Chapter 10
Simultaneous Network Reconfiguration and Sizing of Distributed Generation

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Abstract This chapter introduces simultaneous optimization concept of Network Reconfiguration and Distributed Generation sizing. The main objective of the introduced concept is to reduce the real power loss and improve the overall voltage profile in the electric distribution network through optimal network reconfiguration and Distributed Generation sizing, while at the same time satisfy the system operating constraints. The meta-heuristic methods have been applied in the optimization process due to its excellent capability for searching optimal solution in a complex problem. The applied meta-heuristics methods are Genetic Algorithm, Evolutionary Programming, Particle Swarm Optimization, Artificial Bee Colony and their respective modified types. A detail performance analysis is carried out on IEEE 33-bus systems to demonstrate the effectiveness of the proposed concept. Through simultaneous optimization, it was found that power loss reduction is more as compared to conducting reconfiguration or DG sizing approach alone. The test result also indicated that Evolutionary Particle Swarm Optimization produced better result in terms of power loss and voltage profile than other methods.

Keywords Distributed generation · Optimization techniques · Power loss reduction · Reconfiguration · Meta-Heuristic method

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F. Shahnia et al. (eds.), *Electric Distribution Network Planning*,
Power Systems, https://doi.org/10.1007/978-981-10-7056-3_10

10.1 Introduction

The major issues nowadays that most power utilities are trying to achieve in generation, transmission and distribution systems are to ensure high service quality, reliability and efficiency of the overall power system. Distribution system is the final stage in the process of power delivering power from the generation to the individual customer. It has contributed the greatest amount of power loss in which resulted to poor voltage magnitude. The performance of electric distribution networks becomes inefficient due to the increase in power loss and reduction in voltage magnitude especially in the heavily loaded network. The studies in [1, 2] report that 70% of the total losses are occurring in the electric distribution networks while transmission and sub transmission lines account for only 30% of the total losses is as shown in Fig. 10.1.

One of the well-known techniques to minimize power loss is through network reconfiguration [3]. This technique can reduce the power loss and improve the overall voltage profile provided that the most optimum configuration can be determined. The application of network reconfiguration in the electric distribution networks can be divided into two categories; planning and operation. In planning, network reconfiguration is needed to identify the best configuration via changing the on/off sectionalizing and tie-switches in the network. By doing that, the load will transfer from heavily loaded feeders to relatively less heavily loaded feeders, so that the power loss is minimized. Meanwhile, the network reconfiguration during operation plays an important role in the process of rerouting power supply in the network due to a fault. In this context, reconfiguration is required to restore power supply automatically and quickly to un-faulted sections of the system to improve the system reliability. Instantaneous response to the damage system prevents it from propagating allowing as many loads as possible to function. Network reconfiguration requires optimization technique to determine the best combination set of switches to be open. The execution of the process of selection should fulfill the

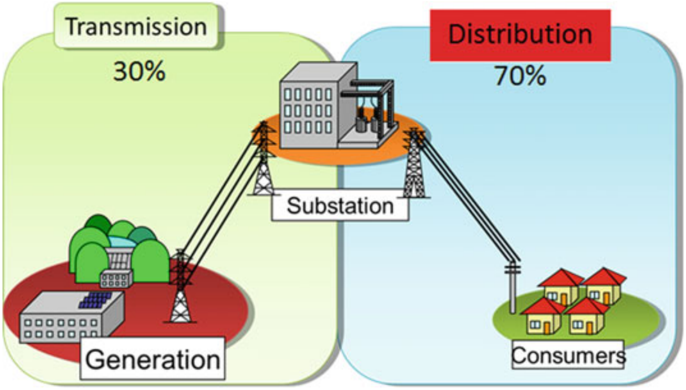


Fig. 10.1 Illustration of a power system delivering power to customers

requirement of optimization (minimize power loss) and satisfying the operating constraints. The application of reconfiguration network is much simpler and cost efficient compared to other techniques. In general, reconfiguration have two primary aim which are to provide the maximum amount of electrical supply to the end customers and reconfigure the network automatically as soon as there are problems arises such as fault.

Another technique that able to reduce power loss is by interconnecting local power supply in electric distribution networks. By having local supply, electrical power can be delivered to the load in a short distance, which able to reduce power loss. Local power supply from renewable energy sources such as mini-hydro, wind, solar and Bio-fuel are nowadays is connected in networks to generate electrical power. In view of this matter, a new identity appeared in the electric distribution networks known as “Distributed Generations” (DG). DG is related to the use of small generating units installed at strategic points on the networks and mainly close to the load centers. It can be used in an isolated way, supplying the consumer’s local demand, or in an integrated way, supplying energy to the remaining system [4]. In general, DG is the generation of electricity by facilities smaller than the central plants, usually 10 MW or less [5].

From studies, DG penetration is predicted will surpass more than 25% of the total generation in the foreseeable future [6]. Studies also revealed that the usage of Renewable Energy DG could reduce 60% of the carbonic pollution from conventional power generation by 2050 [7]. With this regard, changing the environment of power systems design and operation has caused the need to consider active distribution network. The integration of distribution system would lead to the improvement of the voltage profile, load balancing, reliability such as service restoration and increase energy efficiency. Therefore, it is very crucial to ensure that the DG size is at the optimal value to maximize its benefits. An inappropriate size of DG will cause of power loss in the system to be higher than the initial configuration.

