



Sine Cosine Algorithm for Optimal Placement and Sizing of Distributed Generation in Radial Distribution Network

S. Ang, U. Leeton^{*}, K. Chayakulkeeree, and T. Kulworawanichpong

Abstract— Distributed generation (DG) is widely preferred in distribution networks due to its potential solution for loss mitigation and voltage profile improvement. To find the optimal location and size of DGs in the distribution system are the purposes of this research paper. Newton-Raphson power flow method is used to solve the power flow in the system. In this paper, the overall active power loss minimization in the system is the objective functions. The optimal location and size of DGs are obtained by sine cosine algorithm (SCA). The proposed algorithm was tested with 15, 33, 69 and 85 buses radial distribution networks considering single and multiple DG units in the system. Furthermore, the obtained results of the proposed method were compared with those obtained by methods in order to show the performance and effectiveness. The solutions with minimum power losses were achieved by the proposed method compared to the other three methods.

Keywords— Distributed generation, optimization, radial distribution system, sine cosine algorithm.

1. INTRODUCTION

In an electrical power system, there are three divisions which are a generation, transmission, and distribution. Distribution section is more important, since it is connected closely to the customers. It is the part which the voltage is stepped down from medium voltage to low voltage for consumer's utilization. Hence, the reliability of the system is mainly ensured by an efficient distribution system [1]. With increasing demand and network expansion, it has been causing the challenging for the engineers to maintain the quality and reliability of the system economically and effectively [2]. When the heavy load is connected to the system, the voltage magnitude is dropped and the system loss is also increased. In this 21st century, the electrical power supply should be able to meet customer's requirement. Based on the research, distribution has been contributed approximately 70% of the loss including primary and secondary part; hence, distribution has been considered as the main concern nowadays. In these regards, the system operation design and on-site power generation have been considered in order to deal with the problems. DG which also defined as a dispersed generation, or embedded generation is a modernized technology of power generation in this modern century in smart distribution system technology; moreover, DG is given the definition as on-site small scale power generations which are interconnected or connected directly to distribution network [3]. It can be grid connected or stand alone electrical generation units which locate near the utilization site. In addition, DG refers to electrical power production near to consumer location integrating

with renewable and non-renewable energy resources [4] as shown in Fig. 1. Mostly, it is not required the transmission lines in order to connect DG to the delivery system [5], [6]. The integration of DG in distribution network can reduce the system loss and improve voltage profile effectively [7].

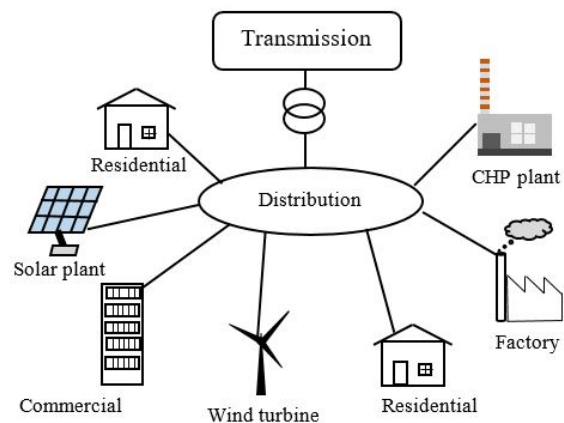


Fig.1. Diagram of DGs in distribution system.

The trends of renewable energy consumption in the smart grid distribution have been increasing due to the environmental concern and fossil energy depletion. DG is becoming the important part of the electrical power grid development in the future since the presence of DG in distribution can improve the reliability, reduce power loss, enhance power quality, deduct transmission investment cost, and mitigate greenhouse gases emission. In regarding of DG application, there are several important factors to consider such as, the DG technology, the number and capacity of DG, the type of DG connection, etc. In fact, the integration of DG in distribution network has impacts to the system voltage and power control. To avoid and solve these issues, DG

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should have placed in the most appropriate location, and the size and number of DG accessed also are the great importance to consider. Otherwise, non-optimal location and size of DG can cause to increase system losses, voltage fluctuation, voltage flicker, protection failure, harmonic, system instability, and ineffective investment cost [8].

Optimization is the mathematical tools used to obtain the optimal solution of the objective function. Since the optimal power flow has been proposed by French scholar in 1962s [9], it has taken over decades to develop the more efficient algorithm to solve optimization problems which can be linear or non-linear. Many methods have been applied to solve optimization problems up to now. It is grouped as conventional and intelligent methods. The well-known conventional methods are newton method [10], gradient method [11], linear programming [12], quadratic programming [13], and Interior point method [14] have been widely used. These methods are preferred for fast calculation and online computation. On the other hand, these methods are not suitable for some optimization problems with discrete variables due to their difficulties to reach the convergence and global solution. Due to continuously developed technology in last decade, many novel intelligent techniques have been developed for dealing with complex problems. Those recently intelligent methods include genetic algorithm [15], particle swarm optimization [16], artificial bee colony (ABC) [17], whale optimization algorithm (WOA) [18]. Heuristic search algorithm likes GA was considered as the most suitable for solving simultaneous multi-dimensional problems for global optimum solution. Furthermore, GA can reach convergence easily and it has complex encoding and decoding operation. PSO is a heuristic method which bases on the behaviour of swarms of fish, bird, etc. has better convergence than GA due to its combination of social psychology principle and better calculation to enhance the behaviour of the swarms. ABC which was proposed by Karaboga in 2005 has been recognized as the most efficient and novel swarm intelligent technique. It is based on the intelligent behaviour of the honeybee to find the nectar sources. Moreover, ABC was successfully applied to solve all kinds of optimization problems, so it has better performance to numerical optimization than GA and PSO.

