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Regular paper

Performance Enhancement of Distribution Network with DG Integration Using Modified PSO Algorithm

This paper addresses performance enhancement of distribution network with distributed generator (DG) integration using modified particle swarm optimization (PSO) algorithm. The effort of performance enhancement is done by using optimization of distribution network configuration. The objective of the optimization is minimizing active power loss and improving voltage profile while the distribution network is maintained in the radial structure. In this study, configuration optimization method is based on a modified PSO algorithm. The method has been tested in an IEEE model of 33-bus radial distribution network test system and a real-life radial distribution network of 60-bus Bantul distribution system, Indonesia. The simulation results show the importance of reconfiguring the network for enhancing the distribution network performance in the presence of DG.

Keywords: Distribution network; configuration optimization; power loss; particle swarm optimization; distributed generator.

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1. Introduction

Power distribution networks are mostly operated in radial configuration. The dynamics of the distribution system operations often requires reconfiguration of the network. Distribution network reconfiguration is achieved by using sectionalizing switches that remain normally closed and tie switches that remain normally open. The main purpose of the reconfiguration is to minimize active power losses in order to improve distribution system performance. Merlin and Back has become the pioneer in the distribution network reconfiguration effort [1]. The effort has been made to obtain the minimal active power losses using conventional technique. Other conventional technique has been proposed by researchers as presented in [2]. Most of conventional techniques do not necessarily guarantee global optimization. In the development, the use of artificial intelligence (AI) based techniques for network reconfiguration has become something of interest for many researchers, as can be seen in [3]–[17].

In [5], the use of genetic algorithm (GA) for distribution network reconfiguration technique to minimize the active power loss has been proposed. Augugliaro et al. [6] and Jeon et al. [7] and have presented simulated annealing techniques in large scale distribution system for active power loss reduction purpose. Mendoza et al. [8] have proposed a new GA based methodology with the fundamental loops for network reconfiguration. Another

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variant of the GA for distribution network reconfiguration has been proposed in [9]. They have developed a GA method based on the matroid and graph theories. In [10], the use of ant colony optimization (ACO) method for placement of sectionalizing switches in distribution networks has been presented. In [11], network reconfiguration based on a simple branch exchange technique of single loop has been proposed. In the technique, loops selection sequence affects the optimal configuration and the network power loss. In [12], harmony search algorithm (HSA) was used to reconfigure large-scale distribution network in order to minimize active power losses. The technique is conceptualized using the musical process of harmony searching in perfect state. In [13]–[16], the use of fuzzy multi-objective technique for optimal network reconfiguration has been presented. The technique of particle swarm optimization (PSO) for distribution network reconfiguration purpose has been presented in [17] and [18]. In their work, there are several objectives, i.e., active power loss, load balancing among the feeders, deviation of bus voltage, and branch current constraint violation. Criteria for selecting a membership function for each objective are not provided.

In the last two decades, the use of renewable energy sources as an alternative power generation has become popular. The power generation generally is having a capacity of up to 10 MW and located in several places that are connected to the grid distribution system, often called distributed generator (DG) [19-20]. The Government of Indonesia is one country in the world which is committed to utilizing renewable energy sources to generate electricity. The benefits of DG integration in distribution system are reducing power losses, improving voltage profiles and load factors, eliminating system upgrades and reducing environmental impacts [21]–[23]. Integration of DG in distribution system has become an interesting challenge for researchers to find the most appropriate method in the planning and operation of the distribution system [24]–[26].

In this paper, a modified PSO algorithm is presented to solve distribution network reconfiguration problem in the presence of DG under dynamic condition for reducing the active power loss. Radially of the network post-reconfiguration must remain in which all loads must be simultaneously supplied. Also, effect of DG type and voltage profile of the network is investigated. All objective functions are simultaneously weighted. Weighting of objective functions is a new issue in a multi-objective optimization [15]–[16]. The weighting of all objective function is the important contribution in this work. Another contribution is the application of modified PSO algorithm for optimization of a real-data of 60-bus Bantul radial distribution network. The effort is done in order to enhance the distribution system performance, especially for Bantul distribution network, Indonesia.

2. Methodology

2.1 Problem Formulation

The aim of network reconfiguration is to minimize active power losses and to improve voltage quality. The constraints of network reconfiguration problem are load flow equations, upper and lower limits of bus voltages, and upper and lower limits of line currents. Network reconfiguration for active power loss minimization can be formulated as follows:

$$\min P_{loss} = \sum_{i=1}^{N_k} R_i \frac{(P_i^2 + Q_i^2)}{V_i^2} \quad (1)$$

Subject to:

$$F(x) = 0 \quad (2)$$

$$V_{i,\min} \le V_i \le V_{i,\max} \quad (3)$$

$$I_{i,\min} \le I_i \le I_{i,\max} \quad (4)$$

where P_{loss} is an objective function of active power loss; N_k is the distribution branch number; R_i is line resistance at bus *i-th*; P_i is active power flowing out of bus; Q_i is reactive power flowing out of bus; V_i is the magnitude of voltage at bus *i-th*; $V_{i,min}$ is lower voltage limit at bus *i-th*; $V_{i,min}$ is upper voltage limit at bus *i-th*; I_i is the magnitude of current at bus *i-th*; $I_{i,min}$ and $I_{i,min}$ are lower and upper current limits at bus *i-th*, respectively;

2.2 Particle Swarm Optimization Technique

Particle swarm optimization (PSO) technique was first published by Eberhart and Kennedy [27]. The technique was inspired by a swarm of bird movement in searching of food. The model of the swarm movement can be used as a powerful optimizer. In search space of n-dimensional, it is assumed that the *i-th* individual position is $X_i = (x_{i1}, ..., x_{id}, ..., x_{in})$ and the *i-th* individual speed is $V_i = (v_{i1}, ..., v_{id}, ..., v_{in})$. The particle best experience *i-th* is recorded and represented by $Pbest_i = (pbest_{i1}, ..., pbest_{id}, ..., pbest_{in})$. In this research, the fitness of each particle (*pbest*) is active power loss. The best global position swarm optimization is $Gbest_i = (gbest_1, ..., gbest_d, ..., gbest_n)$. Velocity of each particle is computed based on initial velocity of each personal, the distance from the personal best position, and the distance from the global best position, as can be seen in the equation below:

$$V_i^{(t+1)} = \omega \cdot V_i^{(t)} + c_1 \cdot rand_1(\circ) \cdot (Pbest_i - X_i^{(t)}) + c_2 \cdot rand_2(\circ) \cdot (Gbest_i - X_i^{(t)}) \quad (5)$$

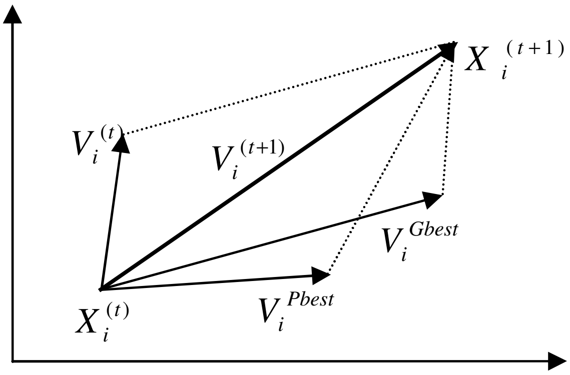

Fig. 1. The concept of optimization using PSO.

From equation (5), it can be determined the velocity vector of the *i-th* particle. Then, the latest position of the particle can be defined by:

$$X_i^{(t+1)} = X_i^{(t)} + V_i^{(t+1)} \quad (6)$$

where $i = 1, 2, ..., N$ is the particle index; t is iteration number; $rand_1$(o) and $rand_2$(o) are a number of random between 0 and 1; and N is the swarm number.