Many researchers have employed various methods to overcome the problem of optimal reconfiguration and DG sizing in the electric distribution networks [8–16]. However, the existing methods have some limitations and drawbacks in their solutions such as the solution might trap in the locally optimal solution. This is due to the process of finding the optimum solution used sequential approach (e.g.: find the optimal DG first and followed by optimal reconfiguration or vice versa). Moreover, the reconfiguration is a complicated combinatorial and non-differentiable constrained optimization problem. It involves with many candidate-switching combinations. These obstacles really put the reconfiguration process in difficulties to achieve the comprehensive optimal solution and take too long time to reach the convergence point. Apart from that, the combination switches obtained from their results sometimes is not in radial which is important characteristic in assist finding optimal power loss.

Although there are various methods for network reconfiguration, the DG effect in the network reconfiguration has not been considered widely by researchers. There are very few researchers who considered network reconfiguration with DG [17–19]. Most of them have already fixed the size of DG or solve sequentially and the impact of DG on the distribution system has not been discussed seriously. None of them tried to solve the reconfiguration and DG problem simultaneously.

The installation of DGs in the distribution system indeed can improve energy efficiency and voltage profile, and at the same time minimize power interruption power. However, in order to ensure the effectiveness of DG in the distribution system, selecting the optimal size of DG plays an important role in giving the greatest impact on the operations and control of the electric distribution networks. Thus, the correct size (dispatch value) of DG becomes a vital point for the network system in order to produce a lower amount of power waste. In literature, the term DG size is commonly applied to represents the power dispatch value of the DG. Thus, throughout this chapter, DG size refers to the DG dispatch value.

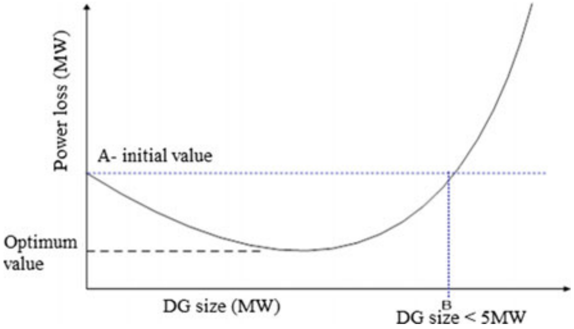
Considering the existing limitations, this chapter introduces simultaneous optimization concept in finding optimal network reconfiguration and DGs size. The meta-heuristics methods used in chapter are Genetic Algorithm (GA), Evolutionary Programming (EP), Particle Swarm Optimization (PSO) and Artificial Bee Colony (ABC). Meanwhile, the modified versions of these methods which contribute greatly to this chapter are Modified Genetic Algorithm (MGA), Evolutionary Particle Swarm Optimization (EPSO), Modified Particle Swarm Optimization (MPSO) and Simplified Artificial Bee Colony (SABC).

10.2 Optimal Network Reconfiguration and Distributed Generation Sizing

Electric distribution network reconfiguration can be seen as a combinatorial optimization problem, comprising distribution system planning, loss minimization and energy restoration. Generally, the network reconfiguration is defined as altering the topological structure of distribution feeders by changing the opened or closed state of sectionalization and tie switches (to transfer load from heavily loaded feeders to relatively less heavily loaded feeders) so that the power loss is minimized and at the same time constraints are met. These two types of switches are designed for both protection and configuration management. It is normally being configured radially for effective coordination of their protective systems. Network is reconfigured to reduce the system power loss (network reconfiguration for power loss reduction), improve the voltage profiles and relieve overloads in the network (network reconfiguration for load balancing) and finally increase energy efficiency of the system. This operation transfers load from one feeder to another, which will significantly improve the operating condition of the overall system. In order to deal with these problems, several methods such as GA [18], PSO [19], EP [20, 21] and ABC [14] have been applied in network reconfiguration.

The existing of DG in the system will allow the network to contribute in supplying the most optimum power to the load. However, selecting the optimal size of DG plays an important role to avoid any drawback to the network. The connection

Fig. 10.2 Power loss dependence on DG size [22]



of high capacity and excess number of DG units to electrical power system will lead to very high power loss [22]. When DG is accessed to the distribution network, it can be simplified into 3 different scenarios: in scenario-1, the loads at each bus are all greater than power generation of each DG. In scenario-2, the total loads are greater than the total power generation of DG, while in scenario-3, the total loads are less than the total power generation of DG. For scenario-1, DG's access can reduce the power loss of all lines. However, in scenario-2, DGs access may increase the power loss of some lines, but the total power loss reduces. Meanwhile, in scenario-3, if the total power generation is less than two times of the total loading, the influence is the same as the scenario-2, or DGs access will increase the power loss. However, if the total power generation is in a high proportion of the system, it will bring down the power quality.

There is a tendency for losses to follow the U-shape trajectory as shown in Fig. 10.2 [22]. Specifically, losses begin to decrease when connecting small amounts of DG size until they achieve their minimum level. If the DG increases then losses begin to rise. Thus, it is worth pointing out that at high DG sizes, losses can become larger than those without DG connected. In this chapter, the DG size varies from 0 to 5 MW. According to the U-Shape when the DG size is larger than the B point value, the power loss in the system has become larger than A, which is the initial value. This factor makes the optimal size of DG become an important consideration for the network to have lower power loss value. Thus, it can be seen that DGs access may reduce or increase the power loss depends on the size of DG and the network structure. The use of the reconfiguration method in cooperating with the DG units with appropriate size can help the system to have a much lower power loss in the distribution system.

10.3 Problem Formulation

Reconfiguration techniques in the distribution network will change the direction of power flow throughout the network. In this chapter, the main objective for doing the reconfiguration is to obtain the minimum active power loss in the system based on active current formulation. Therefore, the objective function is:

$$\text{Minimise}\left\{P_{losses} = \sum_{l=1}^{n} I_l|^2 k_l R_l\right\} \tag{10.1}$$

where:

I Number of lines in the system.
I_I Line real active current.
R_I Line resistance.
k_I is the variable that represents the topology status of the branches (1 = close, 0 = open).