The earlier optimizations developed are population based stochastic algorithms. Some novel well-known algorithms for single objective problems are moth-flame optimizer (MFO) [19], bat algorithm (BA) [20], ant colony optimization (ACO) [21], cuckoo search (CS) [22], mine blast algorithm (MBA) [23], krill herd (KH) [24], interior search algorithm (ISA) [25], etc. However, these algorithms have limited capabilities to handle uncertainties [26], local minima [27], misleading global solutions [28], better constraints handling [29], etc. Emerging algorithms have been proposed to overcome these difficulties. SCA is a most recent optimization algorithm which was presented in 2016 by Seyadlali [30]. It is new stochastic optimization algorithm which based its update roles on the sine and cosine functions.

There are various methods which have been proposed

to solve optimization of DG application in the distribution system. Prakash and Khatod presented the analytical method in optimal location and size of DG in radial distribution network [31]. The multi-objective function was used to reach all the objectives including optimal location and size of DG, loss reduction, voltage profile improvement, and DG installation cost using various AIs (PSO, GA, and GSA) was presented in [32]. Uniya and Kumar made a comparison between sensitive based and optimization based approach to figure out the most appropriate bus for DG installation, while GA and PSO were applied for the comparative purpose [33]. [2] used PSO to find both location and size of DG in IEEE 16 bus system. Application of Hereford ranch algorithm (HRA) was applied to find location and capacity of DG [34]. A new algorithm which is a combination of GA and PSO was presented in [35] in solving optimization of DG in the system. ABC was proposed to determine the optimal size and location of DG with considering power factor at unity, 0.95, and 0.85 [36]. [1] developed WOA to solve DG optimization considering the different type of DG and comparing with voltage sensitivity index. To the best knowledge of authors, SCA has not been used in literature in determining optimal placement and size of DG in the radial distribution networks.

This paper illustrates the application and performance of SCA in optimal location and size of DG in the distribution network. Four radial distribution networks of 15, 33, 69 and 85 buses were tested with the proposed algorithm. This paper is organized into 6 sections. The more description of DG is detailed in next section and the problem formulation of which objective function involves minimization of active power loss minimization and system constraints are described in section 3. Section 4 provides the brief description of the SCA algorithm applied to solve the problems. The algorithm procedure of working by flow chart step-by-step is described. The simulation result and discussion are placed in Section 5. Finally, the conclusion of the paper is included in Section 6.

2. DISTRIBUTED GENERATION OVERVIEW

DG has been defined as a small source of electric power generation or storage which is not considered as any part of a central power system and it is relatively closed to the load area. Furthermore, DG has been also considered as the small power generation which has a capacity less than 30MW. It is likely installed near or at customer sites in order to fulfill specific customer's needs and improve power quality [37]. According to IEEE, it was defined as the generation of electricity by facilities that are sufficiently smaller than central power plants and it is designed to interconnect or connect directly to any point in a power system. Furthermore, it is also known as small scale power generating unit which injects power directly to a customer's site or within the local distribution network. The scope and limitation of DG contribution have been studied over years by many researchers. Based on the technologies of DG, it is categorized into three divisions: (1) renewable generation; (2) modular distributed generation; (3)

production of combine heat and power distributed generation. Furthermore, there is two main type of DG base on energy sources. They are renewable and non-renewable energy. The renewable energy resources comprise of the wind, solar, hydro, geothermal, thermal, and oceans. In addition, the non-renewable energy sources exist internal combustion engine, combined cycle combustion engine, and fuel cell. Regarding of clean energy consumption trend, Energy sources of DG is mostly designed to consume non-polluted energy with free of greenhouse gases emission [38]. The kind of DGs can be identified based on the capacity of DGs, and it is divided into four types [39]:

- Micro distributed generation: 1W to 5kW
- Small distributed generation: 5kW to 5MW
- Medium distributed generation: 5MW to 50MW
- Large distributed generation: 50MW to 300MW

Nowadays, advanced technologies in new material and design for electrical power generation and storage units which including solar photovoltaic panel, micro turbine, gas turbine, fuel cell, supercapacitor, and advancedly digital control have increased the efficiencies and applications for DG in electrical power production iorder to improve quality and stability of the system. Due to the change of electical power market regulation in the whole sale and retails market, it has opened the chances for the customers to install DG to fulfill their own energy needs. Also, it is also the good ways for the utilities to meet power demands in the system.

