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Distributed Generation Location and Size Determination to Reduce Power Losses of a Distribution Feeder by Firefly Algorithm

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Abstract

In order to minimize power losses caused by high current and improve the voltage profile in the network distribution, the introduction of dispersed generations also called productions decentralized in distribution network (DG) plays an important role. The installation of DGs directly affects the power requested or purchased. The sizing and placement of DGs in the system must be optimal because a wrong choice has a negative impact on the system behavior. To solve this combinatorial problem, an algorithm known as Firefly algorithm is proposed in this paper. This is a meta-heuristic algorithm inspired by the behavior of fireflies flashing. The main objective of firefly flash is to act as a signaling system to attract other fireflies. Networks tested IEEE69-bus and IEEE33-bus are used to evaluate the effectiveness of this method. The results are compared with those obtained by genetic algorithm (GA) to IEEE69-bus, and Shuffled frog leaping algorithm (SFLA) for IEEE 33-bus.

Keywords: *Distributed Generation, Firefly Algorithm, Power losses*

1. Introduction

Distributed Generation (DG) in distribution networks are used for various objectives: reducing power loss, improving the voltage profile along feeders, and increasing the maximum transmitted power in cables and transformers [1]. However, the installation of DG in distribution networks requires consideration of their appropriate location and size. Because a non-optimal location with a optimal size or a non-optimal size with a optimal location can result in an increase in system losses, damaging voltage state, voltage flicker, protection, harmonic, stability and implying in an increase in costs and, therefore, having an effect opposite to the desired [3]. For these reasons, the use of an optimization method capable of indicating the best of locating and sizing DG in distribution systems can be very useful for the system planning engineers. Many techniques have been developed for solving this difficult combinatorial problem: such as genetic algorithm, tabu search, analytical based methods [3], heuristic algorithms [2] and metaheuristic algorithms developed based on the swarm intelligence in nature like PSO, AFSA [6] and SFLA [13].

Firefly Algorithm (FA) proposed in [15] for optimal placement and sizing of distributed generation (DG) in radial distribution system to minimize the total real power losses and to improve the voltage profile, also proposed in [16] for the solution of the optimal power flow problem in objective to minimize the total fuel cost of generation and environmental pollution and also maintain an acceptable system performance, is used in this paper to find optimal solution.

The Firefly Algorithm (FA) is a metaheuristic, nature-inspired, optimization algorithm which is based on the social (flashing) behavior of fireflies, or lighting bugs, in the summer sky in the tropical temperature regions. It was developed by Dr. Xin-She Yang at Cambridge University in 2007 and it is based on the swarm behavior. In particular, although the firefly algorithm has many similarities with other algorithms which are based on the so-called swarm intelligence, such as the famous Particle Swarm Optimization (PSO), Artificial Bee Colony optimization (ABC) and Bacterial Foraging (BFA) algorithms. Furthermore, according to recent bibliography, the algorithm is very efficient and can outperform other conventional algorithms, such as genetic algorithms, for solving many optimization problems, a fact that has been justified in a recent research, where the statistical performance of the firefly algorithm was measured against other well-known optimization algorithms using various standard stochastic test functions. Its main advantage is the fact that it uses mainly real random numbers, and it is based on the global communication among the swarming particles (the fireflies), and as a result, it seems more effective in multiobjective optimization [4].

In this paper DG is considered as an active power source. The best location and size of DG unit in the distribution system to minimize the total loss are found by Firefly algorithm. This will also improve the voltage profile. IEEE 69-bus and IEEE 33-bus distribution test systems are used to show the effectiveness of the FA.

2. Problem Formulation

The features like radial structure, high R/X ratio and unbalanced loads make radial distribution systems special. High R/X ratios in distribution lines result in large voltage drops, low voltage stability and high power losses [14]. What made the power flow distribution system different from that of the transport system. In this method of analysis power flow, the main goal is to reduce data preparation and ensure the calculation for any size distribution. The proposed algorithm can find the network topology just by reading the data lines and bus, identifying the type of each bus: final, intermediate or common. The voltage of each node is calculated using a simple algebraic equation. Although this method is based on the forward sweep, it calculates the power flow radial distribution networks simple and complex.