The technical constraints that must be considered for the reconfiguration optimization are:

(a) Distributed Generator operation:

$$p_i^{\min} \le p_{dg,i} \le p_i^{\max} \tag{10.2}$$

where P_i^{min} and P_i^{max} are the lower and upper bound of DG output and all DG units shall function within the acceptable limit.

(b) Power injection:

$$\sum_{i=1}^{k} P_{DG} < (P_{Load} + P_{Losses}), \quad k = no.\ of\ DG \tag{10.3}$$

In order to avoid problem in protection setting, extra power from DG units are not allowed to be injected into the main grid (Substation). At all time the total power output from DG units should be less than the total load demand in the electric distribution network. Thus, there will be a power supply from the main grid to the network at all time.

(c) Power balance:

$$\sum_{i=1}^{k} P_{DG} + P_{Substation} = P_{Load} + P_{Losses} \tag{10.4}$$

The sum of power generated from DG units and power from substation must be equal to the summation of power load and power loss. This is to comply with the principle of equilibrium in power generation and load demand concept.

(d) Voltage bus:

$$V_{\min} \leq V_{bus} \leq V_{\max} \tag{10.5}$$

The voltage for each bus should operate within the acceptable limit which is in between 1.05 and 0.95 (±5% of rated value).

(e) Radial configuration:
The radiality of the network should be maintained throughout the reconfiguration process. In order to ensure radial network is maintained, a set of rules has been adopted for selections of switches [23].

a. All switches that do not belong to any loop are to be closed state.
b. All switches connected to the sources are to be closed state.
c. All switches contributed to a meshed network need to be closed state.

For the implementation of the optimization methods, the variable used for tie switches represented by *S* and as for *DG* size is represented by P_{Dg}. The proposed chromosome or particle can be written as

$$X_{im} = \left[S_1, S_2, \ldots, S_N, p_{Dg,1}, p_{Dg,2}, \ldots, p_{Dg,k}\right] \tag{10.6}$$

where i = 1,2,3…m. The variable m indicates the population size from a set of random distributions. N = number of tie switches and k = numbers of DG. If the method only to find the optimum value of DG that can minimize the power loss, the chromosome or particle can be written as

$$X_{im} = \left[p_{Dg,1}, p_{Dg,2}, \ldots, p_{Dg,k}\right] \tag{10.7}$$

10.4 Description of Modified Meta-Heuristic Methods

In this chapter, besides applying conventional GA [18], EP [20], PSO [23] and ABC [24] methods, its modified version have been applied as well. The modification of each method is summarized in Table 10.1. Details description on the modification can be found in the respective reference.

Table 10.1 Modification of meta-heuristic methods

Method	Modification from the conventional method
Modified Genetic Algorithm (MGA) [18]	Basically, the steps involved in MGA are mostly similar to GA steps except a slight difference in the mutation process. The chromosomes which consist of tie-switches and DG size are represented in real coded compared to binary coded as represented in conventional method in order to increase the efficiency and reduce the computational time. Too long string or chromosome will increase the time consuming in the searching space for the optimum especially when the system operates in the larger and more complex system. The advantage of MGA is the acceleration in the searching speed because the encoding and decoding process is not needed as required in binary-coded. Furthermore, it is a simple design tool to treat complex constraints because the method is close to problem spaces
Evolutionary Particle Swarm Optimization (EPSO) [19]	EPSO is developed based on merging two methods PSO and EP. EPSO is proposed to improve and enhance the convergence speed of conventional PSO. The proposed EPSO undergoes the similar steps as the traditional PSO accept selection process part where EP employs a selection through the tournament scheme to choose the survivals for the next generation. Three steps involved are as – Combination old and new position – sort the population based on fitness value – select the best element from the survival particle (lower value) With these the particles can move quickly to the optimal point compared to the conventional PSO
Modified Particle Swarm Optimization (MPSO) [23]	Generally, the steps involved in MPSO are almost similar to conventional PSO. However, the quality and efficiency of the current PSO has been slightly modified. A new parameter (bold) is inserted into the original PSO Equation as shown below; $V_j^{k+1} = \omega \times V_j^k + C_1 \times rand_1 \times \left(P_{bestj}^k - X_j^k\right) + C_2 \times rand_2 \times \left(G_{best}^k - X_j^k\right) + \boldsymbol{C_3 rand_3} \times \left(\boldsymbol{B_{best}^k} - \boldsymbol{X_j^k}\right)$ The purpose of the additional new parameter is to avoid the fitness value being trapped in local optima and increasing the exploration capability of particles in the search space. Therefore, the exploration and exploitation capability of MPSO is improved and provide the best solution quality and consistent results near to the global optimum
Simplified Artificial Bee Colony (SABC) [24]	The operation of the SABC is nearly similar to the original ABC. A slight modification in term of the searching for new food sources procedure has been implied on this simplified mode. A new and better concept of changing information between the bees in the population is applied. The following equations show a new searching area that is used by Employed and Onlooker Bees in the SABC algorithm $B_{i,rand(D)} = SW_{rand(N),rand(D)}$ where B_i is presenting the new searching location by *it* bees in the current iteration and SW is the switches. Therefore, the new switches that need to be opened in next iteration are: $SW^{new} = f\left(SW^{old}\left(B_{i,rand(D)}\right)\right)$ The implementation of B_i in the SABC will avoid the unacceptable switch number appeared during the reconfiguration process compared to original ABC

10.5 Implementation of the Proposed Concept

From the base system, five different scenarios are formed to analyze the robustness and efficiency of the proposed concept based on different meta-heuristic methods (GA, EP, PSO, ABC, MGA, EPSO, MPSO and SABC). The lists of each scenario are as

- scenario-1: Original network as a base scenario
- scenario-2: Optimal network reconfiguration
- scenario-3: Optimal DG sizing
- scenario-4: Optimal reconfiguration and DG sizing based on Sequential approach
- scenario-5: Optimal reconfiguration and DG sizing based on Simultaneous approach.