3. PROBLEM FORMULATION

The main objectives of this research paper are to find the optimal size and location of DG in the distribution system to minimize active power loss in the distribution network. In this research paper, DG is considered as active power producer operating in unity power factor at a particular voltage The objective function for loss minimization can be written as below.

$$\text{Minimize } f_i(x,u), i = 1, 2, \dots, N, \tag{1}$$

$$\text{Subject to } g(x,u) = 0, h(x,u) \leq 0, \tag{2}$$

where,

- f_i is the objective function i ,
- N_{obj} is the number of objective function,
- g is the equality constraints,
- h is the inequality constraints,
- x is the vector of dependent variables, and
- u is the vector of independent variables.

Power Loss Objective Function

The power loss can be obtained by computing the power flow between two buses as illustrated in the Fig. 2, and it can be formulated in the following equations.

Where V_i and V_k are the bus voltage at bus i and k respectively. The power flow between buses i and k at bus i is given as:

$$S_{ik} = P_{ik} + jQ_{ik}, \tag{3}$$

$$S_{ik} = V_i I_{ik}^*, \tag{4}$$

$$S_{ik} = V_i (V_i^* - V_k^*) Y_{ik} + V_i V_i^* Y_{ik0}, \tag{5}$$

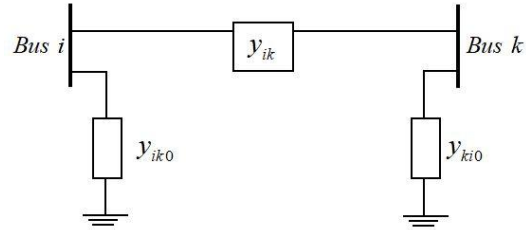


Fig. 2. Diagram of power flow between two buses.

Similarly, the power flow of between buses k and i at bus k is given as,

$$S_{ki} = V_k (V_k^* - V_i^*) Y_{ki} + V_k V_k^* Y_{ki0}, \tag{6}$$

Hence, the loss between these two buses is the sum of power flow in Equation 5 and 6.

$$S_{Total\ loss} = S_{ik} + S_{ki}, \tag{7}$$

The total power loss in a system is obtained by summing all the power flow of branches. The power loss in the slack bus can be obtained by summing the power flow at the terminated bus [40]. In this paper, the reactive power loss is neglected, so the objective function of total real power loss reduction is obtained as:

$$F_{Loss} = \text{real} \left(\sum_{i=1}^n S_{i\ Total\ loss} \right). \tag{8}$$

where, n is the number of the bus branches, and $S_{Total\ loss}$ is the total complex power loss.

System Limit Constraints

System limit constraints are considered as inequality constraints which comprise of voltage magnitude, and real power injection of DG. These variables are optimized and they are limited to be within the constraints during the optimization process. The system variable constraints are expressed as,

$$V_{i\ min} \leq V_i \leq V_{i\ max}, \tag{9}$$

$$I_{ik} \leq I_{ik\ max} \tag{10}$$

$$V_{min,DG} \leq V_{DG} \leq V_{max,DG}, \tag{11}$$

$$P_{min,DG} \leq P_{DG} \leq P_{total\ demand}. \tag{12}$$

where,

- V_i is the voltage magnitude at bus i ,
- V_{DG} is the voltage magnitude at the bus with DG,

- I_{ik} is the current of the i_{ik} branch,
- $I_{ik \max}$ is the maximum current of the i_{ik} branch,
- $P_{total \ demand}$ is the total real power demand in the system,
- P_{DG} is the real power generation of DG.

Power Balance Constraints

The power balance is considered as the equality constraints which balance power generation, load demand, and power loss. Also, the well-known basic load flow equations are written as [2],

$$S_i = P_i + jQ_i = V_i I_i^* \tag{13}$$

$$S_i = V_i \sum_{k=1}^n V_k Y_{ik} = \sum_{k=1}^n |V_i| |V_k| |Y_{ik}| \angle (\delta_i - \delta_k + \theta_{ik}) \tag{14}$$

When real and imagination part is resolved, then the power flow equation without DG can be written as,

$$P_i = \sum_{k=1}^n |V_i| |V_k| |Y_{ik}| \cos(\delta_i - \delta_k + \theta_{ik}) = P_{G,i} - P_{D,i} \tag{15}$$

$$Q_i = \sum_{k=1}^n |V_i| |V_k| |Y_{ik}| \sin(\delta_i - \delta_k + \theta_{ik}) = Q_{G,i} - Q_{D,i} \tag{16}$$

The basic power balance equations are:

$$P_{G,i} = P_{D,i} + P_L \tag{17}$$

$$Q_{G,i} = Q_{D,i} + Q_L \tag{18}$$

The power flow equation considering the loss with DG for practical distribution system and DG is the real power generation units operating in unity power factor. Then, the power flow equation can be written as,

$$P_i + P_{DG,i} = P_{D,i} + P_{L,i} \tag{19}$$

$$Q_i = Q_{D,i} + Q_{L,i} \tag{20}$$

The final power flow equations for a distribution system with DG are,

$$\sum_{k=1}^n |V_i| |V_k| |Y_{ik}| \cos(\delta_i - \delta_k + \theta_{ik}) + P_{DG,i} = P_{D,i} - P_{L,i} \tag{21}$$

$$\sum_{k=1}^n |V_i| |V_k| |Y_{ik}| \sin(\delta_i - \delta_k + \theta_{ik}) = Q_{D,i} - Q_{L,i} \tag{22}$$

where:

- P_i, Q_i real and reactive power flow at bus i ,
- $P_{D,i}, Q_{D,i}$ real and reactive demands at bus i ,
- V_i, V_k voltage magnitudes at bus i and k ,
- $P_{DG,i}$ the real power generated by DG at bus i ,
- δ_i, δ_k voltage angles at bus i and k ,
- Y_{ik} the magnitude of the ik th element in bus admittance matrix,
- θ_{ik} the angle of the ik th element in bus admittance matrix, and
- n the total number of buses.

4. SINE COSINE ALGORITHM

Optimization algorithms aim to obtain the optimum values which can be minimum or maximum based on the given objective function. There are many approaches to solve optimization problems. Stochastic population-based optimization approaches tend to give the best results in a reasonable time. SCA is a novel stochastic optimization algorithm based on proposing multiple initial random candidate solutions then fluctuating it around the best solution using a mathematical model based on sine and cosine functions [41]. SCA consists of two phases which are exploration and exploitation phase. Random selection and combination to form a set of solution are solved by exploration phase, and exploitation deals with random change in random solutions [42]. The working steps of SCA can be written as below [43].

Begin Main SCA Algorithm

Initialize a set of search agents which is the solution and number of maximum iterations T_{\max} ,

While $T < T_{\max}$ **Do** for each iteration,

Foreach search agent X_i in the population **Do**

Evaluate X_i via the fitness function,

If $f(X_i)$ is better than $f(P)$ **then**,

Set $P = X_i$,

End

End

Update r_1 using Equation 24,

Generate randomly the new values for

r_2, r_3 and r_4 ,

Foreach search agent X_i in the population **Do**

Update X_i using Equation 23,

End

End

Return P best solution obtained so far.

End

Equations of updating the positions in the two phases are given as,

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 \times \sin(r_2) \times |r_3 P_i^t - X_i^t|, & r_4 < 0.5 \\ X_i^t + r_1 \times \sin(r_2) \times |r_3 P_i^t - X_i^t|, & r_4 \geq 0.5 \end{cases} \tag{23}$$

$$r_1 = a - t \frac{q}{T} \tag{24}$$

where,

X_i^t the current solutions position at t^{th} iteration in i^{th} dimension,

P_i^t the position of the destination at t^{th} iteration in i^{th} dimension,

r_4 a random number in $[0,1]$,

r_1, r_2, r_3 random numbers,

t the current iteration,
 T the maximum number of the iterations, and
 a a constant.

For the equations, the parameter r_1 directs the next position movement which can be either inside or outside of space. The parameter r_2 determines the distance of the movement whether should be toward or outward from the destination. The parameter assigns a random weight for the destination to emphasize when $r_3 > 1$ and de-emphasize when $r_3 < 1$ stochastically the effect of destination in defining the distance. Finally, r_4 switches equally between the sine and cosine component in Equation 24.

Proposed Algorithm for DG application

The details of the proposed algorithm are described as the followings.

1. Read line data and load data of the system and compute power flow using Newton-Raphson power flow method.
2. Initialize the setting parameters (number and location of DG, max. iteration, population).
3. Compute power loss and store size of DG.
4. Update population determines losses by performing load flow.
5. If the obtained loss is less than the previous case, store current results and discard the previous one or else go back to step 4.
6. Print the results if the maximum iteration or tolerance is reached.
7. The algorithm is ended.

5. SIMULATION RESULT AND DISCUSSION

The proposed algorithm was implemented by MATLAB 2014a and the 15, 33, 69 and 85 buses of radial distribution system were the tested cases. The objective function of loss minimization was implemented using SCA which was set with 50 of the population and 200 maximum iteration of parameter setting values. The main aims of this paper were to determine the optimal location and size of DG in the radial distribution networks. The optimal location of DG in the system was selected at the bus where the power loss obtained was minimum. Moreover, single and multiple of DG operating at unity power factor was considered in this research. The obtained results of the proposed algorithm were compared with those obtained from voltage sensitivity index method [46], ABC modified method [47], and index vector method [1]. The obtained solutions showed that the proposed method provided the better solutions with the compared methods.

15 bus system

15 buses of the radial distribution system which was tested with the proposed algorithm are shown in Fig. 3. The bus data and line data can be obtained in [44]. Bus 1 is considered as the reference bus and bus 2 to 15 are the load buses. The system power loss before minimization

was 43.2kW which were obtained using Newton-Raphson method.

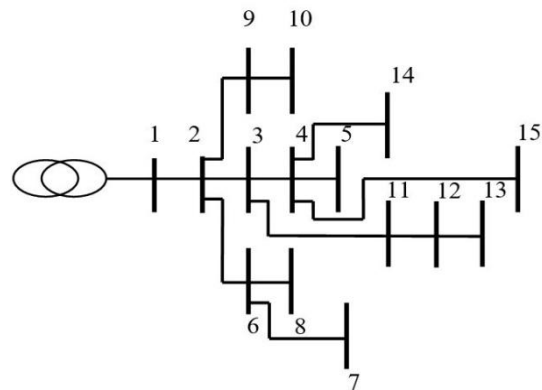


Fig. 3. 13 Buses of radial distribution system.