Then, the inertia weights ω can be defined by the equation:

$$\omega^{(t+1)} = \omega^{\max} - \frac{\omega^{\max} - \omega^{\min}}{t_{\max}} \times t \qquad (7)$$

where ω_{max} is the maximum inertia weight; ω_{min} is the minimum inertia weight; t_{max} is the maximum iterations; and t is the actual number of iterations. In our work, the inertia weight magnitude decrease linearly from 0.9 to 0.4.

The modified PSO technique is specified below:

1. Input the distribution system data and initialize the parameters of PSO.
2. Run the program of load flow to measure the fitness (active power loss) of each particle (*pbest*) and store it with the best value of fitness (*gbest*).
3. Update velocity of particle using (5).
4. Update position of particle using (6).
5. Decrease the inertia weight (ω) linearly from 0.9 to 0.4.
6. Perform violation of particle position:
   If particle position pos(j)>mp, then pos(j)=mp.
   Else if particle position pos(j)<mp, then pos(j)=1.
7. Perform violation of particle velocity:
   If particle velocity vel(j)>mv, then vel(j)=mv.
   Else if particle velocity vel(j)<-mv, then pos(j)= -mv.
8. Decrease the inertia weight (ω) linearly from 0.9 to 0.4.
9. Repeat steps 2-8 until a criteria is obtained.

3. Simulation Results and Discussion

In this work, two test electrical distribution systems, i.e., a standard of 33-bus radial distribution network test system and a practical 60-bus radial distribution system of Bantul, Indonesia, are examined. It should be noted that the 60-bus distribution system is an extracted feeder in a 150/20 kV substation from the Bantul district in Indonesia. Reconfiguration of distribution network with DG integration using modified PSO method has been implemented in Matlab software. Based on the DG technology, two types of DG which are connected to distribution network in our study, i.e., solar photovoltaics and wind farms, are modeled. Operation of DG is assumed to be in steady state condition. Hence, DG of solar photovoltaics injects active power while the DG of wind farms injects both active and reactive powers.

3.1 A Test System of 33-Bus Radial Distribution Network

In this section, the results of optimal reconfiguration of 33-bus 12.66-kV radial distribution network with DG integration using modified PSO to minimize active power losses and to improve the voltage quality of the system are presented. The radial system consists of one main feeder and three laterals. The system has 33 buses and 32 sections, as shown in Fig. 2. The switch of the system consists of 32 sectionalizing switches and 5 tie switches. Sectionalizing switches of the system are closed in normal conditions while tie switches are open in normal conditions. Load and branch data of the 33-bus distribution network can be found in [18]. The five tie switches are 33, 34, 35, 36 and 37. The total load of the system is 3715 kW and the initial power loss of the system is 208.46 kW. The base of the distribution system is V=12.66 kV and S=10 MVA.

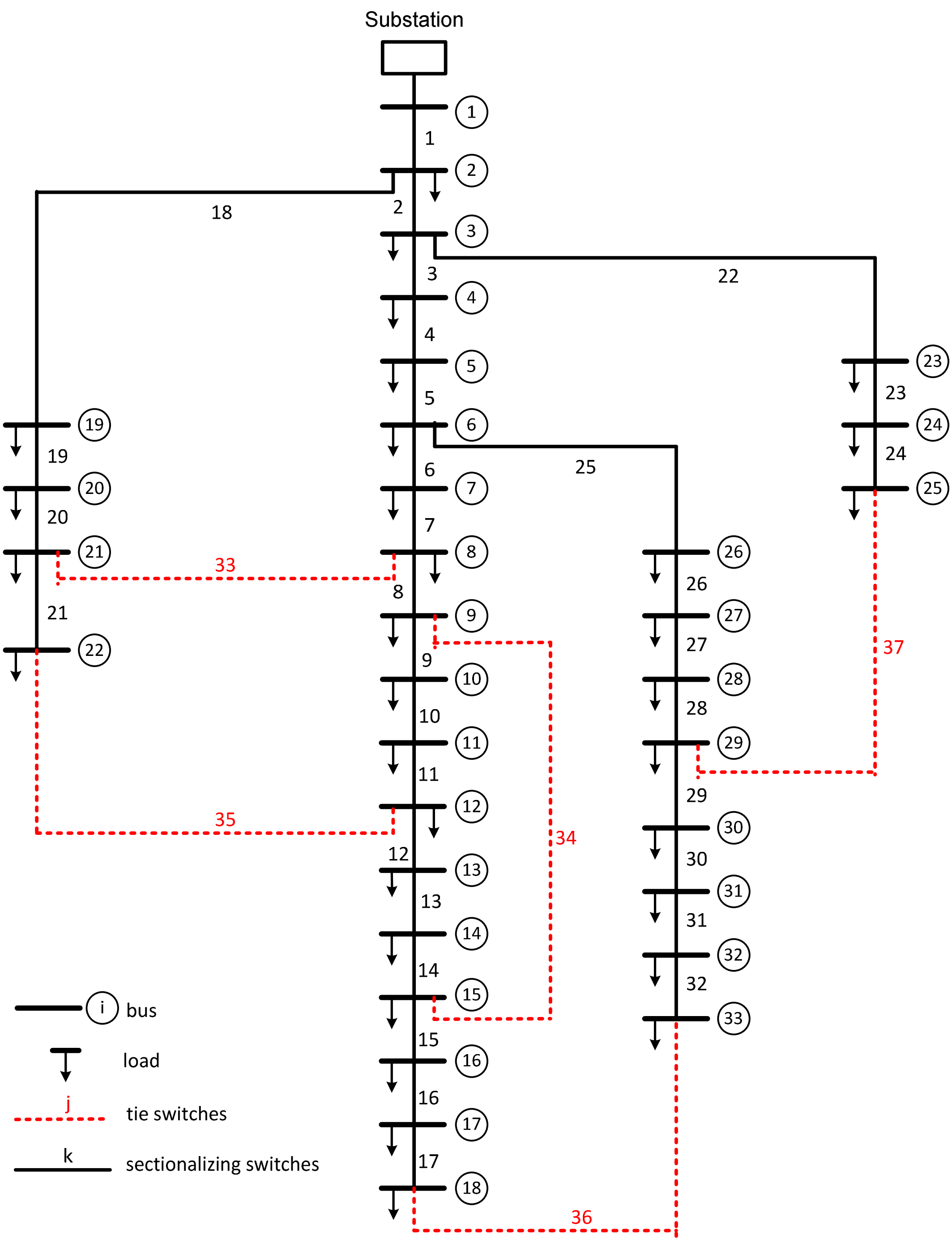

Fig. 2. An IEEE model of 33-bus radial distribution network [18]

The Initial configuration of the network without DG integration is shown in Fig.2. In order to analyze the impact of DG integration to distribution network, we have installed as many as five DGs on buses of 12, 17, 22, 25, and 27, respectively, as shown in Fig. 3 and Table 1. The DG models that have used in our study consist of both solar photovoltaics and wind farms. We have assumed that power factor of all DG solar photovoltaics are unity, while wind farms are ranging from 0.8 to 0.9 (lagging).