The parameter used in the simulation of each algorithm depends on the characteristics of the method used. However, the basic data of the network such as bus data and line data shall be the same for all the methods. The initialization population is determined by selecting tie switches from the set of the original tie switches as well as the DG size. Those variables are generated randomly by the program and it is utilized to compute the power loss in the next step. The number of population is 50 and the maximum number iteration is set 100 which is applied and used in all the proposed algorithms. The minimum and maximum voltages are set between 0.95 and 1.05 pu respectively. The simulation process will stop once the results achieve maximum number of iteration or convergence level. All the tests and simulations developed in this work are conducted on a Personal Computer with processor Intel Core Duo CPU 3.07 GHz.

The flow chart of the reconfiguration process is illustrated in the Fig. 10.3. The range of the DG size varies between 0 and 5 MW which is based on the literature review [25] where most researchers use similar networks in their work.

The following steps can be used to develop programming codes to apply the proposed simultaneously optimal network reconfiguration and DG sizing.

Step 1 Randomize N number of switches and DG output. Check either the random number fulfils all the constraints. If *yes* then save the opened switches and DG output. *Else* delete and re-randomize the new output.

Step 2 Evaluate the fitness functions $(f\ (x))$ for successful population: $f(x)$ = Power loss (Eq. (10.1)).

Step 3 Change the tie switches and sectionalizing switches through simulation process according to the proposed methods respectively (GA, EP, PSO, ABC, MGA, EPSO, MPSO and SABC).

Step 4 Evaluate the new fitness function (load flow analysis) and check the radiality of the output through Graph Theory.

Step 5 Check the stopping criteria, if the iteration number > iter max or all population give the similar values and then stops. Otherwise go to *Step 3*.

Step 6 Show the optimal results. End.

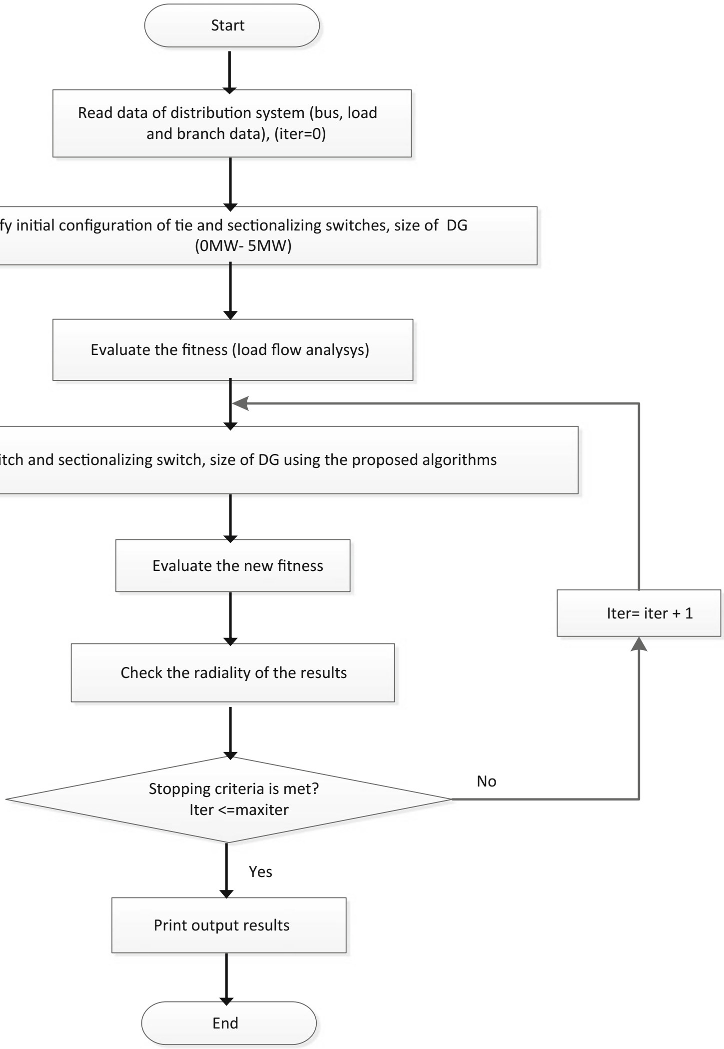


Fig. 10.3 Flowchart of network reconfiguration process

10.6 Test Results of 33-Bus System

The initial test network of the 33-bus system is shown in Fig. 10.4. The overall information of 33-bus distribution network is given in Appendix A.1.2. The network consists of 33 buses, 38 lines, 5 tie switches represented by dotted lines and 3 branches (excluding the main branch). The total load of the system is 3715 kW and 2300 kVar. In scenario-3, scenario-4 and scenario-5, three DGs unit have been installed and placed at bus number 6, 16 and 25 [26, 27] respectively.

