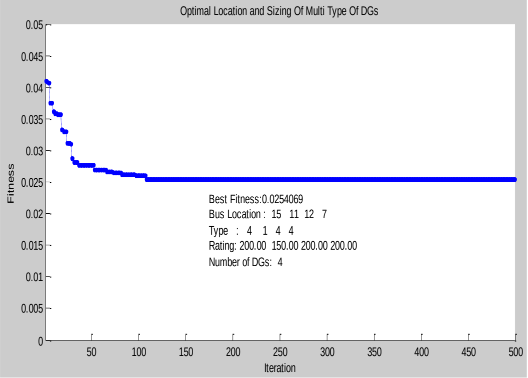

Fig. 4. Convergence characteristics of fitness function using GA.

Figure 5 shows a graph of the voltage profile on each bus in the IEEE 15 Bus system simulation without the placement of DGs and the voltage profile after the placement of DGs and capacitors. It can be seen that the lowest voltage is on bus 13, which is 0.9446 pu. There are still some buses which experience under-voltage, namely bus 12 – bus 15. After adding DGs and capacitor, all bus voltages become normal. This indicates that the addition of DG renewable energy sources and capacitors in the IEEE 15 bus system can increase the lowest voltage from 0.9446 pu to 0.9725 pu.

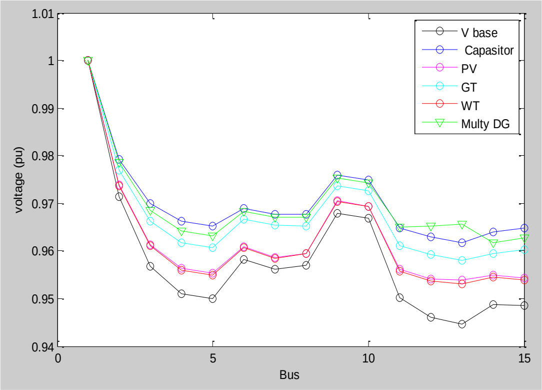

Fig. 5. Bus voltages before and after DG and capacitor placement on the IEEE 15 bus system.

Figure 6 shows a graph of the voltage profile on each bus in the IEEE 33 Bus system simulation without the placement of DG and the voltage profile after the placement of DG and capacitor. It shows that the lowest voltage is on bus 18, which is 0.9038 pu. There are still 54 percent of buses experiencing under voltage. After the placement of DGs and capacitors, the remaining 12 percent of the buses experience under-voltage. This indicates that the addition of DG renewable energy sources and capacitors in the IEEE 33 bus system can increase the lowest voltage from 0.9033 pu to 0.9533 pu.

Figure 7 shows a graph of the voltage profile on each bus in the IEEE 69 Bus system simulation without the placement of DGs and the voltage profile after the placement of DGs and capacitors. It shows that the lowest voltage is on bus 65, which is 0.9092 pu. There are still 13 percent of buses experiencing under-voltage. After the placement of DG and capacitor, all buses become normal. This shows that the addition of DG renewable energy sources and capacitors in the IEEE 69 bus system can increase the lowest voltage from 0.9092 pu to 0.955 pu.

Table 1 shows installed the initial conditions of the IEEE 15 Bus system before power system installed from DGs and capacitor active power loss is 12.36 kW and reactive power loss is 11.46 kVAr. In the capacitor's installation, active power loss is 7.32 kW and reactive power loss is 6.8 kVAr. It shows there is decrease in the active power losses of 5.04 kW and reactive power of 4.66 kVAr.

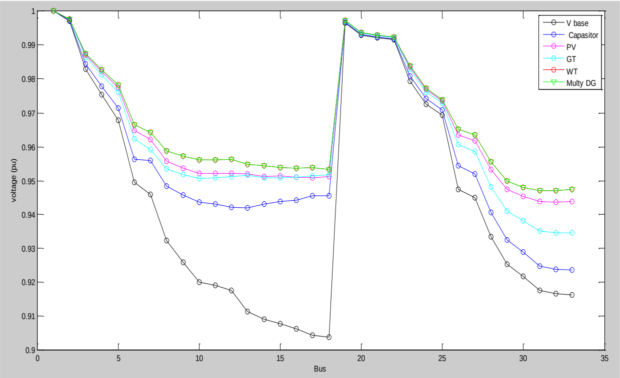

Fig. 6. Bus voltages before and after DG placement on the IEEE 33 bus system.