Table 1 shows the scenario of comparison of single and two DGs in the system. It shows the optimal location and size with corresponding of real power loss reduction after placing DG units in the system. It was noticed that two DG units provided the higher loss reduction when compared with those obtained from single DG unit. Also, it was observed that all the solution come out with satisfaction of the objective function and the constraints. It was proved that the real power loss was reduced to 27kW after placing a DG unit with a capacity of 929.5kW at bus 3. It could save up to 37.50% of loss reduction. When two DG were placed at bus 4 and 6 with the capacity 667.81kW and 337.90kW respectively, the power loss was reduced up to 44.12%. Hence, the installation of DG unit can improve significantly the loadability.

Table 1. Single and Multiple DG Units in 15 Bus System Comparison

	Without DG	With DG	
	Base case	1 DG	2 DGs
Loss (kW)	43.2	27.0	24.14
Location (bus)	-	3	4, 6
Size (kW)	-	929.5	667.81, 337.90
Loss reduction (%)	-	37.50	44.12
Minimum voltage (p.u.)	0.9578	0.9749	0.9835

To evaluate and convey the effectiveness and performance of the proposed method, the obtained results of single DG unit were compared with obtained those of in [1]. it could be investigated that the proposed method provided the better solutions in term of loss reduction as shown in Table 2.

Table 2. Result comparison of 15 bus system

	[1]	[46]	[47]	Proposed
Loss (kW)	33.10	-	-	27.0
Location (bus)	6	-	-	3
Size (kW)	675.24	-	-	929.5
Loss reduction (%)	23.37	-	-	37.50

The voltage profile of before and after installing single DG in the system was compared as shown in Fig. 4. It was investigated that the voltage profile in the base case was poor because it was closed to the lower boundary of the specified range, but it was improved significantly after placing the DG with optimal bus and size. The voltage of buses at the end of the system was dropped before installing DG. However, it was enhanced to the better range.

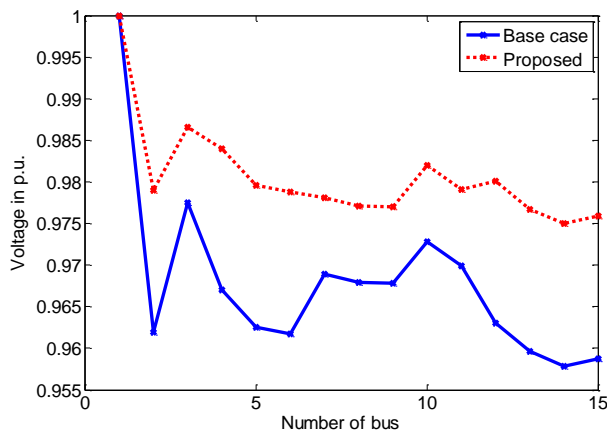


Fig.4. Voltage profile comparison of 15 bus system.

33 Bus System

The 33 buses of the radial distribution system are shown in Fig. 5. It consists of totally 33 buses and 32 lines or branches. The whole system is connected to a power transformer at 12.66kV of the secondary side while it is loaded totally of 3.715MW and 2.3MVar. Bus 1 is considered as the reference bus and others are load buses. The system data can be obtained in [45].

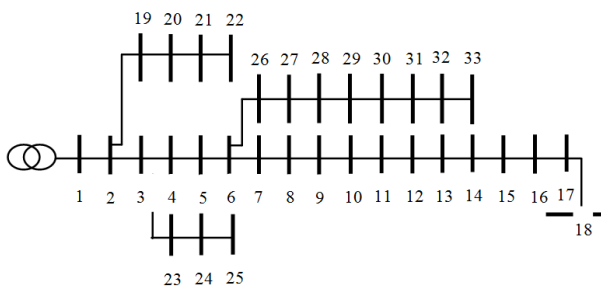


Fig.5. 33 Bus of radial distribution system.

Table 3 illustrates the obtained results from installing single and two DG units in the system including location, loss reduction, and minimum voltage. It was noticed that when two DG units installed at bus 13 and 30 with

the capacity of 1.177MW and 0.843MW respectively, and the power loss was reduced to 81.59kW. The most appropriate place for single DG was bus 6 with the capacity of 2.62MW. The minimum voltage profile of two DG was better than single DG case. The loss reduction could be saved up to 60.48% for two DG units while it could be saved to 49.84% for single DG unit.