Table 1. DG Location and Capacity of 33-Bus Test System

DG Location	Name of DG	Active Power (kW)	Power Factor	Reactive Power (kVAr)
12	DG1	250	0.8	187.50
17	DG2	250	0.9	121.08
22	DG3	300	1	0
25	DG4	400	0.9	193.73
27	DG5	300	0.8	225

The PSO parameters that have been used to 33-bus distribution system are consists of population size of 20 and maximum iteration of 100. The minimum and maximum voltages are set at 0.90 and 1.00 p.u., respectively. The results of the case study are shown in Fig. 3, Fig. 4, Fig. 5, Fig. 6, and Table 2. Fig. 3 shows a 33-bus radial distribution network with integration of 5 DGs before reconfiguration. Network reconfiguration using modified PSO algorithm has resulted that there are four tie switches that must be closed, i.e., switches of 33, 35, 36, and 37, while the sectionalizing switches to be opened are switches of 7, 10, 28, and 31, as shown in Fig. 4 and Table 2.

Fig. 3 shows power loss dispersion before reconfiguration, after installing DG, and after reconfiguration for 33-bus radial distribution test system. It can be observed that the magnitude of the power loss of each bus depends on the length of line between the bus and the size of each load bus. It is shown that the longer the line, the greater the power loss. Similarly, from Fig. 3, it is also shown that the greater the load that is served by a bus, the greater the power loss. It can be seen that the presence of DG as many as five units on buses of 12, 17, 22, 25, and 27 has the effects on the power loss reduction over the system, especially on buses closest to the DG.

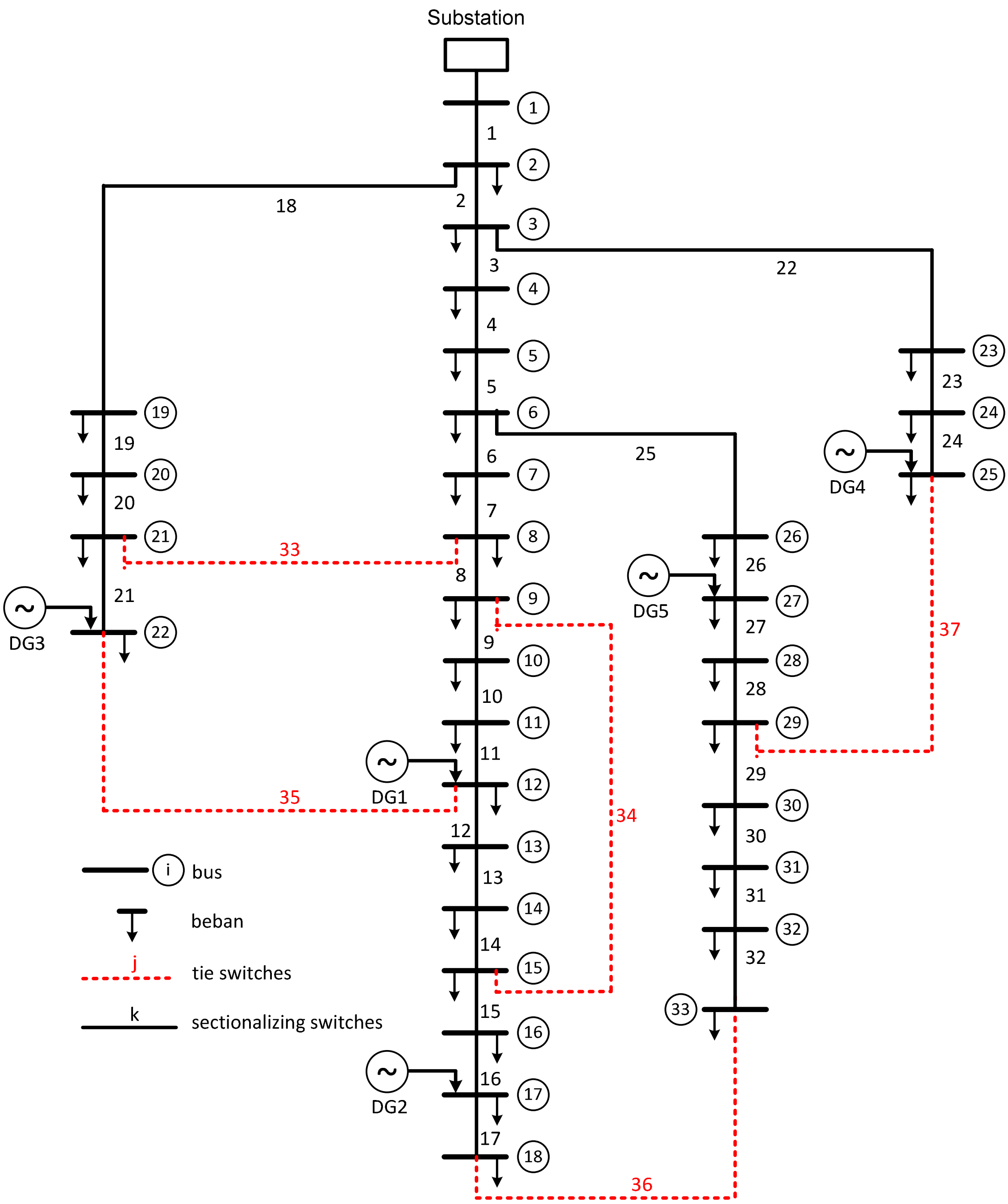

Fig. 3. A 33-bus radial distribution network with integration of 5 DGs before reconfiguration

Fig. 5 shows power loss dispersion before reconfiguration, after installing DG, and after reconfiguration for 33-bus radial distribution test system. It can be observed that the magnitude of the power loss of each bus depends on the length of line between the bus and the size of each load bus. It is shown that the longer the line, the greater the power loss. Similarly, from Fig. 3, it is also shown that the greater the load that is served by a bus, the greater the power loss. It can be seen that the presence of DG as many as five units on buses of 12, 17, 22, 25, and 27 has the effects on the power loss reduction over the system, especially on buses closest to the DG.

