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PSO Based Multi-objective Optimization for Reconfiguration of Radial Distribution Network

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Abstract

This paper proposed particle swarm optimization (PSO) algorithm based multi-objective optimization for reconfiguration of radial distribution network with the presence of distributed energy resources (DER). The benefits of DER integration in distribution system are reducing power losses, improving voltage profiles and load factors, eliminating system upgrades, and reducing environmental impacts. However, the presence of DER could also cause technical problems in voltage quality and system protection. Reconfiguration of distribution network is aimed to minimize power loss and to improve voltage quality in order to enhance the distribution system performance. In this study, reconfiguration method is based on an improved PSO. The method has been tested in an IEEE model of 33-bus radial distribution network test system. The simulation results show the importance of reconfiguring the network for enhancing the distribution system performance in the presence of DER.

Keywords: distribution network, reconfiguration, efficiency, particle swarm optimization, distributed energy resources.

1. Introduction

Electric power distribution networks are mostly operated in radial configuration. The dynamics of the distribution system operation 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 [1] have become the pioneer in the distribution network reconfiguration effort. 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]–[15]. In [3], the use of genetic algorithm (GA) for distribution network reconfiguration technique to minimize the active power loss has been proposed. Augugliaro et al. [4] and Jeon et al. [5] and have presented simulated annealing techniques in large scale distribution system for active power loss reduction purpose. Mendoza et al. [6] have proposed a new GA based methodology with the fundamental loops for network reconfiguration. Another variant of the GA for distribution network reconfiguration has been proposed in [7]. They have developed a GA method based on the matroid and graph theories. In [8], the use of ant colony optimization (ACO) method for placement of sectionalizing switches in distribution networks has been presented. In [9], 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 [10], 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 [11]–[14], 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 [15]. 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 energy resources (DER) [16-17]. The Government of Indonesia is one country in the world which is committed to utilizing renewable energy sources to generate electricity. The benefits of DER integration in distribution system are reducing power losses, improving voltage profiles and load factors, eliminating system upgrades and reducing environmental impacts [18]–[20]. Integration of DER 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 [21]-[24]. In this paper, an improved PSO algorithm is presented to solve distribution network reconfiguration problem in the presence of DER 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 DER 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 [13]–[14]. The effort is done in order to enhance the distribution system performance.

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:

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

Subject to:

$$F(x) = 0 \tag{2}$$

$$V_{i,\min} \le V_i \le V_{i,\max} \tag{3}$$

$$I_{i,\min} \le I_i \le I_{i,\max} \tag{4}$$

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

2.2. Improved Particle Swarm Optimization

Particle swarm optimization (PSO) algorithm was first published by Eberhart and Kennedy [25]. The algorithm was inspired by a flock of birds movement in searching of food. The movement model can be used as a powerful optimizer. In one n-dimensional search space, let us assume that the position of the i-th individual is Xi = (xi1, ..., xid, ..., xin) and the speed of the i-th individual is Vi = (vi1, ..., vid, ..., vin). The particle best experience i-th is recorded and represented by Pbesti = (pbesti1, ..., pbestid, ..., pbestin). The best global position for swarm search is Gbesti = (gbest1, ..., gbestd, ..., gbestn). The modified velocity of each particle is calculated based on the personal initial velocity, the distance from the personal best position, and the distance from the global best position, as shown in the following equation:

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

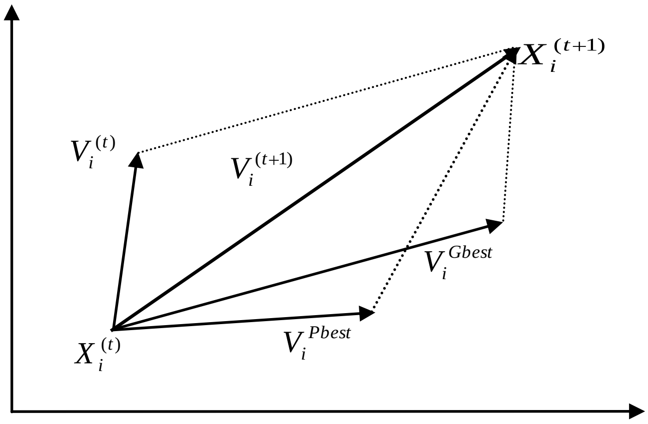

Fig. 1. The concept of optimization using PSO.