Table 3. Single and multiple dg units in 33 bus system comparison

	Without DG	With DG	
	Base case	1 DG	2 DGs
Loss (kW)	206.5	103.60	81.59
Location (bus)	-	6	13, 30
Size (MW)	-	2.62	1.177, 0.843
Loss reduction (%)	-	49.84	60.48
Minimum voltage (p.u.)	0.9064	0.9433	0.9685

Table 4. Result Comparison of 33 Bus System

	[1]	[46]	[47]	Proposed
Loss (kW)	129.0	103.90	104.30	103.6
Location (bus)	15	6	6	6
Size (MW)	1.061	2.490	2.400	2.620
Loss reduction (%)	37.53	49.68	48.49	49.84

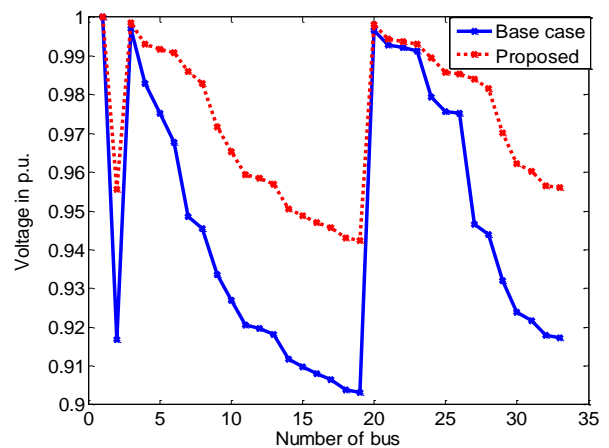


Fig.6. Voltage profile comparison of 33 bus system.

To verify the accuracy and efficiency of the proposed method, the obtained results of single DG unit were compared with obtained those of in [1], [46], and [47] as illustrated in Table 4. Furthermore, it gained the better results compared to [1], [46], and [47] methods in real power loss reduction as well as voltage profile improvement. From the comparison, the minimum power loss was obtained with the proposed method when

compared to the compared methods.

It was investigated that the voltage profile in the base case was poor because it was closed to the lower boundary of the specified range especially the buses which were located at the end of the system, but it was improved significantly after placing single DG at the optimal bus and size as shown in Fig. 6. The voltage of buses at the end of the system was dropped before having DG, and it was improved significantly after installing DG.

69 Bus System

The 69 buses of the radial distribution system are shown in Fig. 7. It consists of totally 69 buses and 68 lines or branches. The whole system is connected to a power transformer at 12kV of the secondary side. Bus 1 is considered as the reference bus and the remaining are load buses. The system data can be obtained in [45].

Table 5. Single and mutiple DG units in 69 bus system comparison

	Without DG		With DG	
	Base case	1 DG	2 DGs	
Loss (kW)	230.02	82.41	70.77	
Location (bus)	-	60	60, 18	
Size (MW)	-	1.890	1.816, 0.479	
Loss reduction (%)	-	61.17	69.23	
Minimum voltage (p.u.)	0.9008	0.9667	0.9803	

Table 5 illustrates the results of the simultaion after placing single and two DG units in the system. The

results showed the significant power loss reduction and improvement of the voltage profile of two DG unit case. It was noticed that when two DG units installed at bus 60 and 18 with capacity 1.816MW and 0.479MW respectively, the power loss was reduced to 70.77kW. Meanwhile, the most appropriate place for single DG was bus 60 with the capacity of 1.890MW. The minimum voltage profile of two DG units case was better than single DG case.

Also, the loss could be reduced up to 69.23% for two DG units, while it could be reduced 61.17% for single DG unit. Table 6 reveals that the proposed method could gain better results compared to [1], [46], and [47] methods in loss reduction and voltage improvement. The losses of DG of [1], [46], [47], and the proposed methods were 90.96kW, 90.70kW, 91.24kW, and 82.41kW respectively. Hence, it could be concluded that the proposed method provides better results than those obtained from the compared methods.

Table 6. Result comparison of 69 bus system

	Without DG		With DG	
	Base case	1 DG	2 DGs	
Loss (kW)	297.04	162.43	150.07	
Location (bus)		8	9, 32	
Size (MW)		2.434	1.60, 0.830	
Loss reduction (%)		45.31	49.47	
Minimum voltage (p.u.)	0.8987	0.9451	0.9529	

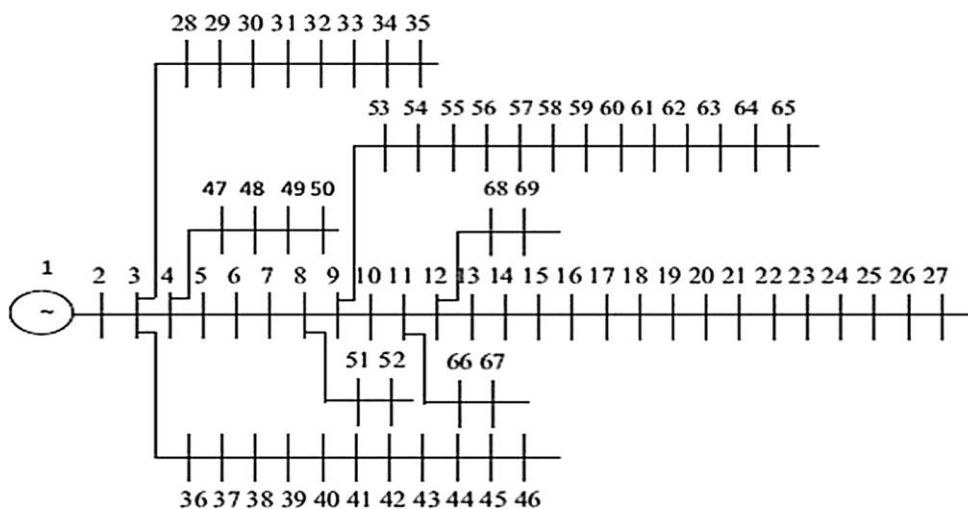


Fig.7. 69 Bus of Radial Distribution System [1]