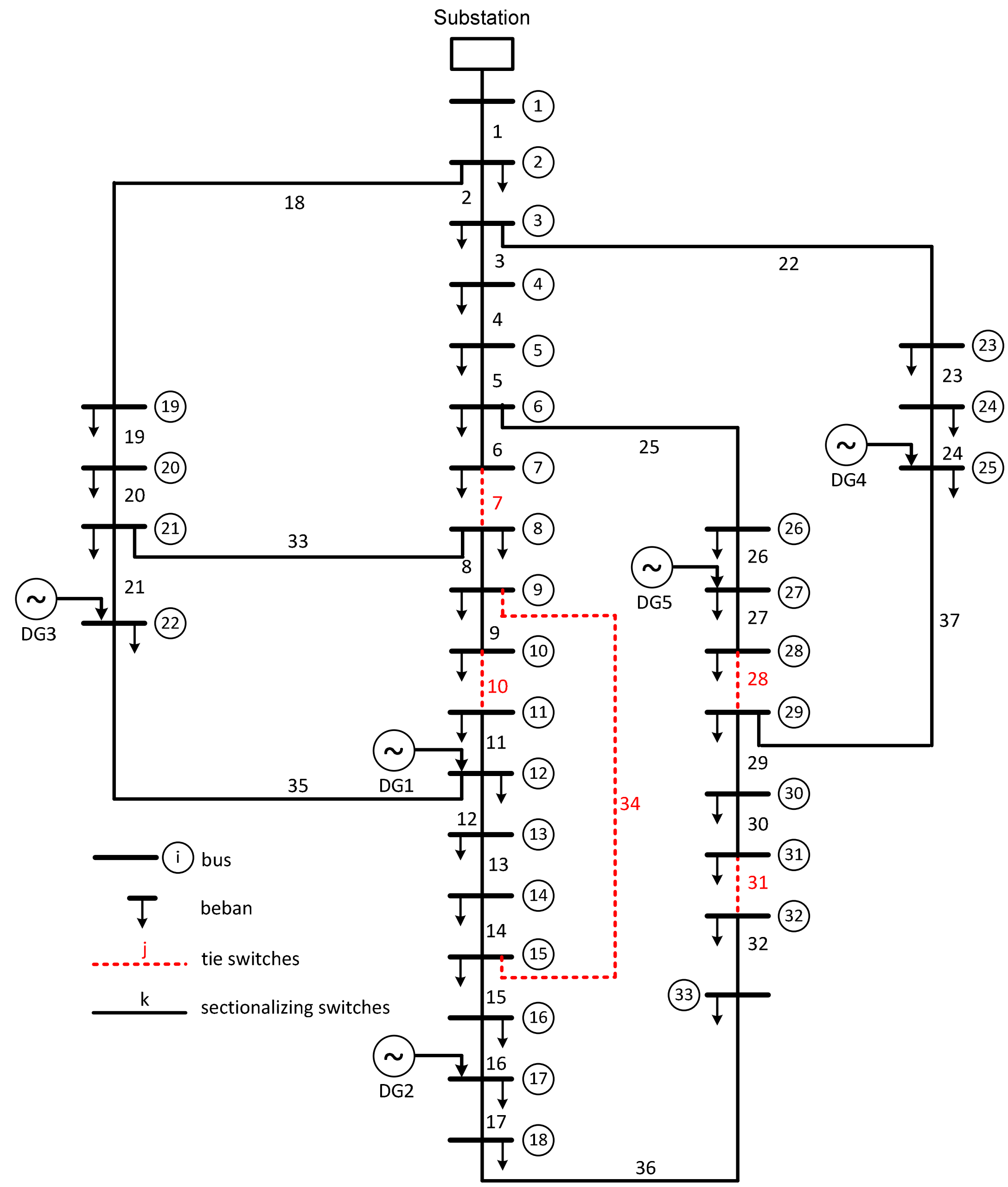

Fig. 4. A 33-bus radial distribution network with integration of 5 DGs after reconfiguration

Before reconfiguration the network as a base case, total active power loss under study is 203.46 kW. Total active power loss after installing as many as five DGs is 133.45 kW, while total active power loss after reconfiguration of network with DG integration is 74.56 kW, as shown in Table 2. From the Table can also be seen that integration of five DGs has resulted in reduction of power loss. Percentage of power loss reduction after installing the DGs is 35.98%, while percentage of power loss after reconfiguration of network with DG integration is 64.23%. These results have proved that the reconfiguration of the network have a considerable influence on the reduction of active power loss in distribution system. Reduction of power loss is certainly improving the efficiency of the distribution network. Table 2 also reported that the efficiency of the distribution network of 33-bus radial system in the original condition is 95.19%. The efficiency has increased to 96.41% after integration of as many as five DGs in the system. After integration of the five DGs, optimization is carried out on the network configuration. The result showed that an increasing in efficiency be a 97.99% after network reconfiguration is achieved.

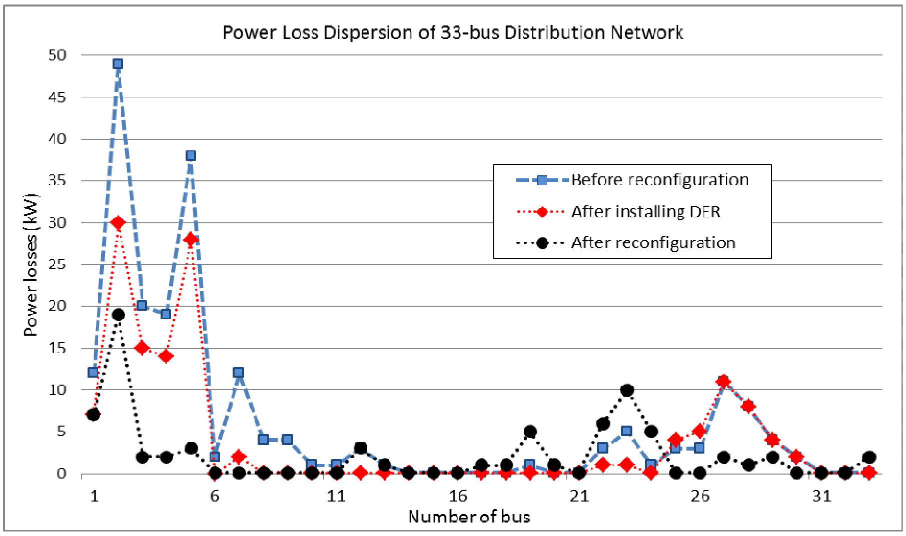

Fig. 5. Power loss dispersion of 33-bus distribution test system

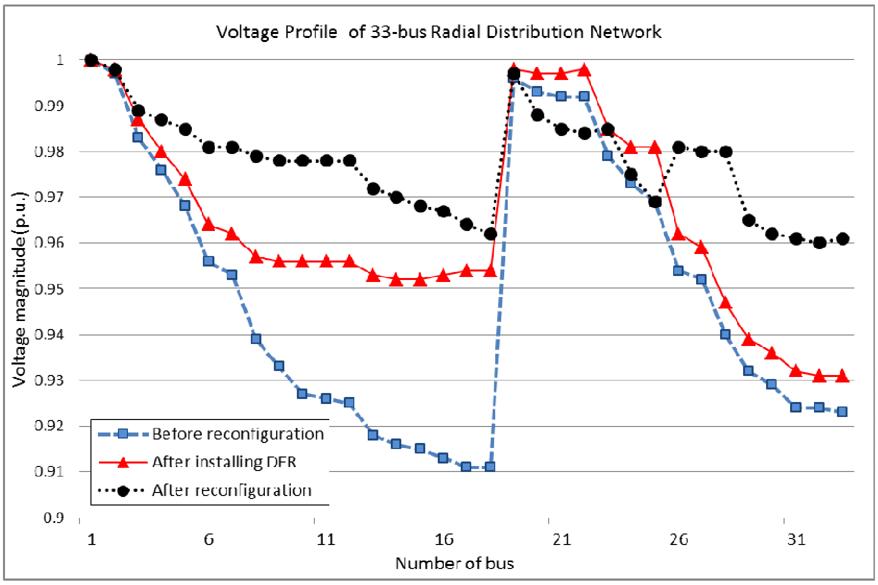

Fig. 6. Voltage profile of 33-bus radial distribution test system

For voltage profile of the network, it is interesting to find that with integration of DG on 33-bus radial distribution network, voltage quality of each bus is improved, as shown in Fig. 6. The voltage quality is to be improved further by doing reconfiguration of distribution network than ever before. It should be noted in the results that only a voltage magnitude along the main feeder of bus is presented. Before reconfiguration the network as a base case, it is resulted that the highest voltage magnitude is 1.00 p.u. on bus 1, while the lowest voltage magnitude is 0.911 p.u. on bus 18, as shown in Fig. 6 and Table 2. In Fig. 5, it can be seen that on the original condition of the network, the farther away from the substation location, the lower the amplitude of the bus's voltage.

Table 2. The Simulation Results of 33-Bus Radial Distribution Network

Test Case of Distribution Network	Parameters of Analysis					
	Active Power Loss (kW)	Percentage of Loss Reduction (%)	Efficiency of Distribution Network (%)	Minimum Voltage (p.u.)	Tie Switches to be Closed	Sectionalizing Switches to be Open
Without DG integration before reconfiguration	203.46	-	95.19	0.911 (V_{18})	NA	NA
With DG integration before reconfiguration	133.45	35.98	96.41	0.931 (V_{33})	NA	NA
With DG integration after reconfiguration	74.56	64.23	97.99	0.960 (V_{32})	33 35 36 37	7 10 28 31

Integration of DG has resulted in increasing of voltage magnitude. After integration of DG on 33-bus distribution network, the highest voltage magnitude is 1.00 p.u. on bus 1, while the lowest voltage magnitude is 0.931 p.u. on bus 33, as shown in Fig. 6 and Table 2. It can be observed from Fig. 4 that integration of DG as many as five units on buses of 12, 17, 22, 25, and 27 has the strong effects on the voltage profile improvement, especially on buses that are closest to the DG. The voltage improvement is occurred almost the entire bus, except for bus 1, because the magnitude of the voltage has reached its maximum limit.