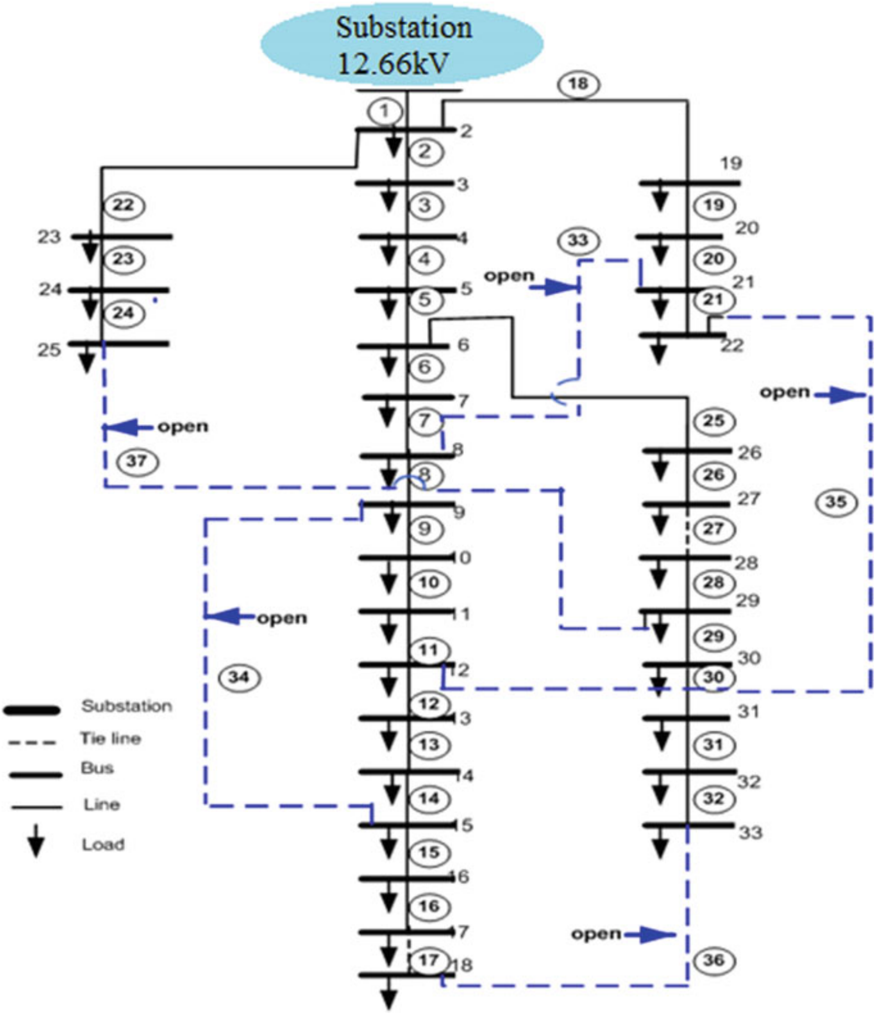


Fig. 10.4 Initial configuration of the 33-bus radial distribution system

As mentioned in the previous section, the analysis of reconfiguration involves the network with and without DG units. In the scenario of a network with DG, the optimal size of DG units is obtained from the simulation in which both parameters DG size and the opened switches are adjusted during simulation simultaneously. The size of each DG is set within the limits of the DG capacity. For example, in this chapter, the range is set between 0 and 5 MW. The capacity depends on the type of DG such as medium distribution generation 5 < 50 MW and large distributed generation 50 < 300 MW [28].

In this chapter, the DG location is assumed to be based on its suitability of geographical location or any optimal location methods [20, 29]. Tie switch and sectionalizing switch are considered as the main control variables. Since the process of randomization at each iteration produces different results, there is a need to do simulation repeated for several times in order to get the best results. Thus in this scenario, the simulation is conducted for 30 times. The value which appears the same for many times shall be chosen and assumed to be the best results. The result obtained consist of the opened switches, total power loss and optimal DG sizing are shown as in Eq. (10.6). However, the number of elements in particle or chromosome depends on how many tie-switch and DG used in the system. Then, the network after reconfiguration shows the new opened switches which have produced the lowest power loss.

10.6.1 Impact of Network Reconfiguration and DG Sizing on Power Losses

From the analysis conducted on the simulation, the results are discussed in details. At the initial stage (scenario-1), the network of 33-bus system is run without the presence of reconfiguration and DG. The network has given the initial total power loss of 202.3 kW through five initial open switches of 33, 34, 35, 36 and 37 for all methods used. With regard to Table 10.2 in scenario-2, reconfiguration is employed in the network of 33-bus system. The impact of reconfiguration of the power loss reduction can be observed for all methods. The total power loss has been improved by 34.5% for MGA, MPSO, and EPSO whenever the network reconfiguration is applied. However, there is a slight difference in SABC method where the power loss are improved about 32.77%.

Meanwhile, in scenario-3 the network of 33-bus system is operated using DG which is placed on bus number 6, 16 and 25. The impacts of the DG presence are then analyzed. The results obtained show greater power loss as compared to scenario-2. The total power loss has been reduced between 61.9 and 66.5%. In scenario-4, operation conducted involving both reconfiguration and DG has taken place. However, reconfiguration process is only done upon obtaining the right size of DG. In other word, both techniques are run sequentially. The results obtained reveal even greater power loss reduction as compared to scenario-2 and scenario-3. Thus, the presence of DG in the reconfiguration process has indeed caused the reduction of power loss.