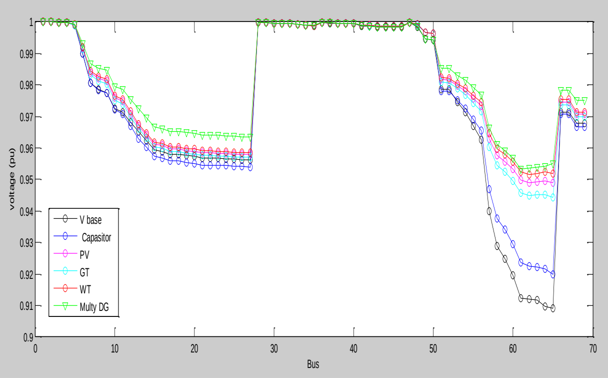

Fig. 7. Bus voltages before and after DG placement on the IEEE 69 bus system.

Table 1. The results of analysis of intermittent DGs renewable energy sources and Capacitor banks optimization on the IEEE 15 bus system

Case	Condition	Location (bus)	P Loss (kW)	Qloss (kVar)	P Loss Reduction (%)	Q Loss Reduction (%)
1	Before Installation of DG and Capacitor	-	12.36	11.46	-	-
2	Installation of Capacitors	4, 15, 7, 12	7.32	6.80	40.78	40.66
3	Installation of DGs type 2	14, 13, 12, 15	10.26	9.48	16.99	17.28
4	Installation of DGs type 3	15, 4, 12, 7	9.24	8.50	25.24	25.83
5	Installation of DGs type 4	14, 13, 12, 15	10.28	9.52	16.83	16.93
6	Installation of Multi Type	Capacitor (11), DGs type 4 (15, 7,12)	7.16	6.68	42.07	41.71

DG type 2 installation in the IEEE 15 Bus system resulted active power loss of 10.26 kW and reactive power loss of 9.48 kVAr. It shows there was decrease in the active power losses of 2.1 kW and reactive power loss of 1.98 kVAr. DG type 3 installation in the system resulted active power loss of 9.24 kW and reactive power loss of 8.50 kVAr. It shows there is decrease in the active power losses of 3.12 kW and reactive power loss of 2.96 kVAr. DG type 4 installation in the system resulted active power loss of 10.28 kW and reactive power loss of 9.52 kVAr. It shows there is decrease in the active power loss of 2.08 kW and reactive power loss of 1.94 kVAr.

Multi type installations in the IEEE 15 Bus system resulted active power loss of 7.16 kW and reactive power loss of 6.68. It shows there is decrease in the active power loss of 5.2 kW and reactive power loss of 4.78 kVAr. Multi DG installation in the IEEE 15 bus system can reduce active power loss of 42.07 percent and reactive power loss of 41.71 percent.

Table 2 is the result of analysis of intermittent DGs renewable energy sources and Capacitor banks optimization in the IEEE 33 bus system. The simulation results show that the placement of the capacitor and DG on the IEEE 33 bus system is different based on the type of DG and capacitor installed. The most optimal location to reduce losses is the placement of DG type 4 and multi DGs. Multi DG installation in the IEEE 33 bus system can reduce active power losses by 53.23 percent and reactive power losses by 54.79 percent.

Table 3 is the results of analysis of intermittent DGs renewable energy sources and Capacitor banks optimization in the IEEE 69 bus system. The simulation results show that the placement of the capacitor and DG on the IEEE 69 bus system is different based on the type of DG and capacitor installed. The most optimal location for reducing losses is obtained by adding multi-type DG. Multi DG installation in the IEEE 69 bus system can reduce active power losses by 58.17 percent and reactive power losses by 54.80 percent.