Equation (5) determines the velocity vector of the i-th particle. Therefore, the latest position of the particle can be determined by using the equation:

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

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

Inertia weights ω can be determined by the equation:

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

where ω_{max} is the maximum inertia weight; ω_{min} is the minimum inertia weight; t_{max} is the maximum number of iterations; and t is the actual number of iterations. The value of inertia weight decrease linearly from 0.9 to 0.4.

The improved PSO algorithm is described as follows:

1. Input the data of distribution network and initialize the parameters of PSO.
2. Run the program of power 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 Analysis

In this section, the results of optimal reconfiguration of 33-bus 12.66-kV radial distribution network with DER integration using improved 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 [26]. 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 system is V=12.66 kV and S=10 MVA.

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

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

Bus Number	DER Active Power (kW)	DER Power Factor	DER Reactive Power (kVAr)
12	250	0.8	187.50
17	250	0.9	121.08
22	300	1	0
25	400	0.9	193.73
27	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, and Table 2. Network reconfiguration using improved 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 Table 2. Fig. 3 shows power loss dispersion before reconfiguration, after installing DER, 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 DER 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 DER.

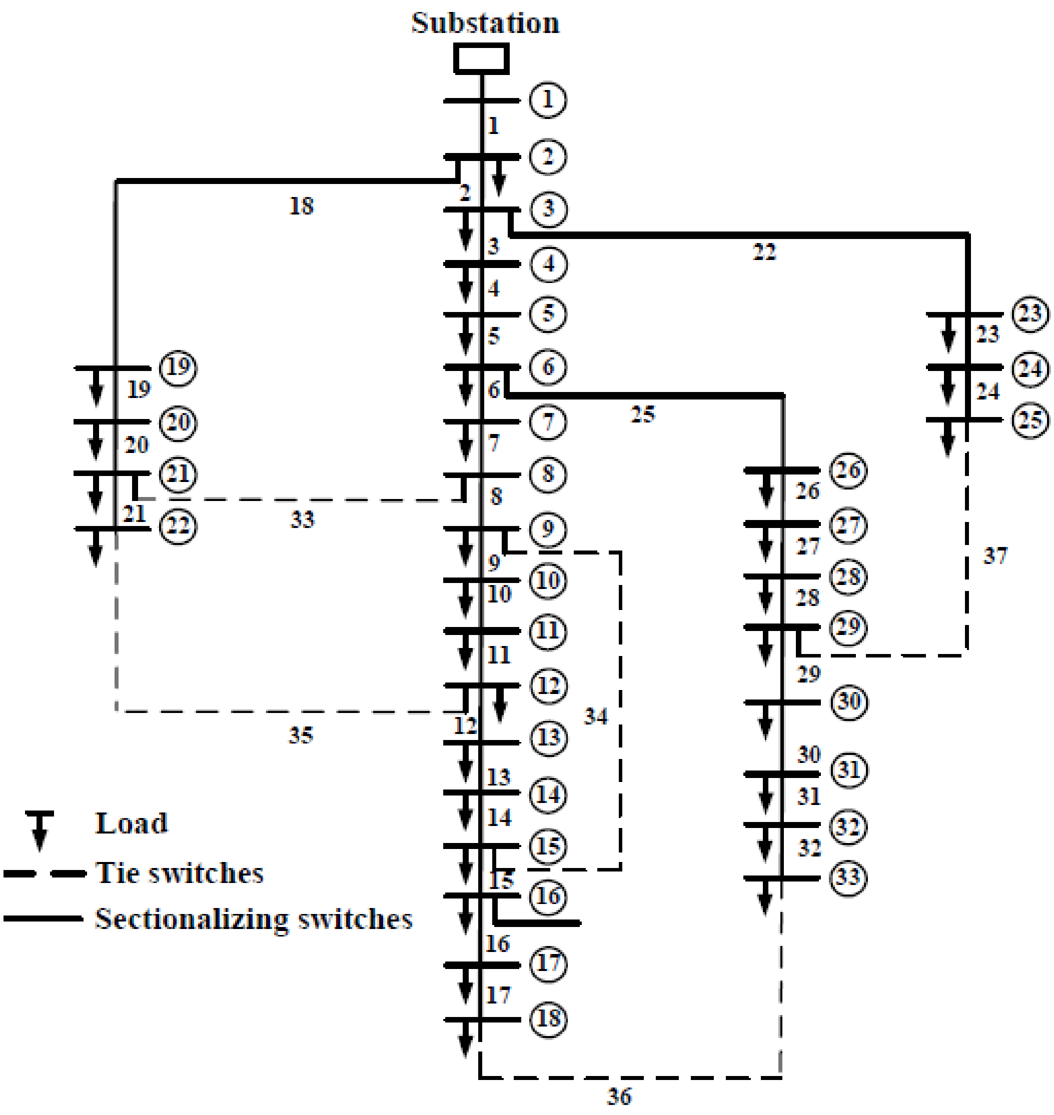

Fig. 2. 33-bus radial distribution network.

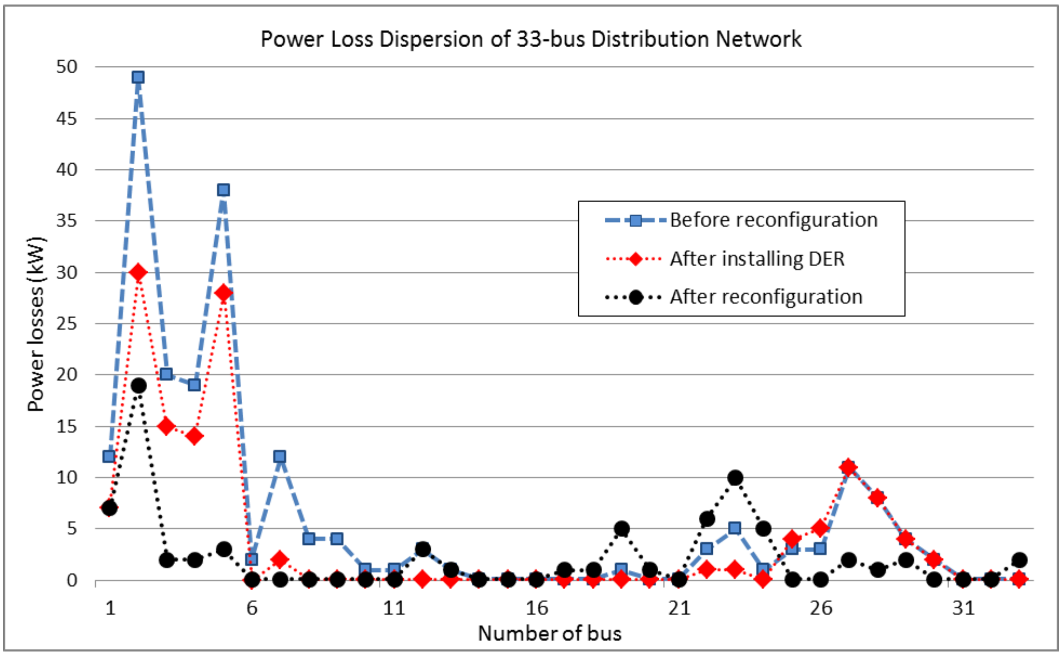

Fig. 3. Power loss dispersion of 33-bus distribution test system.

Before reconfiguration the network as a base case, total active power loss under study is 208.46 kW. Total active power loss after installing as many as five DERs is 133.45 kW, while total active power loss after reconfiguration of network with DER integration is 74.56 kW, as shown in Table 2. From the Table can also be seen that integration of five DERs has resulted in reduction of power loss. Percentage of power loss reduction after installing the DERs 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 94.39%. The efficiency has increased to 96.41% after integration of as many as five DERs in the system. After integration of the five DERs, 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. The IEEE model of 33-bus radial distribution network with integration of 5 DGs after reconfiguration has shown in Fig. 4.