The network condition of scenario-5 is almost identical to scenario-4 except that this time both reconfiguration and DG are being applied simultaneously. In other words, the switches that will open and the size of DG are determined

Table 10.2 The overall performance of simulation results of the 33-bus distribution system

Scenario	Method	Opened switches	Power loss (MW)	Loss reduction (%)	DG size (MW)		
					6	16	25
scenario-2	GA	6, 10, 14, 17, 28	136.5	32.53	–	–	–
	PSO	7, 10, 28, 14, 32	136.4	32.58	–	–	–
	EP	16, 5, 10, 25, 13	135.2	33.17	–	–	–
	ABC	7, 9, 14, 32, 37	139.5	31.04	–	–	–
	MGA	6, 9, 13, 17, 25	132.5	34.50	–	–	–
	EPSO	7, 10, 13, 16, 25	130.5	35.49	–	–	–
	MPSO	7, 10, 28, 14, 34	132.43	34.54	–	–	–
	SABC	6, 9, 14, 31, 37	136.0	32.77	–	–	–
scenario-3	GA	33, 34, 35, 36, 37	110.6	45.33	1.4107	0.902	0.5061
	PSO	33, 34, 35, 36, 37	109.6	45.82	1.0038	0.9004	0.5167
	EP	33, 34, 35, 36, 37	106	47.60	0.7315	0.7224	1.0270
	ABC	33, 34, 35, 36, 37	110.5	45.38	0.7540	0.5300	1.5004
	MGA	33, 34, 35, 36, 37	104.0	48.59	1.0190	0.9120	0.5061
	EPSO	33, 34, 35, 36, 37	102.5	49.33	0.7310	0.6564	1.1560
	MPSO	33, 34, 35, 36, 37	109.2	46.02	1.1488	0.9023	0.5167
	SABC	33, 34, 35, 36, 37	109.5	45.87	0.7740	0.5310	1.5004
scenario-4	GA	7, 8, 10, 16, 28	112.0	44.64	1.041	0.905	0.7001
	PSO	7, 10, 14, 28, 32	93.5	53.78	1.0439	0.9061	0.7012
	EP	7, 9, 34, 36, 37	99.4	50.87	1.0499	0.9098	0.7099
	ABC	11, 20, 24, 32, 34	129.7	35.89	1.3004	0.53	0.7054
	MGA	7, 9, 28, 36, 37	99.5	50.82	1.048	0.907	0.7001
	EPSO	7, 9, 33, 36, 37	94.2	53.44	1.1127	0.918	0.729
	MPSO	7, 10,14, 28, 32	97.1	52.00	1.0489	0.9118	0.7312
	SABC	11, 20, 24, 32, 34	101.6	49.78	1.2604	0.531	0.774

(continued)

Table 10.2 (continued)

Scenario	Method	Opened switches	Power loss (MW)	Loss reduction (%)	DG size (MW)		
					6	16	25
scenario-5	GA	7, 10, 14, 28, 30	100.9	50.12	1.1490	0.9427	0.6332
	PSO	7, 9, 14, 28, 32	92.3	54.37	1.1523	0.9545	0.6312
	EP	7, 10, 12, 16, 28	94.1	53.48	1.1519	0.9378	0.6680
	ABC	11, 20, 31, 34, 37	103.9	48.64	1.133	0.9510	0.6220
	MGA	7, 10, 12, 16, 28	96.88	52.11	1.1519	0.9335	0.6678
	EPSO	6, 10, 13, 16, 28	89.4	55.81	1.1590	0.9747	0.6632
	MPSO	7, 9, 14, 28, 32	92.46	54.30	1.1733	0.9651	0.6363
	SABC	11, 20, 31, 34, 37	97.5	51.80	1.1019	0.7575	0.7780

simultaneously during simulation. The results for the network of 33-bus system show the greatest improvement on power loss reduction between 31.4 and 51.8%. The performance of the test of power loss for scenario-5 of the proposed methods is depicted in Fig. 10.5. From the results obtained in scenario-5, the SABC is observed to generate highest improvement which is 6.19% as compared to the original method. This is then followed by EPSO (4.89%), MGA (3.9%) and MPSO (2.97%). However, in overall results, EPSO still maintain as the method which produces the lowest power loss due to the changing of switch during the simulation process and injection of the active power by the DG simultaneously.

After reconfiguration, the optimal sizes of DG of each method have also been altered as illustrated in Table 10.3. With reference to scenario-5, three DG are installed at different locations which have been fixed earlier. Once the program is run, the sizes of DG will vary automatically between the predetermined ranges until it reaches the optimal values. This can be seen from the Table 10.2 which shows that the optimum DG size is different of each method. SABC produced the smallest size of DG which is 2.6374 MW followed by MGA 2.7532 MW. While for MPSO and EPSO are 2.7747 and 2.7969 MW respectively. If the total size of DG is in a high proportion of the total load system, it will bring down the power quality. The analysis indicates that the maximum energy saving is achieved when the DG size is placed at bus no. 6, 16 and 25 as shown on the diagram. However, the total size of DG of each method is still within the range.