Table 2. The results of analysis of intermittent DGs renewable energy sources and capacitor banks optimization on the IEEE 33 bus system

Case	Condition	Location (bus)	P Loss (kW)	Qloss (kVar)	P Loss Reduce (%)	Q Loss Reduce (%)
1	Before Installation of DG and Capacitor	-	210.99	143.13	-	-
2	Installation of Capacitors	15, 14, 18, 17, 16	185.74	128.06	11.97	10.53
3	Installation of DGs type 2	32, 33, 18, 13, 15	113.32	74.95	46.29	47.64
4	Installation of DGs type 3	14, 33, 18, 13, 17	139.20	93.39	34.03	34.77
5	Installation of DGs type 4	14, 33, 32, 12, 17	98.69	64.71	53.23	54.79
6	Installation of Multi Type	DGs type 4 (14, 33, 32, 12, 17)	98.69	64.71	53.23	54.79

Table 3. The results of analysis of intermittent DGs renewable energy sources and Capacitor banks optimization on the IEEE 69 bus system.

Case	Condition	Location (bus)	P Loss (kW)	Qloss (kVar)	P Loss Reduction (%)	Q Loss Reduction (%)
1	Before Installation of DG and Capacitor	-	225	102.2	-	-
2	Installation of Capacitors	61, 64, 63, 60, 62	179.68	81.45	20.14	20.30
3	Installation of DGs type 2	62, 61, 60, 64, 63	123.50	57.03	45.11	44.20
4	Installation of DGs type 3	61, 63, 62, 60, 64	147.52	67.37	34.43	34.08
5	Installation of DGs type 4	61, 63, 64, 62, 65	105.74	49.37	53.00	51.69
6	Installation of Multi Type	DGs type 4 (61, 63, 64, 62, 65)	94.12	46.20	58.17	54.80

Figure 8 shows the percentage reduction in Active and Reactive power losses in the IEEE 33 bus system. Simulation is done by installing 4 types of DG and Capacitors. The simulation results show that the DG allocation with the Multi DG type and the wind turbine type can reduce active and reactive power losses with the highest percentage, followed by PV. The use of bank capacitors has the lowest losses reduction capability.

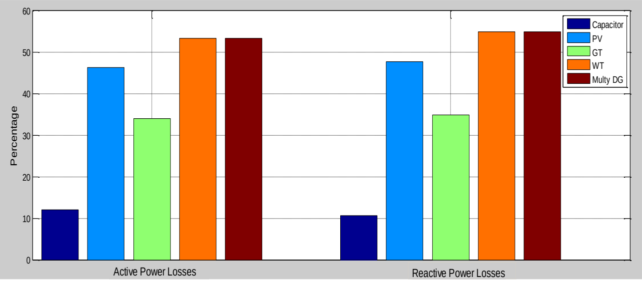

Fig. 8. Percentage reduction in active and reactive power losses in the IEEE 33 bus system.

Figure 9 shows the percentage reduction of Active and Reactive power losses in the IEEE 69 bus system. The simulation is carried out by installing 4 DG and Capacitor Banks. The simulation results show that the placement of DG with the Multi DG type can reduce active and reactive power losses with the highest percentage, followed by wind turbines. The use of capacitor banks can reduce losses to the lowest.

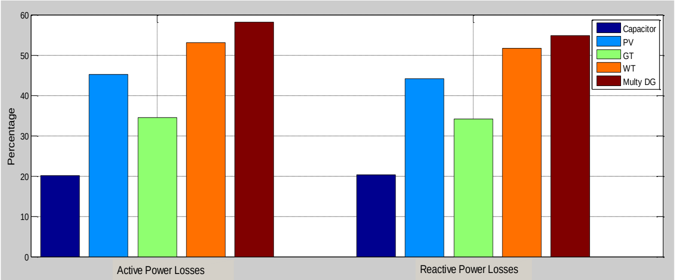

Fig. 9. Percentage reduction in Active and Reactive power losses in the IEEE 69 bus system.

Table 4 shows the optimal location and size of 3 DG in the IEEE 33 Bus system. The simulation is carried out by installing 3 DGs in the system, which is then determined for the most appropriate location and size to obtain the smallest losses and a good voltage profile. The simulation results show that the optimal location using the GA method is in Bus 13, Bus 24, and Bus 30. The optimal allocation in the GA method is similar with the PSO, Hybrid, SOS, and NeSOS methods. However, it is different from the allocation using the IA method, namely on Bus 6, Bus 12, and Bus 31. Allocation of 3 DG using the GA method on the IEEE 33 Bus system can reduce losses by 65.02 percent. This percentage is lower when using the PSO, Hybrid, SOS method, and NeSOS, but higher when using the IA method, i.e., 61.62 percent.