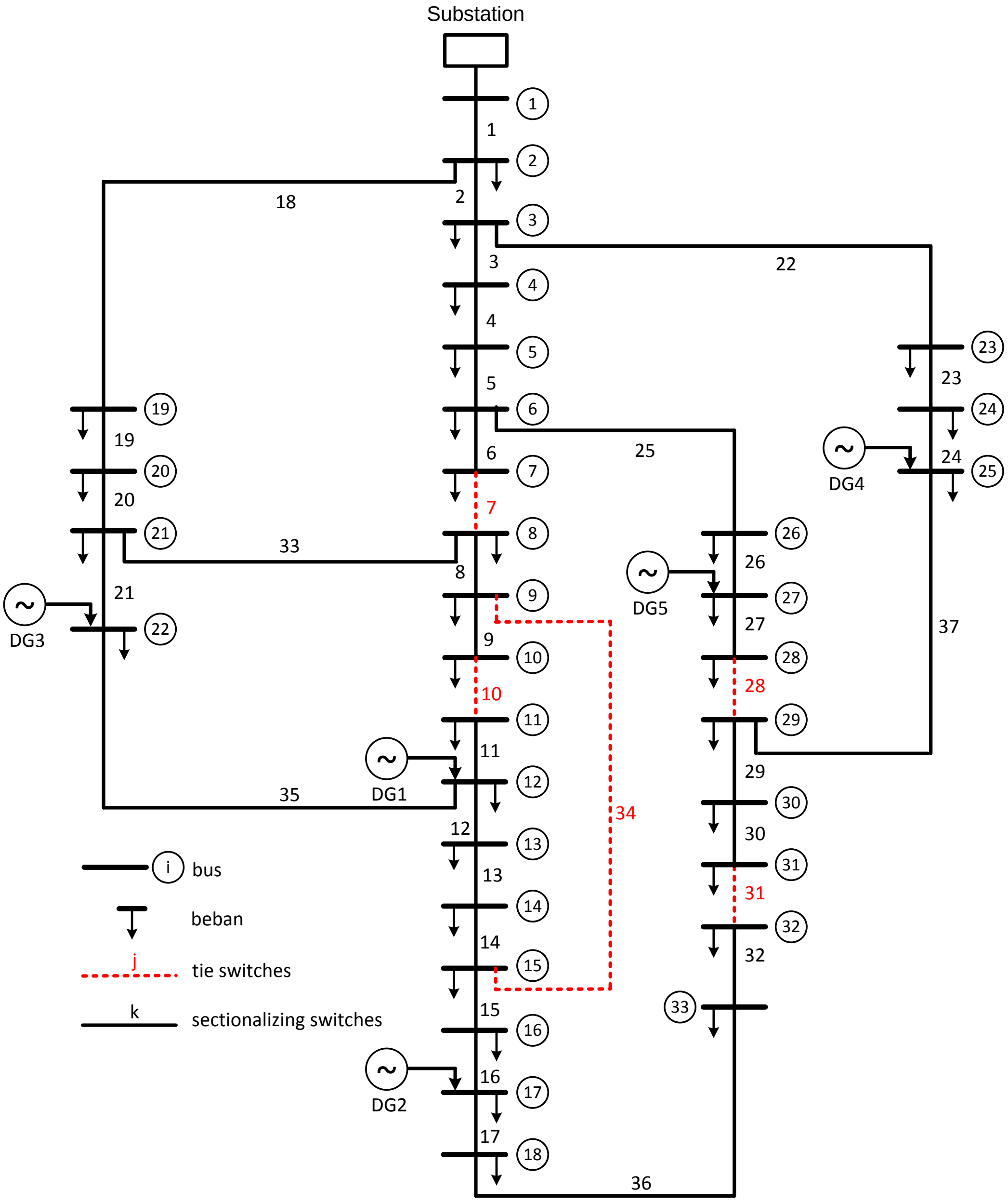

Fig. 4. A 33-bus radial distribution network with integration of 5 DGs after reconfiguration.

For voltage profile of the network, it is interesting to find that with integration of DER in 33-bus radial distribution network, voltage quality of each bus is improved, as shown in Fig. 5. 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. 5 and Table 2. In Fig. 3, 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. Integration of DER has resulted in increasing of voltage magnitude. After integration of DER in 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. 5 and Table 2. It can be observed from Fig. 5 that integration of DER 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 closest to the DER. The voltage improvement is occurred almost the entire bus, except for bus 1, because the magnitude of the voltage has reached its maximum limit.