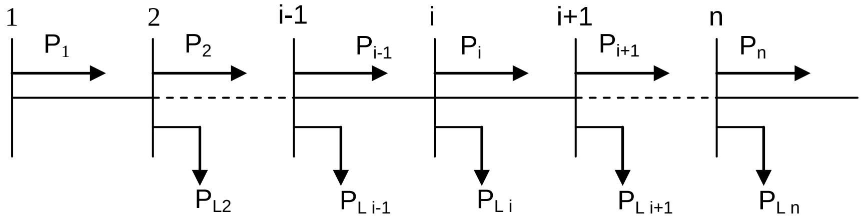

Figure 1. Single-Line Diagram of a Radial Distribution Network

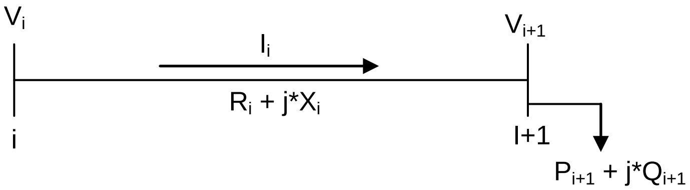

Figure 2. Electrical Equivalent of Figure 1

From Figure 1 and 2, the following equations can be written:

$$P_i = P_{i-1} - P_{Li} - R_{i-1,i}\frac{\left(P_{i-1}^2 + Q_{i-1}^2\right)}{|V|_{i-1}^2} \tag{1}$$

$$P_i = P_{i+1} + P_{Li+1} + R_{i,i+1}\frac{\left(P_i^2 + Q_i^2\right)}{|V|_i^2} \tag{2}$$

$$I_i = \frac{|V_i|\angle\delta_i - |V_{i+1}|\angle\delta_{i+1}}{R_i + jX_i} \tag{3}$$

$$P_{i+1} - j * Q_{i+1} = V_{i+1}^{*} * I_i \tag{4}$$

The DG is simply modeled as a constant active (P) power generating source. The specified values of this DG model are real (P_{DG}) power output of the DG. The DGs can be modeled as negative power load model. The load at bus i with DG unit is to be modified as

$$P_{Li} = P_{Load,i} - P_{DG,i} \tag{5}$$

The power loss of any line section connecting buses i and i+1 can be computed as:

$$P_{Loss}(i, i+1) = R_{i,i+1}\frac{\left(P_i^2 + Q_i^2\right)}{|V|_i^2} \tag{6}$$

The total power loss in all feeders, $P_{T,Loss}$ may then be determined by summing up the losses of all line sections of the feeder, which is given as:

$$P_{T,Loss} = \sum_{i=1}^{n-1} P_{Loss}(i, i+1) \tag{7}$$

The equations mentioned above are used to determine the size and location of DG with minimal losses in the distribution system.

$$F_{obj} = \min \sum_{i=1}^{line} P_{Loss} \tag{8}$$

where line is number of transmission lines in the distribution system. The basic steps of the load flow can be summarized at the pseudo code as follows:

The basic steps of the load flow can be summarized at the pseudo code as follows:

```
Initialization bus voltage
Initializing branch current
 For i = 1: number of lines
For j = 1: number of lines
     Search  terminal bus
     Search Intermediaries bus
     Search common bus
            End for j
       End for i
For i = 1: number of bus
      Calculation of load currents
End
For i = 1: length (number of bus Intermediate)
      Calculation of currents of bus intermediate
End for i
For i = 1: length (number of bus Intermediate)
      Calculation of currents injected into the common bus
End for i
For i = 2: Number of bus
       Calculating voltages to each bus
End for i
       Calculate the sum of Power Losses
```

Figure 3. Pseudo Code of the Load Flow of the Distribution System

3. Firefly Algorithm

The firefly algorithm has three particular idealized rules which are based on some of the major flashing characteristics of real fireflies. These are the following [5]:

1) All fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.

2) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly.