Table 4. Optimal location and size of DG in IEEE 33 bus system.

Condition	Method	Location bus	Size (MW)	Capacity (MW)	Power Loss (kW)	Loss Reduction (%)
No DG					210.99	
3 DG	PSO [34]	13 24 30	0.77 1.09 1.07	2.93	72.79	65.50
3 DG	IA [34]	6 12 31	0.90 0,.90 0.72	2.52	81.05	61.62
3 DG	Hybrid [34]	13 24 30	0.79 0,07 1.01	2.87	72.89	65.45
3 DG	SOS [35]	13 24 30	0.802 1.091 1.054	2.947	72.78	65.51
3 DG	NeSOS [35]	13 24 30	0.802 1.091 1.054	2.947	72.78	65.51
3 DG	GA	13 24 30	0.801 1.091 1.055	2.947	73.80	65.02

Table 5 shows the optimal location and size of 3 DG in the IEEE 69 Bus system. The simulation is carried out by installing 3 DGs in the system, which is then determined for the most appropriate location and size to obtain the smallest losses and a good voltage profile. The simulation results show that the optimal location using the GA method is in Bus 11, Bus 17, and Bus 61. The optimal allocation using the GA method is similar with the PSO, Hybrid, SOS, and NeSOS methods. Using the GA method, the allocation of 3 DG can reduce losses by 69.14 percent, while using the PSO method can only reduce active power losses by 69.09 percent.

Table 5. Optimal location and size of DG in IEEE 69 bus system.

Condition	Method	Location bus	Size (MW)	Capacity (MW)	Power Loss (kW)	Loss Reduction (%)
No DG					225	
3 DG	PSO [34]	11 17 61	0.460 0.44 1.70	2.60	69.54	69.09
3 DG	Hybrid [34]	11 17 61	0.510 0.380 1.67	2.56	69.54	69.09
3 DG	SOS [35]	11 17 61	0.527 0.381 1.719	2.626	69.431	69.14
3 DG	NeSOS [35]	11 17 61	0.527 0.381 1.719	2.626	69.431	69.14
3 DG	GA	11 17 61	0.527 0.380 1.719	2.626	69.431	69.14

5. Conclusions

Optimal placement of DG Renewable energy and capacitors using GA method varies based on the type and amount of DGs. Placement of 5 DGs in the IEEE 15 bus system can reduce active power losses by 42.07 percent and reactive power losses by 41.71 percent. In the IEEE 33 bus system, it can reduce active power losses by 53.23 percent and reactive power losses by 54.79 percent. In the IEEE 69 bus system, it can reduce active power losses by 58.17 percent and reactive power losses by 54.80 percent. Placement of 3 DGs in the IEEE 69 Bus system using the GA method can reduce losses by 69.14 percent; while using the PSO method, it can only reduce active power losses by 69.09 percent.

Placement of DG renewable energy sources and capacitors in the IEEE 15 bus system can increase the lowest voltage from 0.9446 pu to 0.9725 pu, while in the IEEE 33 bus system, it can increase the lowest voltage from 0.9033 pu to 0.9533 pu. The IEEE 69 bus system can increase the lowest voltage from 0.9092 pu to 0.955 pu. From the simulation and discussion, the optimal placement with multi-type intermittent DGs renewable energy sources and capacitor banks can reduce active power loss and reactive power loss in a microgrid.

Nomenclatures

I_{bus}	Current bus
N	the number of the bus
P_i	active power
P_L	the loss of active power on the system
Q_i	reactive power
Q_L	the loss of reactive power on the system
S_i	Power
V_{bus}	voltage bus
Vi	the bus voltage to i
Vm	the slack bus voltage

Abbreviations

DG	Distributed Generators
GA	Genetic Algorithm
GT	Gas Turbine
PV	Photovoltaic
RES	Renewable Energy Source
WT	Wind Turbine

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