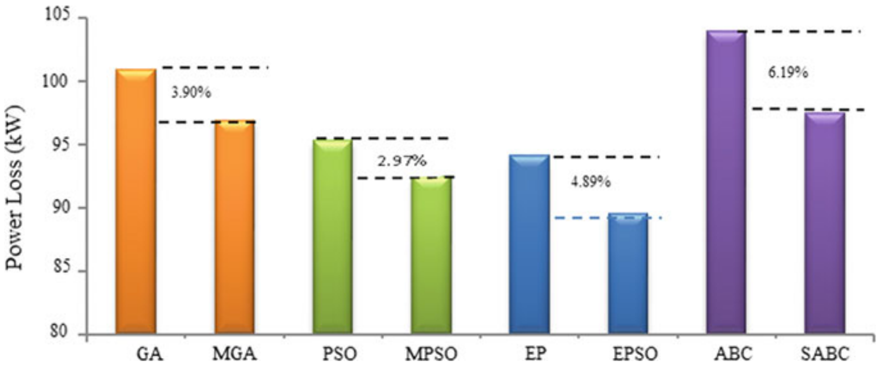


Fig. 10.5 Power losses improvement using the proposed algorithms (scenario-5)

Table 10.3 The performance of the proposed method based on optimal DG sizing

Method	DG size (MW)—scenario-5			Total size of DG (MW)
	6	16	25	
MGA	1.1519	0.9335	0.6678	2.7532
EPSO	1.1590	0.9747	0.6632	2.7969
MPSO	1.1733	0.9651	0.6363	2.7747
SABC	1.1019	0.7575	0.7780	2.6374

Table 10.4 Comparisons of performance of the proposed methods (scenario-5)

30 run times	Power loss (kW)			
	MGA	MPSO	EPSO	SABC
Min solution	96.8	92.4	89.4	97.5
Max solution	98.9	99.8	96.1	99.7
Average	97.4	94.37	92.24	98.3
Standard deviation	0.0009	0.00297	0.00211	0.00107
No. of iteration	35	21	13	30
CPU time (s)	29.4	16.1	12.8	21.5
Original method (s)	GA—60	PSO—28.1	EP—16.8	ABC—44.5

Meanwhile, Table 10.4 shows the comparisons of the performance of the proposed method after 30 runs of the 33-bus distribution system. Every repeated process (run times) was initialized with random new combination switch and DG size, thus the robustness and efficiency of the algorithm in finding the minimum power loss can be evaluated.

From the analysis of the results, the minimum solution or the best output achieved by EPSO is 89.494 kW. However, the maximum solution which indicates the unfavorable value is produced by MPSO and SABC which are 99.8 and 99.7 kW respectively. MPSO gives the highest standard deviation with 0.00297 among others. Nevertheless, the percentage of differences between the ‘min solution’ and ‘max solution’ of each method is 2.12% until 7.42%, which gives the smallest standard deviation as compared to the original method.

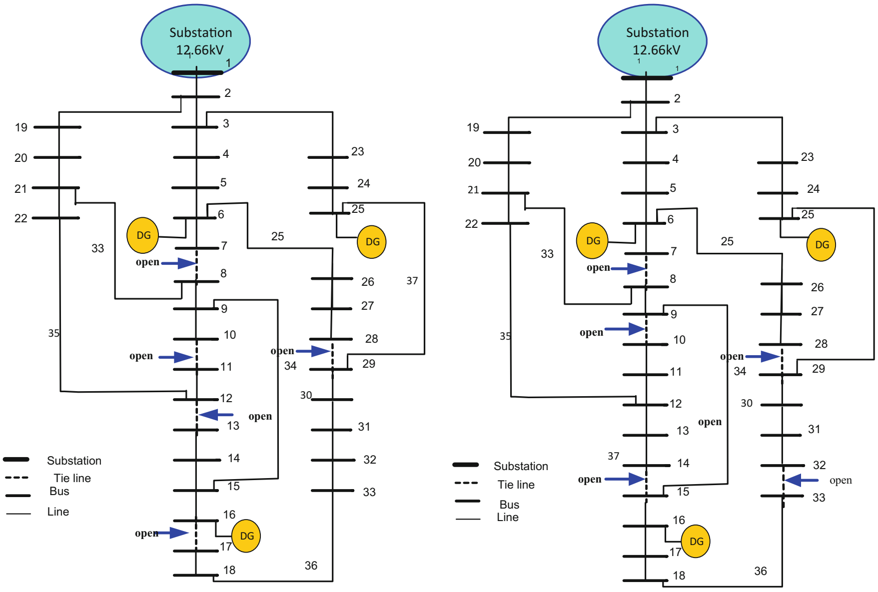
The analysis of this scenario has proven the simultaneous presence of reconfiguration and DG together yields a much better rate of power loss because the new set of switches has been rearranged to create a new configuration system plus the optimal size of DG. Thus, the new network reconfiguration with DGs of 33-bus system operated on simultaneously basis is illustrated in Fig. 10.6.

Meanwhile, the maximum number of iterations to reach the optimal value is 35 iterations for MGA, 30 iterations for SABC. Meanwhile MPSO need 21 iterations and only 13 iterations of the EPSO to reach the optimal point. EPSO method takes only 13 iterations which need 12.8 s to converge while MGA method shows the longest computing time of 29.4 s compared to other methods. This is due to the reason that MGA requires more steps before converging. It means the highest number of iterations, the longer the computing time

The convergence curve summarizes the capability and efficiency of each method and the speed of the algorithm in reaching the optimal point. Figure 10.7 shows the convergence characteristics of the proposed method of 33-bus system. With the updated technique, the value of power loss is improved until the best solution is reached. From the observation, the EPSO is the fastest (13 iterations) algorithm to reach the optimal solution followed by MPSO, MGA and SABC.