3) The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

3.1. Attractiveness

In the firefly algorithm, the form of attractiveness function of a firefly is the following monotonically decreasing function:

$$\beta_r = \beta_0 * \exp\left(-\gamma r_{ij}^{m}\right) \tag{9}$$

where, r is the distance between any two fireflies, β0 is the initial attractiveness at r equal 0, and γ is an absorption coefficient which controls the decrease of the light intensity.

3.2. Distance

The distance between any two fireflies i and j, at positions xi and xj respectively, can be defined as a Cartesian or Euclidean distance as follows:

$$r_{ij} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} \left(x_{i,k} - x_{j,k}\right)^2} \tag{10}$$

Where $x_{i,k}$ is the kth component of the spatial coordinate x_i of the ith firefly and d is the number of dimensions, for d = 2, we have:

$$r_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \tag{11}$$

However, the calculation of distance r can also be defined using other distance metrics, based on the nature of the problem, such as Manhattan distance or Mahalanobis distance.

3.3. Movement

The movement of a firefly i which is attracted by a more attractive (brighter) firefly j is given by the following equation:

$$x_i = x_i + \beta_0 * \exp\left(-\gamma r_{ij}^2\right) * \left(x_j - x_i\right) + \alpha * \left(rand - \frac{1}{2}\right) \tag{12}$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly’s attractiveness to light intensity seen by adjacent fireflies, and the third term is used for the random movement of a firefly in case there are not any brighter ones. The coefficient α is a randomization parameter determined by the problem of interest, while rand is a random number generator uniformly distributed in the space [0, 1]. As we will see in this implementation of the algorithm, we will use β_0 =1.0, $\alpha \in$ [0, 1] and the attractiveness or absorption coefficient γ =1.0, which guarantees a quick convergence of the algorithm to the optimal solution [4].

4. Application of the Firefly Algorithm

The distribution test systems are the 33 bus [11] and 69 bus [10] systems. The 33 bus system has 32 sections; the total loads for this test system are 3.72 MW and 2.3 MVR. The substation voltage is 12.66 KV and the base of power is 10.00MVA. The test data of 33 bus Distribution system is available in papers [11] and [12].