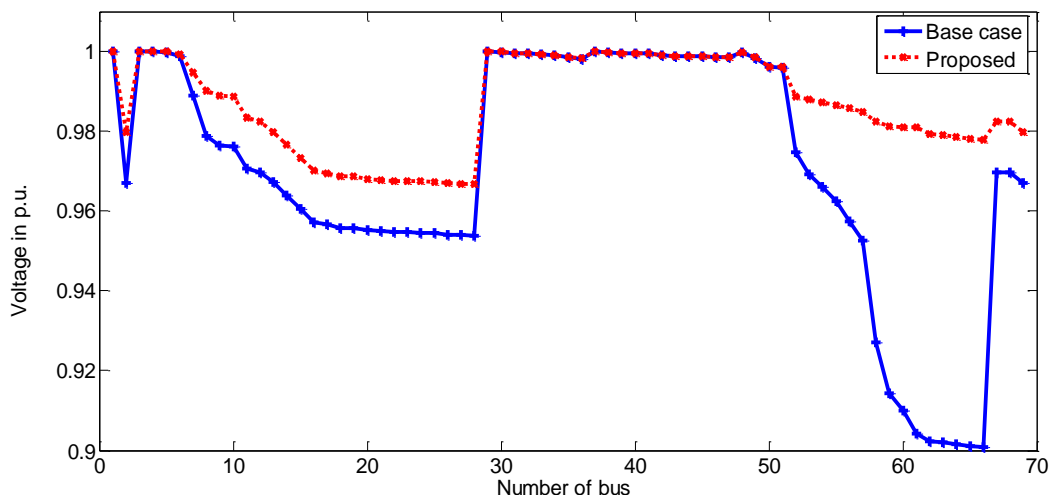


Fig.8. Voltage profile comparison of 69 buses

The voltage profile of before and after installing DG unit in the system was compared as shown in Fig. 8. It was investigated that the voltage profile in the base case was poor because it was closed to the lower boundary of the specified range especially the buses which were located at the end of the system, but it was improved significantly after placing the DG at the optimal bus and size. The voltage of buses at the end of the system was dropped a bit before having DG, and it was improved significantly after installing DG.

85 Bus system

The 85 buses of the radial distribution system are shown in Fig. 9. It consists of totally 85 buses and 84 lines or branches. The whole system is conneted to a power source. Bus 1 is considered as the reference bus and the remainings are load buses. The system data can be obtained in [45]. The system power loss obtained from the power flow simulatoin is 297.04kW.

Table 7. Single and mutiple DG units in 85 bus system comparison

	Without DG		With DG	
	Base case	1 DG	2 DGs	
Loss (kW)	297.04	162.43	150.07	
Location (bus)		8	9, 32	
Size (MW)		2.434	1.60, 0.830	
Loss reduction (%)		45.31	49.47	
Minimum voltage (p.u.)	0.8987	0.9451	0.9529	

Table 7 illustrates the results of the simultaion after placing single and two DG units in the system. The results showed the significant power loss reduction and improvement of the voltage profile of two DG unit case.

It was noticed that when two DG units installed at bus 9 and 32 with capacity 1.60MW and 0.830 MW respectively, the power loss was reduced to 150.07kW. Meanwhile, the most appropriate place for single DG was bus 8 with the capacity of 2.434MW.

The minimum voltage profile of two DG units case was better than single DG case. Also, the loss can be reduced up to 49.47% for two DG units while it could be saved only 45.31% for single DG unit.

Table 8. Result comparison of 85 bus system

	[1]	[46]	[47]	Proposed
Loss (kW)	212.07	-	-	162.43
Location (bus)	55	-	-	8
Size (MW)	0.946	-	-	2.434
Loss reduction (%)	28.60	-	-	45.31

Table 8 reveals that the proposed method can gain better results compared to [1] in loss reduction and voltage improvement. The losses of DG of [1] and the proposed methods were 193.5kW and 162.43kW respectively. Hence, it could be concluded that the proposed method provided better results than those obtained from the compared methods.