Furthermore, optimization of network configuration using modified PSO algorithm on 33-bus network with DG integration has been demonstrated. The results of the optimization can also be seen in Fig. 6 and Table 2. Here, it can be seen that network reconfiguration using modified PSO has the strong impact of bus's voltage magnitude. After reconfiguration, the highest voltage magnitude is kept 1.00 p.u. on bus 1, while the lowest voltage magnitude is 0.960 p.u. on bus 32. This voltage magnitude is better than the magnitude of the voltage before reconfiguring the network. These results prove that the distribution network reconfiguration with DG integration using modified PSO method has been successful in improving the performance of 33-bus radial distribution system.

3.2 A Test System of 60-Bus Bantul Radial Distribution Network

In the section, the modified PSO algorithm is tested on a practical 60-bus Bantul power distribution system. Bantul is one of the districts in Yogyakarta, Indonesia, which is located in Java islands. The results of optimal reconfiguration of 60-bus 20-kV Bantul radial distribution network with DG integration using the proposed method to minimize active power losses and to improve the voltage quality of the system are presented. The system consists of 3 feeders that are powered by a 60 MVA power transformers, i.e. feeders of 6, 7, and 11. This feeder has 60 buses and 55 sections. The system is shown in Fig. 7. The 60-bus Bantul distribution system consists of 55 sectionalizing switches and 5 tie switches. Tie switches of the system are open in normal conditions while sectionalizing switches are closed in normal conditions. System data and parameters for 60-bus Bantul distribution network can be found in Appendix.

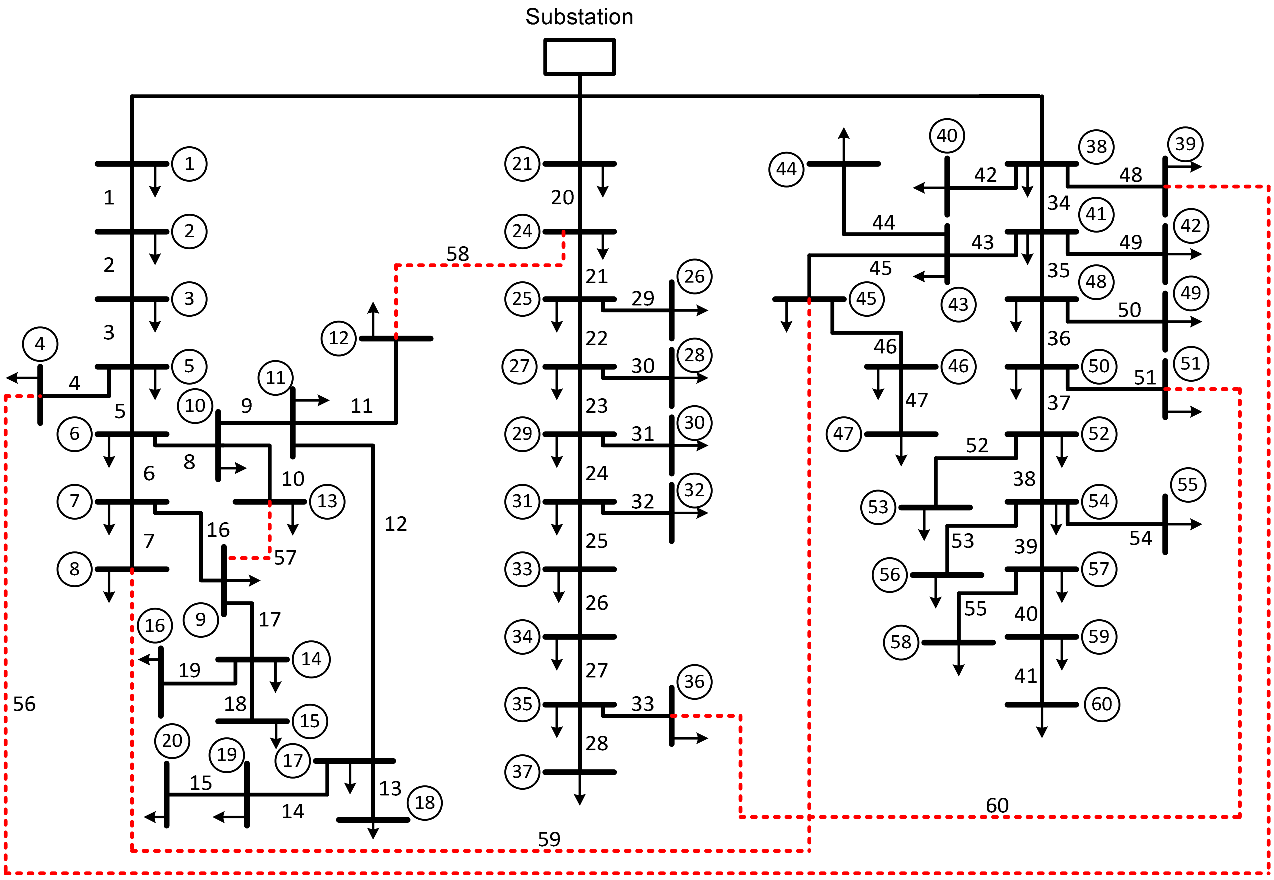

Fig. 7. 60-bus Bantul radial distribution network

Table 3. DG Location and Capacity of 60-Bus Bantul Radial Distribution System

DG Location	Name of DG	Active Power (kW)	Power Factor	Reactive Power (kVAr)
8	DG1	300	1	0
13	DG2	500	0.9	242.16
20	DG3	500	0.8	375
32	DG4	400	0.9	193.73
36	DG5	400	1	0
47	DG6	500	0.9	242.16
59	DG7	500	0.8	375

On 60-bus Bantul distribution network, it has five tie switches, i.e. switches of 56, 57, 58, 59 and 60, respectively. The total load of the distribution system is 26547 kW and the initial power loss of the system is 656.20 kW. The base of the system is nominal voltage system V = 20 kV and transformer reactive power S = 60 MVA. The beginning configuration of the distribution network without DG integration is shown in Fig. 7. We have installed as many as seven DGs, that are consists of solar photovoltaics and wind farms, on buses of 8, 13, 20, 32, 36, 47, and 59, respectively, as can be seen in Fig. 8 and Table 3. In order to analyze the impact of potential DG integration to 60-bus Bantul distribution network, the DG models that have used in our study consist of both solar photovoltaics and wind farms. These two DG types have great potential in the area of Bantul district. In our work, we have assumed that power factor of wind farms are ranging from 0.8 to 0.9 (lagging) while all DG solar photovoltaics are unity.

In this research, we have used the parameters of PSO for configuration optimization of 60-bus Bantul radial distribution system that are consists of population size of 30 and maximum iteration of 1000. The minimum voltage is set at 0.90 while maximum voltage is set at 1.00 p.u. The results of optimization of 60-bus Bantul radial distribution system are shown in Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12 and Table 4. Fig. 8 shows the 60-bus Bantul distribution network with integration of 7 DGs before reconfiguration. Network configuration optimization has resulted that there are four tie switches that must be closed, i.e., switches of 57, 58, 59, and 60, while the sectionalizing switches to be opened are switches of 8, 9, 27, and 43, as can be seen in Fig. 10 and Table 4.