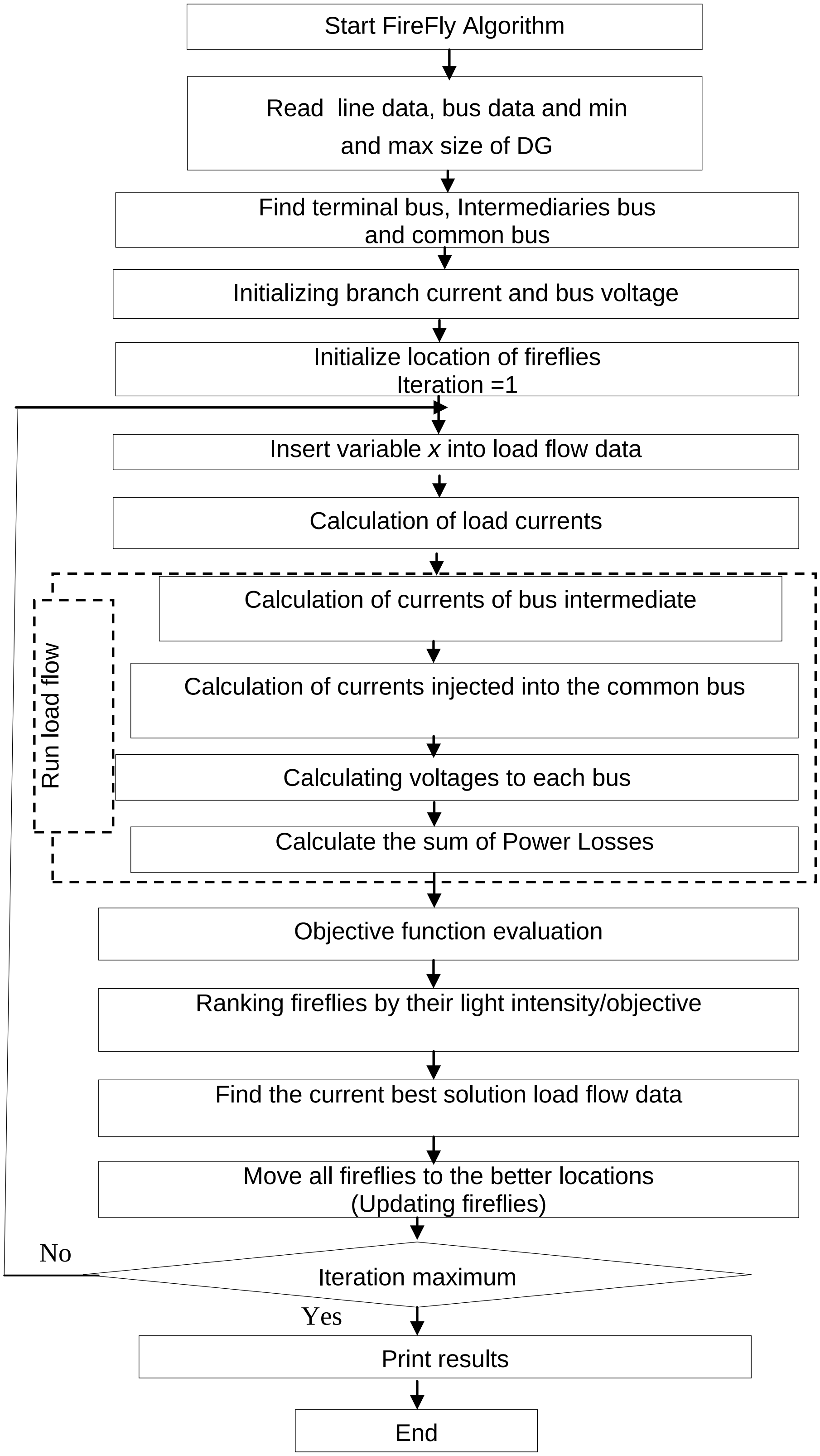

Figure 4. Flow of Optimal Allocation of DG using Firefly Algorithm

Figure 5 shows the test system.The results of FA are compared with those obtained by the method Shuffled Frog Leaping Algorithm SFLA [13].

The 69 bus system has 68 Sections with a total real and reactive power demand of 3802.19 kW and 2694.60 kVAr respectively. Figure 6 shows the test system. The results of FA are compared with those obtained by the Genetic algorithm [10]. The process of incorporating the firefly algorithm for solving the optimal DG placement and sizing problem is shown in Figure 4

The FA properties in this simulation are set as follow [9]:

Number of fireflies: 20
Maximum iteration: 30
Number of DG unit: 1 and 2
DG size: 0.01 MW< PDG < 2.5 MW
Alpha (scaling parameter): 0.25
Minimum value of beta : 0.2
Gamma (absorption coefficient): 1

The following three cases to study the impact of DG installation on the system performance are considered:

Case 1: Calculate the distribution network losses and minimum voltage without DG.

Case 2: Calculate the distribution network losses and minimum voltage with the 1 DG included once its optimal location and size is determined.

Case 3: Calculate the distribution network losses and minimum voltage with the two DG included once its optimal location and size is determined.

4.1. Comparison between FA and SFLA

For this case the test system 33 bus is used. The Figure.7 shows the Firefly convergence characteristic for cases 2 and 3 respectively. The Figure 8 shows the bus voltages before and after installing DG.

For the case 2, the minimum value of losses is 0.1167 MW with FA and is 0.1182 MW with Shuffled Frog Leaping Algorithm (SFLA). For case 3, the minimum value of losses obtained by FA is 0.0969 MW and by SFLA is 0.1054 MW. It also can be noted that the minimum bus voltage for cases 2 and 3 are 0.9398 pu and 0.9484 pu respectively by FA and 0.9384 pu and 0.9687 pu respectively by SFLA. The optimal location and size of DG in case 2 are bus 30 and 1.1904MW respectively .For case 3, the optimal locations are at bus 14 and 30 with respectively sizes 0.6128 MW and 1.0131MW.For the 33 bus system, the case 2 can reduce the total real power loss by 41%. For case 3, they can further reduce the real power loss by 51%. These results show the effectiveness of FA compared to SFLA.