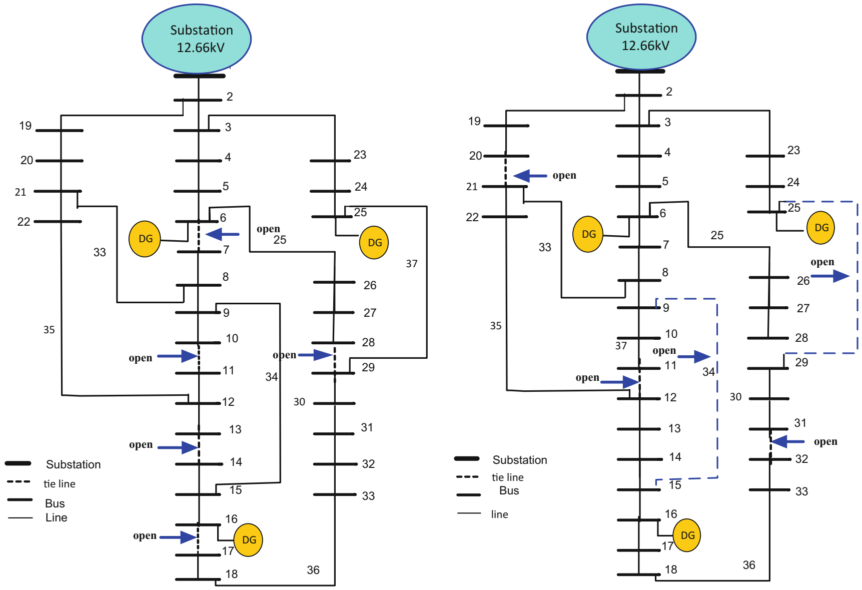
10.6.2 Impact of Network Reconfiguration and DG Sizing on Voltage Profile

The impact on the voltage profile for scenario-5 using the proposed method is depicted in Fig. 10.8. By observing the results, it can be concluded that the voltage profile has been improved and the average bus voltages have reached 0.950 pu as compared to the base scenario which is 0.9131 pu In scenario 5, the system which is operated with reconfiguration and DG simultaneously, the voltage profile of the system has been improved considerably with a minimum node voltage of 0.977692 pu at point 33 of MPSO method and 0.97698 pu at point 33 of SABC method. The improvement is about 7.07%. While the minimum node voltage for MGA and EPSO occurs at the same point which is 0.985983 pu



(a) MGA - 7, 10, 12, 16, 28

(b) MPSO - 7, 9, 14, 28, 32



(c) EPSO - 6, 10, 13, 16, 28

(d) SABC - 11, 20, 31, 34, 37

Fig. 10.6 Network Reconfiguration and DG size simultaneously using **a** MGA, **b** MPSO, **c** EPSO and **d** SABC (scenario-5)

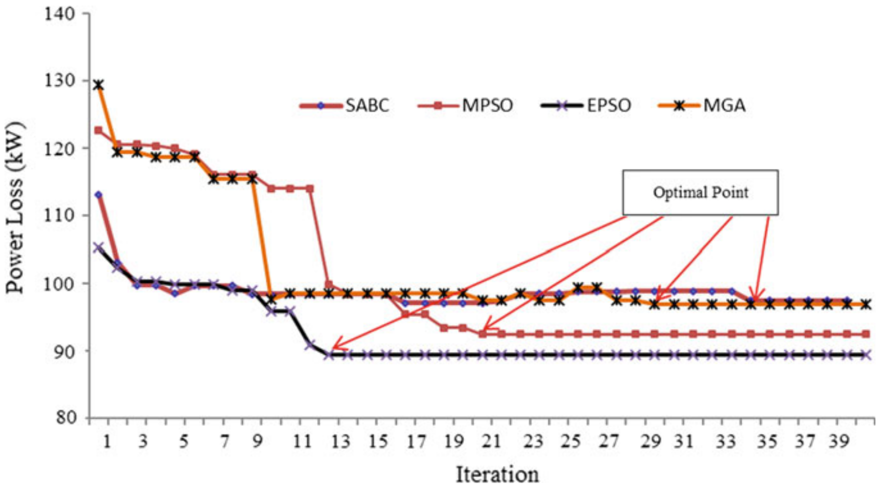


Fig. 10.7 Convergence characteristics of the SABC, MPSO, MGA and EPSO algorithms

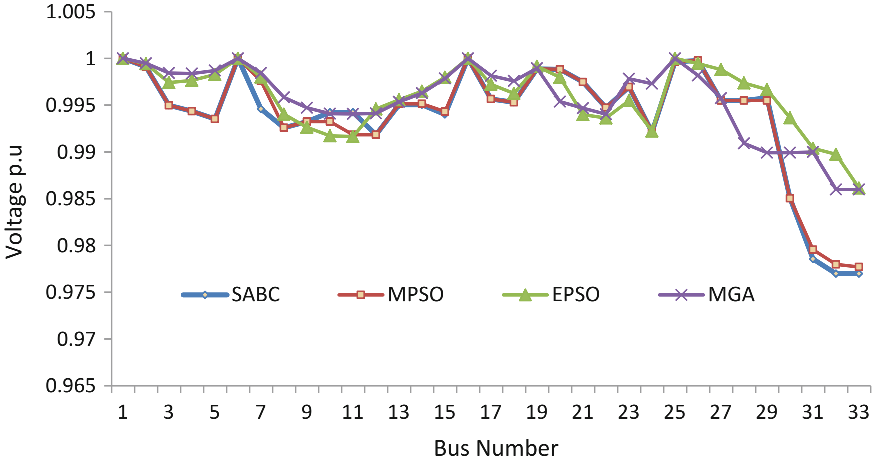


Fig. 10.8 Performance of the voltage profile of the proposed methods

Generally, the voltage profile shows slight differences among the methods accept at point 33. Therefore, the implementation of reconfiguration technique and DG has given better voltage profile compared to without reconfiguration and DG. The voltage profile has been improved more effectively whenever the reconfiguration and DG in the system is operated simultaneously where all bus voltages satisfy the 0.95 pu voltage constraints and near to 1 pu

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