Fig. 9 shows phase of power loss change to iteration change in optimization of 60-bus Bantul distribution network. It can be seen in the figure that in 5th iteration, the power loss is 600 kW. The next iteration is 10th iteration which is resulted in power loss of 576 kW, the 30th iteration resulted in power loss of 526 kW, the 50th iteration generate power loss of 334 kW, the 100th iteration produces power loss of 311 kW, and finally reach the global optimum in the 200th iteration that generates power losses of 293.67 kW.

Fig. 10. 60-bus Bantul distribution network with integration of 7 DGs after reconfiguration. It can be seen that the new tie switches are switches of 8, 9, 27, 43, and 56, respectively. Fig. 11 shows distribution of power loss before reconfiguration, after installing 7 DGs, and after reconfiguration with integration of 7 DGs for 60-bus Bantul radial distribution test system. It can be analyzed that the power loss of each distribution line depends on the length of line between the bus and the size of each load bus. It is shown that the long the line, the greater the power loss. It can also be analyzed from Fig. 11 that the greater the load that is served by a bus the greater in power loss. The presence of DG as many as seven units on buses of 8, 13, 20, 32, 36, 47, and 59 has reducing the power loss of the system, especially on buses closest to the installed DG.

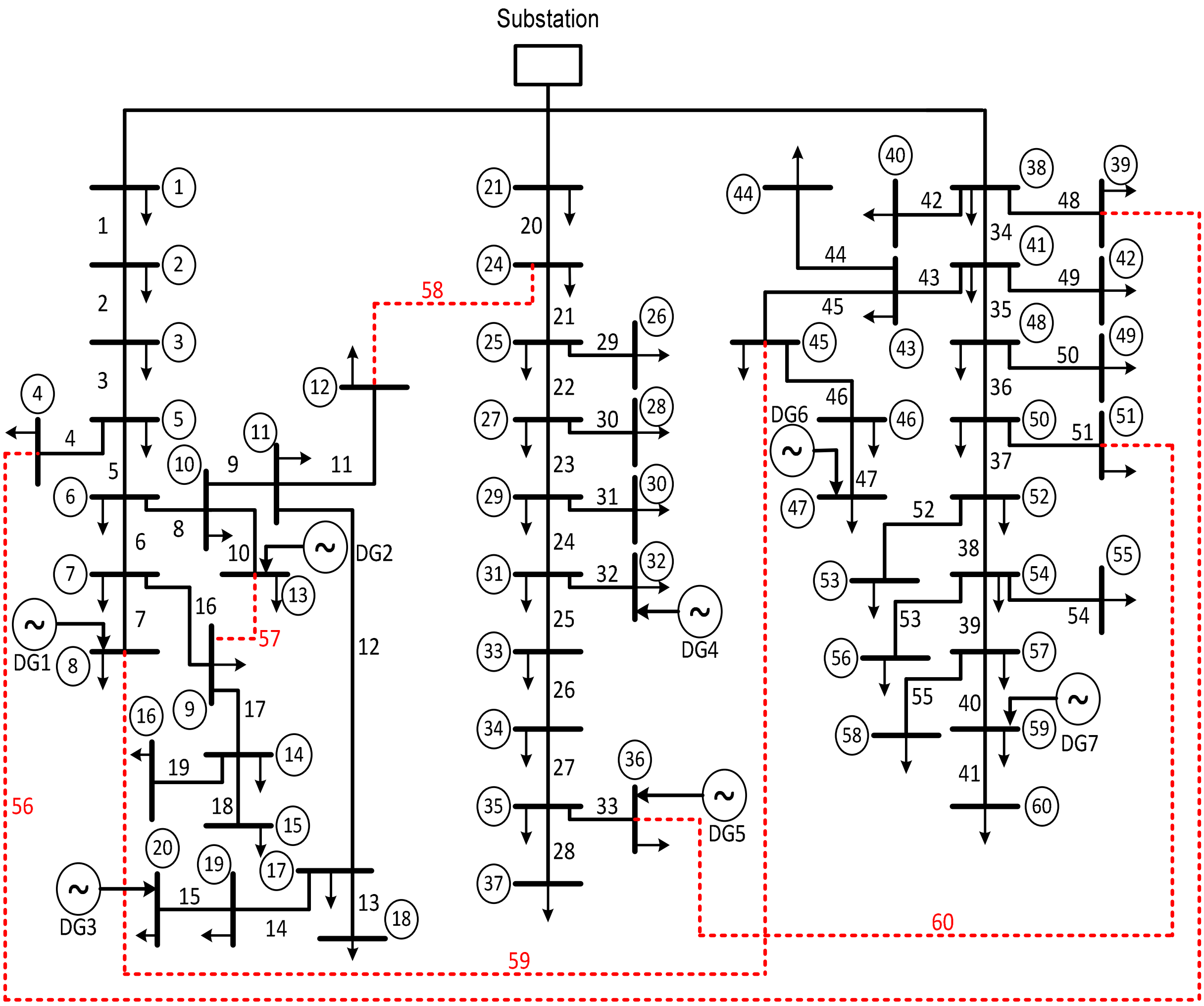

Fig. 8. 60-bus Bantul distribution network with integration of 7 DGs before reconfiguration

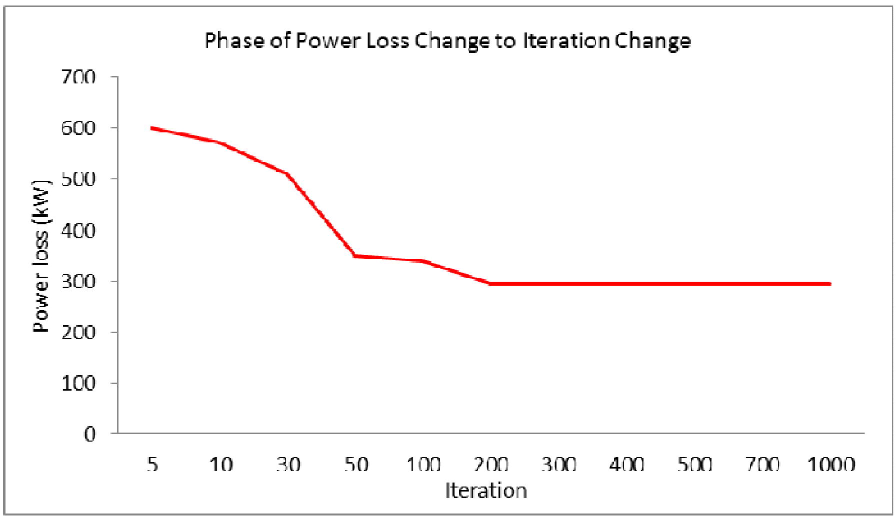

Fig. 9. Phase of power loss change to iteration change in optimization of 60-bus Bantul distribution network