The comparison studies of these 3 cases are tabulated in Table 1.

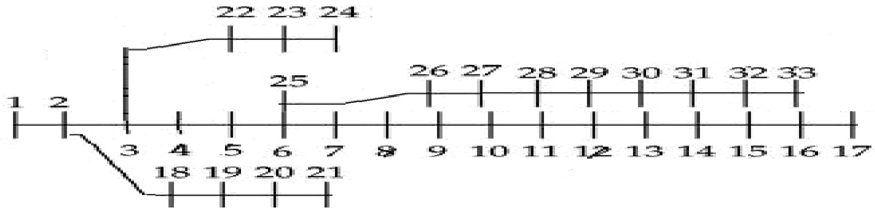

Figure 5. The 33 Bus Radial Distribution System

Table 1. Comparison Results of the 33 Bus System between Firefly Algorithm and Genetic Algorithm for Three Cases

		Real power Losses (MW)	Minimum bus voltage		Optimal location And size	
			BUS Number	voltage (p.u)	Size(MW)	Allocation
Case 1	FA		18	0.9039	-	-
	SFLA	0.2277	18	0.8889	-	-
Case 2	FA	0.1167	18	0.9398	1.1904	30
	SFLA	0.1182	18	0.9384	1.1999	30
Case 3	FA	0.0969	18	0.9484	0.6128 1.0131	14 30
	SFLA	0.1054	18	0.9687	0.6022 1.1246	14 30

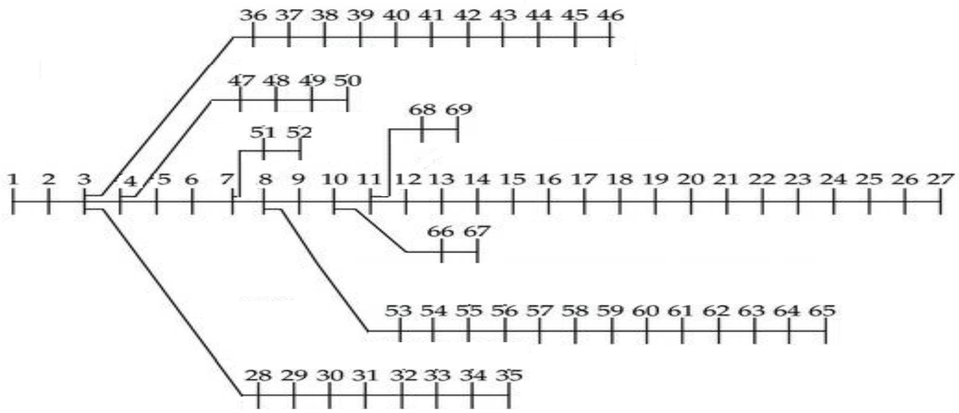

Figure 6. The 69 Bus Radial Distribution System

4.2. Comparison between FA and GA

To prove the effectiveness of FA, the results obtained by this technique using the 69 bus test system are compared with those obtained by GA. The Figure 9 shows the Firefly convergence characteristic with one and two DG. The Figure 10 shows the bus voltages before and after installing DG.

For the case 2, the minimum value of losses is 2.030 MW with FA and is 2.1576 with GA. For case 3, the minimum values of losses obtained by FA are 1.7642 MW and by GA is 2.1181 MW. It also can be noted that the minimum bus voltage for cases 2 and 3 are 0.916255 pu and 0.918514 pu respectively by FA and 0.9104 pu and 0.9106 pu respectively by GA. The optimal location and size of DG in case 2 are bus 54 and 1.5777 MW respectively .For case 3, the optimal locations are at bus 52 and 54 with respectively sizes 1.6079 MW and 2.3589 MW .The comparison studies of these 3 cases are tabulated in Table2.

For the 69 bus system, the case 2 can reduce the total real power loss by 9.07%. For case 3, they can further reduce the real power loss by 20.97%. These results show the effectiveness of FA compared to GA.