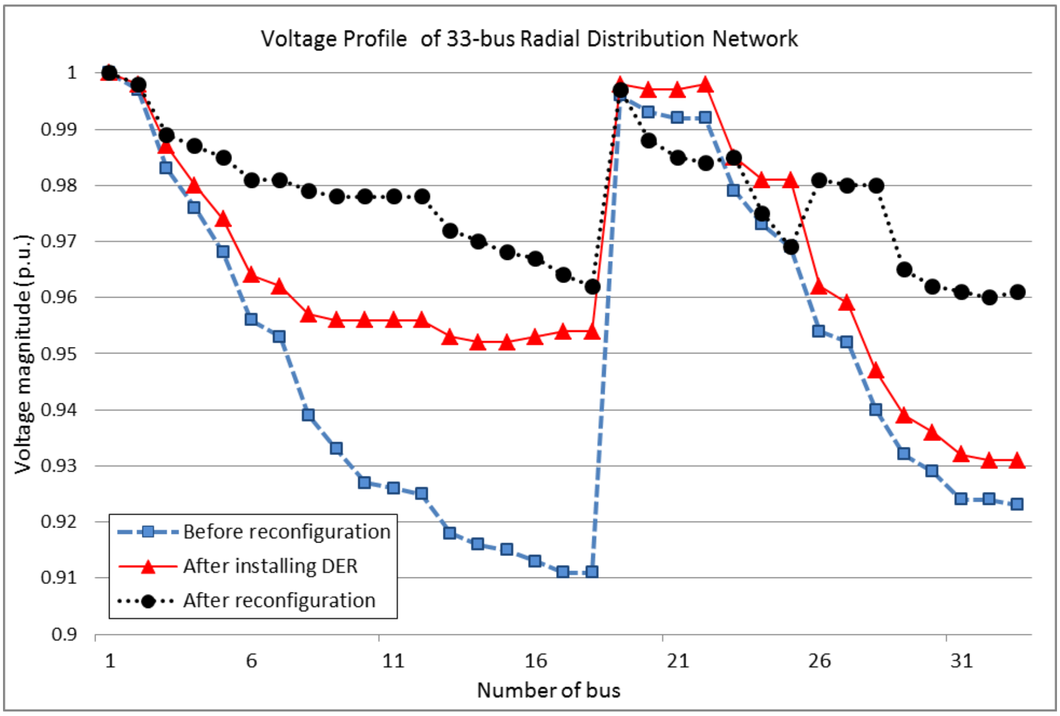

Fig. 5. Voltage profile of 33-bus radial distribution test system.

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.)	Maximum Voltage (p.u.)	Tie Switches to be Closed	Sectionalizing Switches to be Open
Without DER integration before reconfiguration	208.46	-	94.39	0.911 (V_{18})	1.00 (V_1)	NA	NA
With DER integration before reconfiguration	133.45	35.98	96.41	0.931 (V_{33})	1.00 (V_1)	NA	NA
With DER integration after reconfiguration	74.56	64.23	97.99	0.960 (V_{32})	1.00 (V_1)	33 35 36 37	7 10 28 31

Furthermore, optimization of network configuration using improved PSO algorithm on 33-bus network with DER integration has been demonstrated. The results of the optimization can also be seen in Fig. 5 and Table 2. Here, it can be seen that network reconfiguration using improved 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 DER integration using improved PSO method has been successful in improving the performance of 33-bus radial distribution system.

4. Conclusion

The paper proposed a methodology for optimal reconfiguration of radial distribution network with the presence of DER using improved PSO algorithm. The methodology was based on minimizing active power losses and improving voltage quality in order to enhance distribution system performance. The methodology was tested on an IEEE model of 33-bus radial distribution network test system. Based on the numerical results, it was shown that the algorithm is effective in enhancing efficiency of the test distribution systems. Efficiencies of the 33-bus radial system in the original condition, after integration of five DERs, and after network reconfiguration are 94.39%, 96.41%, and 97.99%, respectively. For voltage profile of the network, integration of DER in the test radial networks has resulted in improved voltage quality. The quality is to be improved further by reconfiguring the networks.

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