The voltage profile of before and after installing DG in the system was compared as shown in Fig. 10. It was investigated that the voltage profile in the base case was very poor because it was lower boundary of the specified range at some buses, but it was improved significantly after placing the DG at the optimal bus and size. The voltage of buses at the end of the system was dropped before having DG, and it was improved significantly after installing DG

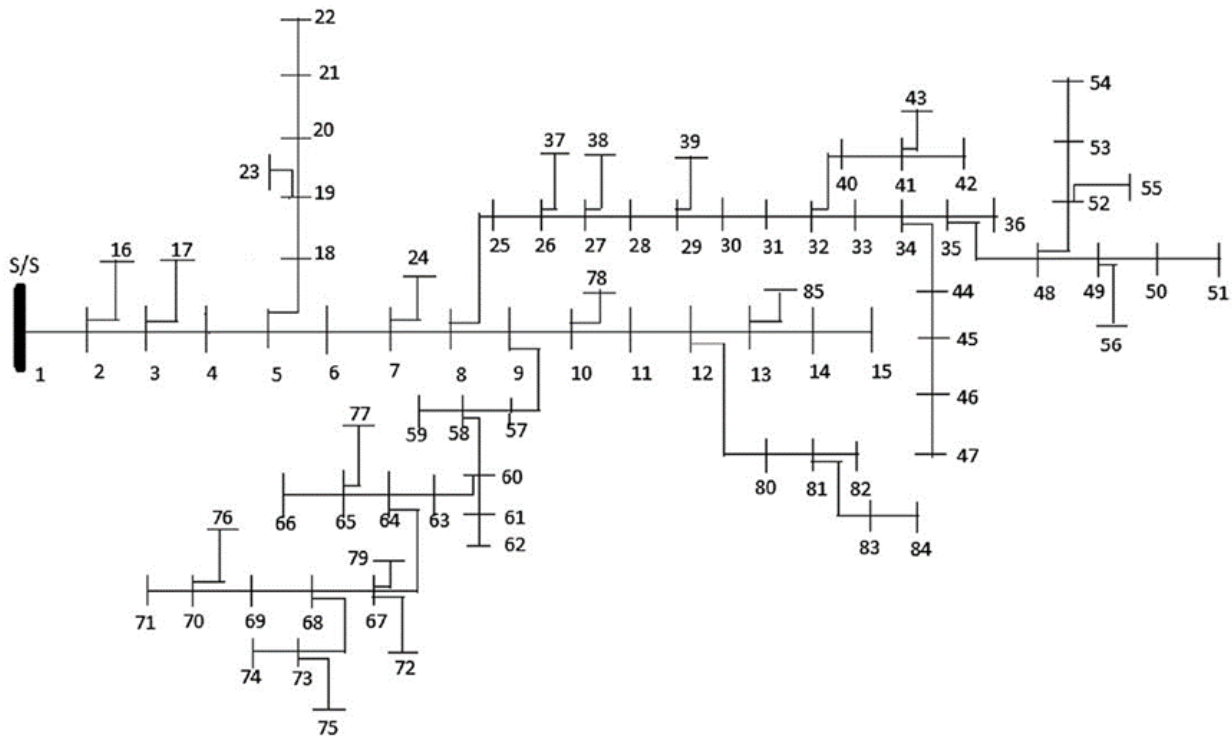


Fig.9. 85 Bus of Radial Distribution System [1].

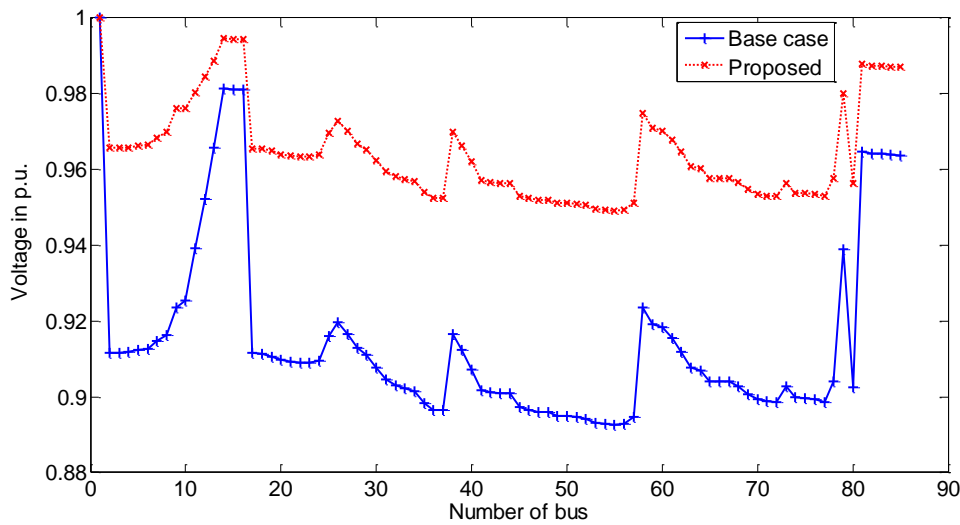


Fig.10. Voltage profile comparison of 85 bus system.

6. CONCLUSION

In this paper, a novel population based algorithm was applied to determine the optimal location and size of DG in the radial distribution system. SCA is modeled based on sine cosine function. Power loss and voltage profile improvement are the main objectives taken in this research. The proposed algorithm was evaluated through 15, 33, 69, and 85 buses of radial distribution network with considering single and double DG units. The better results were obtained with the proposed method when compared with other methods. For the results, it was observed the positive impact of DG units in the system in power loss reduction and voltage profile improvement,

and it was proved the effectiveness and robustness of the proposed method.

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