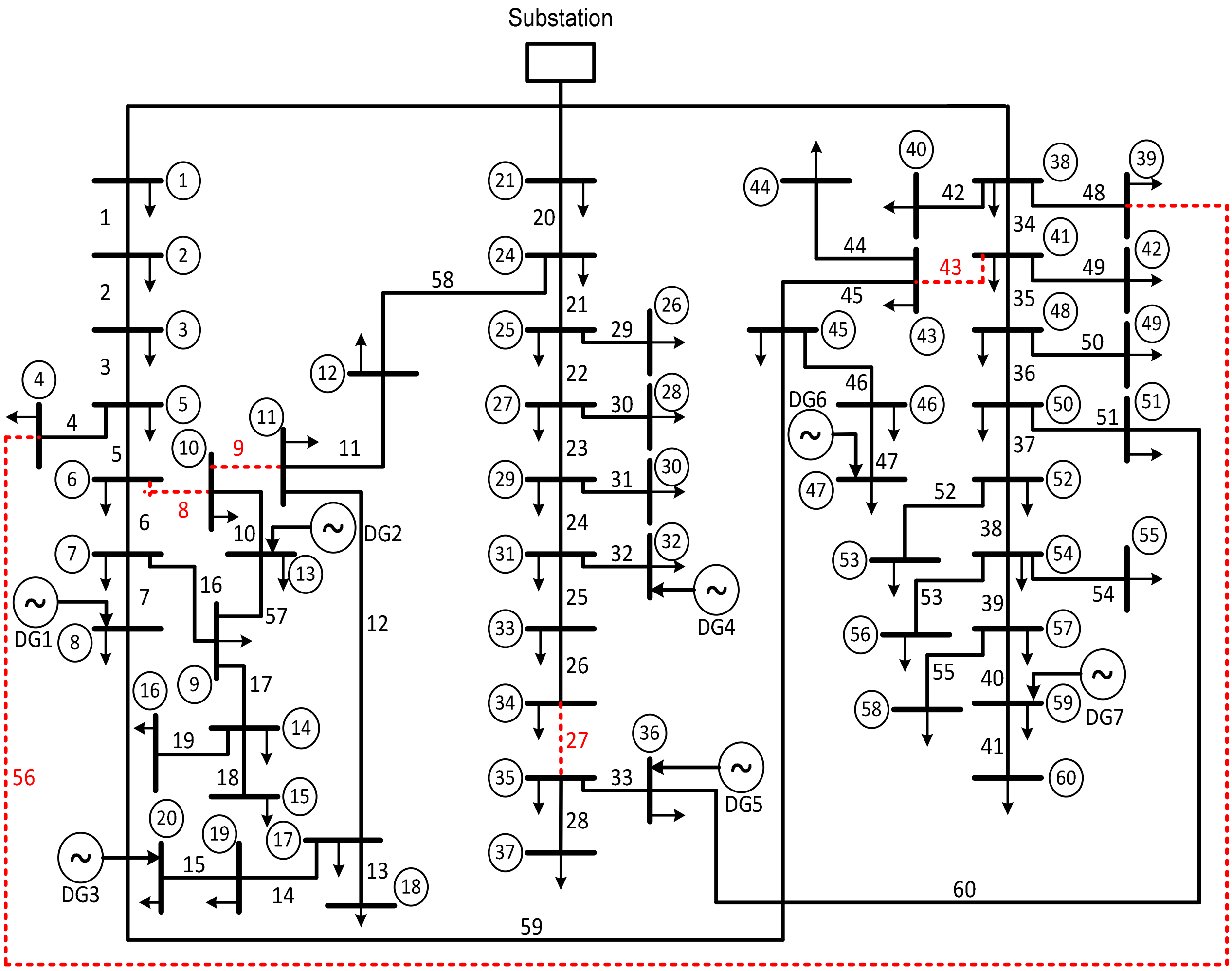

Fig. 10. 60-bus Bantul distribution network with integration of 7 DGs after reconfiguration

In the beginning configuration of 60-bus Bantul distribution network as a base case, the total active power loss is 656.20 kW. After installing as many as five DGs on buses of of 8, 13, 20, 32, 36, 47, and 59, the total active power loss is 475.81 kW while the total active power loss after configuration optimization of network with DG integration is 293.67 kW, as can be seen in Table 4. It can also be seen that integration of the seven DGs has resulted in reduction of power loss in the most of the distribution line. Power loss reduction after installing the DGs is 27.64% in percentage while power loss after configuration optimization of network with DG integration is 55.10% in percentage. These results have proved that the configuration optimization of the network using modified PSO technique have a considerable influence on the reduction of active power loss in the distribution system. Power loss reduction is certainly improving the distribution network efficiency. In Table 4 can also be seen that the distribution network efficiency of 60-bus Bantul radial distribution system in the initial condition is 97.53%. The efficiency has upgraded to 98.20% after integration of seven DGs in the distribution network. After installing of the seven DGs, optimization is carried out on the distribution network configuration. The final result showed that an increasing in efficiency be a 98.89% after reconfiguration has been achieved.

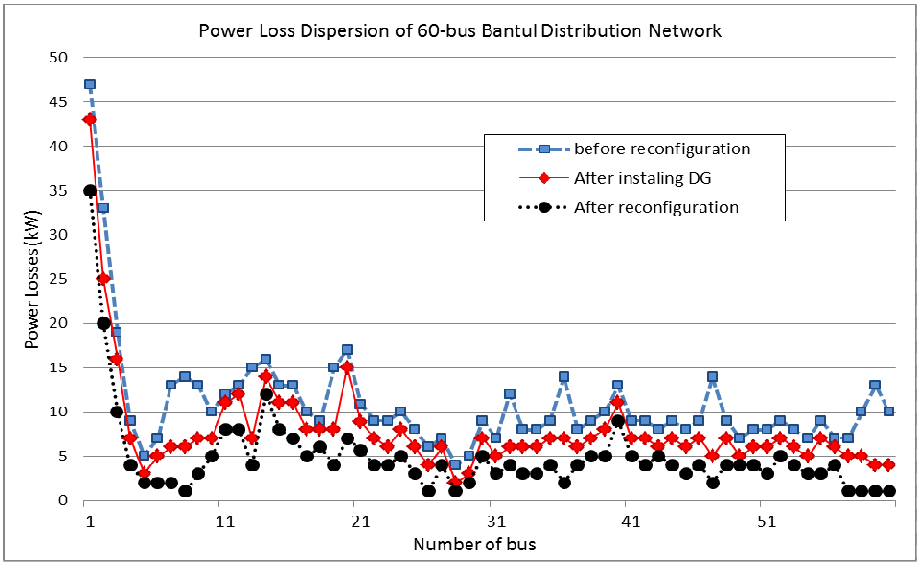

Fig. 11. Power loss dispersion of 60-bus Bantul radial distribution test system

The next discussion is in voltage profile of the distribution network. It is interesting to find that the DG integration on 60-bus Bantul radial distribution network resulting in improving of voltage profile for each bus, as can be seen in Fig. 12. The voltage profile is to be improved further by doing configuration optimization of the radial distribution network than ever before. It should be noted in the results that only a voltage magnitude along the bus main feeder is presented. In the initial configuration the network as a base case, it is resulted that the highest voltage magnitude is 1.00 p.u. on bus 1 while the lowest is 0.910 p.u. on bus 60, as can be seen in Fig. 12 and Table 4. From Fig. 12, It can also be seen that on the initial condition of the network, the farther away from the location of substation, the lower the magnitude of the bus's voltage. Installation of seven DGs has resulted in improving of voltage magnitude. After installation of DG on 60-bus Bantul radial distribution network resulting in the highest voltage magnitude of 1.00 p.u. on bus 1 while the lowest voltage magnitude of 0.935 p.u. on bus 60, as can be seen in Fig. 12 and Table 4. It can be analyzed from Fig. 12 that integration as many as seven DGs on buses of 8, 13, 20, 32, 36, 47, and 59 has the strong effects on the voltage quality improvement, especially on buses that are nearest to the DG. The improvement of voltage is occurred almost the entire bus, except for bus 1, because the voltage magnitude in this bus has reached its maximum limit. Furthermore, configuration optimization of the distribution network using modified PSO algorithm on 60-bus Bantul radial network with integration of seven DGs has been demonstrated, as shown in Fig. 12 and Table 4. It can be seen that optimization configuration of the network using modified PSO has the strong effect of bus's voltage magnitude.

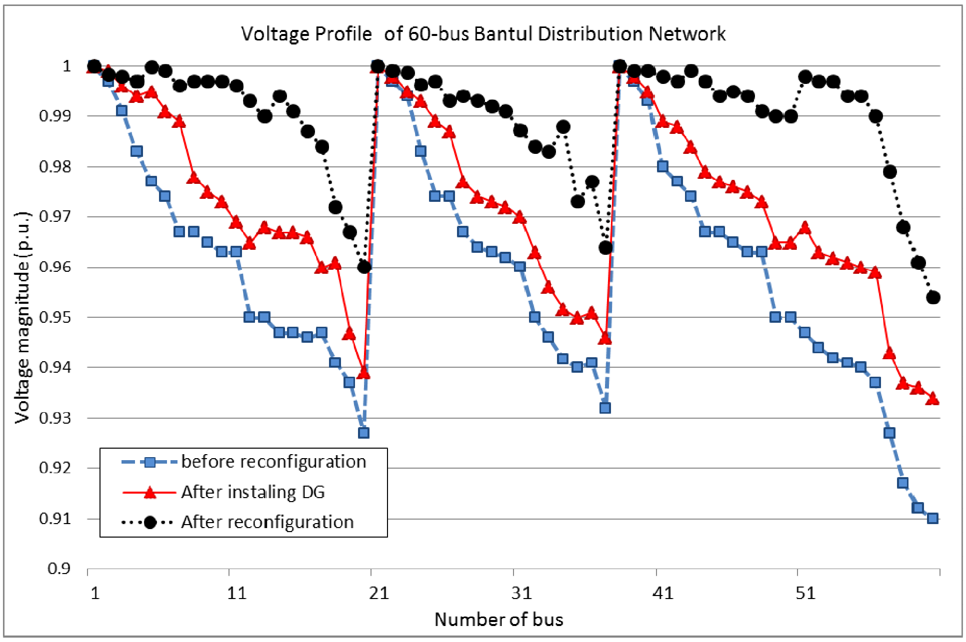

Fig. 12. Voltage profile of 60-bus Bantul radial distribution test system

Table 4. The Simulation Results of 60-Bus Bantul Radial Distribution Network

Test Case of Distribution Network	Parameters of Analysis					
	Active Power Loss (kW)	Percentage of Loss Reduction (%)	Efficiency of Distribution Network (%)	Minimum Voltage (p.u.)	Tie Switches to be Closed	Sectionalizing Switches to be Open
Without DG integration before reconfiguration	656.20	-	97.53	0.910 (V_{60})	NA	NA
With DG integration before reconfiguration	475.81	27.64	98.20	0.935 (V_{60})	NA	NA
With DG integration after reconfiguration	293.67	55.10	98.89	0.953 (V_{60})	57 58 59 60	8 9 27 43

Configuration optimization 60-bus Bantul radial distribution resulting in the highest voltage magnitude is kept 1.00 p.u. on bus 1 while the lowest voltage is 0.953 p.u. on bus 60. This optimization result is better than the result of the voltage before optimization the network. From all of the results prove that the distribution network configuration optimization with integration of DG using modified PSO technique has been successful in improving the efficiency of 60-bus Bantul distribution network. Therefore, the results of this study are expected to be a reference to improve the performance 60-bus Bantul distribution network.

4. Conclusion

The paper proposed a methodology for optimal reconfiguration of radial distribution network with the presence of DG using modified PSO algorithm. The methodology was based on minimizing power losses and improving voltage quality in order to enhance distribution system performance. The methodology was tested on a standard of 33-bus radial distribution network test system and a practical 60-bus radial distribution system of Bantul districts, Indonesia. Based on the numerical results, it was shown that the algorithm is effective in enhancing efficiency of the two test distribution systems. Efficiencies of the 33-bus radial system in the original condition, after integration of five DGs, and after network reconfiguration are 95.19%, 96.41%, and 97.99%, respectively. For a 60-bus Bantul distribution system, the efficiencies in the original condition, after integration of seven DGs, and after network reconfiguration are 97.53%, 98.20%, and 98.89%, respectively. For voltage profile of the network, integration of DG in the two test radial networks has resulted in improved voltage quality. The quality is to be improved further by reconfiguring the networks.

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APPENDIX

System data and parameters for 60-bus Bantul distribution network

Number of Line	Active Power of Load (kW)	Reactive Power of Load (kVAr)	Line Resistance (Ω)	Line Reactance (Ω)
1	270.0	194.9	0.03360	0.12845
2	630.0	454.8	0.18144	0.69363
3	90.0	65.0	0.04032	0.15414
4	279.0	201.4	0.05376	0.20552
5	1368.0	987.6	0.37632	1.43864
6	328.5	237.2	0.10080	0.38535
7	495.0	357.4	0.11424	0.43673
8	382.5	276.1	0.20832	0.79639
9	225.0	162.4	0.17472	0.66794
10	427.5	308.6	0.12096	0.46242
11	585.0	422.3	0.20160	0.77070
12	652.5	471.1	0.10080	0.38535

13	1125.0	812.2	0.28224	1.07898
14	571.5	412.6	0.34272	1.31019
15	0	0.0	0.06720	0.25690
16	1732.5	1250.8	0.32256	1.23312
17	495.0	357.4	0.16800	0.64225
18	450.0	324.9	0.18144	0.69363
19	1012.5	731.0	0.06720	0.25690
20	1057.5	763.5	0.52416	2.00382
21	247.5	178.7	0.16128	0.61656
22	697.5	503.6	0.06720	0.25690
23	180.0	130.0	0.02016	0.07707
24	292.5	211.2	0.06720	0.25690
25	495.0	357.4	0.13440	0.51380
26	2236.5	1614.6	0.45696	1.74692
27	225.0	162.4	0.02688	0.10276
28	2596.5	1874.5	0.23520	0.89915
29	3262.5	2355.4	0.09408	0.35966
30	3028.5	2186.4	0.44352	1.69554
31	90.0	65.0	0.06048	0.23121
32	180.0	130.0	0.17472	0.66794
33	405.0	292.4	0.16800	0.64225
34	1507.5	1088.3	0.30240	1.15605
35	427.5	308.6	0.30240	1.15605
36	1422.0	1026.6	0.66528	2.54331
37	0	0.0	0.01344	0.05138
38	3145.5	2270.9	0.59136	2.26072
39	1404.0	1013.6	0.22848	0.87346
40	630.0	454.8	0.18144	0.69363
41	1215.0	877.2	0.66528	2.54331
42	0	0.0	0.04704	0.17983
43	450.0	324.9	0.29568	1.13036
44	337.5	243.7	0.12096	0.46242
45	67.5	48.7	0.07392	0.28259
46	855.0	617.3	0.65856	2.51762
47	144.0	104.0	0.10752	0.41104
48	0	0.0	0.02016	0.07707
49	1125.0	812.2	0.02016	0.07707
50	549.0	396.3	0.31584	1.20743
51	787.5	568.5	0.16128	0.61656
52	315.0	227.4	0.36288	1.38726
53	1035.0	747.2	0.47712	1.82399
54	1386.0	1000.6	0.28224	1.07898
55	157.5	113.7	0.16800	0.64225
56	787.5	568.5	0.38304	1.46433
57	135.0	97.5	0.10752	0.41104
58	261.0	188.4	0.22176	0.84777
59	1291.5	932.4	0.55776	2.13227
60	1444.5	1042.9	0.21504	0.82208