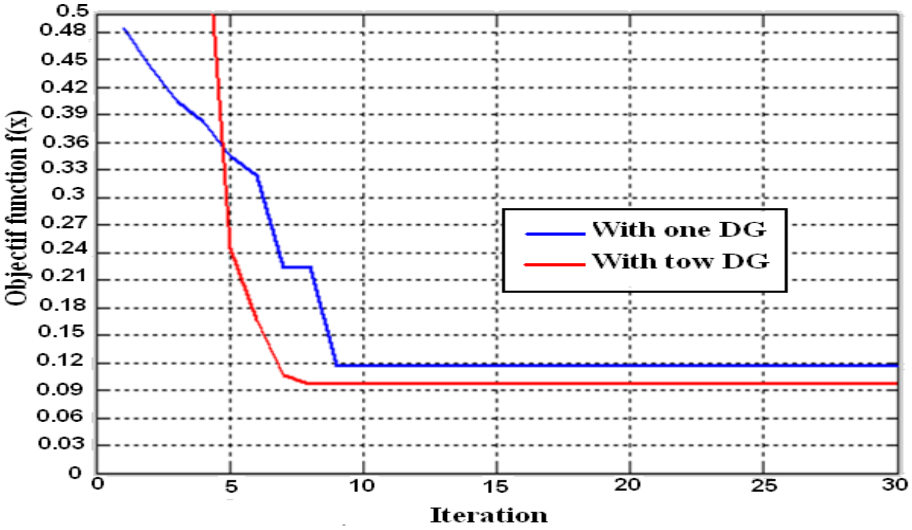

Figure 7.Firefly Convergence Characteristic in 33 Bus System

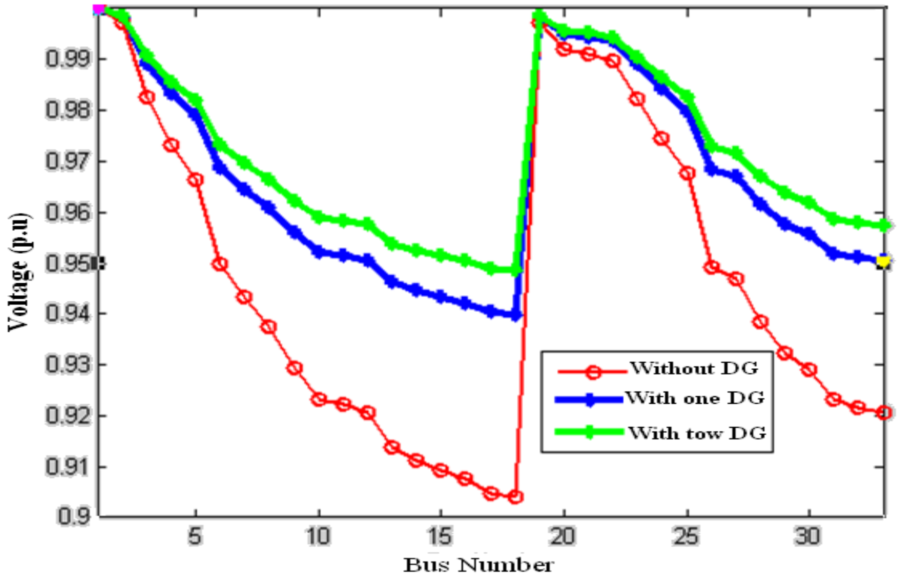

Figure 8. Bus Voltage Before and After DG Installation in 33 Bus System

Table 2. Comparison Results of the 69 Bus System between Firefly Algorithm

		Real power Losses (MW)	Minimum bus voltage		Optimal location And size	
			BUS Number	voltage (p.u)	Size(MW)	Allocation
Case 1	FA	2.2324	54	0.9026	-	-
	GA	2.4277	54	0.9028	-	-
Case 2	FA	2.0300	54	0.9162	1.5777	54
	GA	2.1576	54	0.9104	1.1910	54
Case 3	FA	1.7642	54	0.9185	1.6079	52
					2.3589	54
	GA	2.1181		0.9106	0.6300	52
					1.1910	54

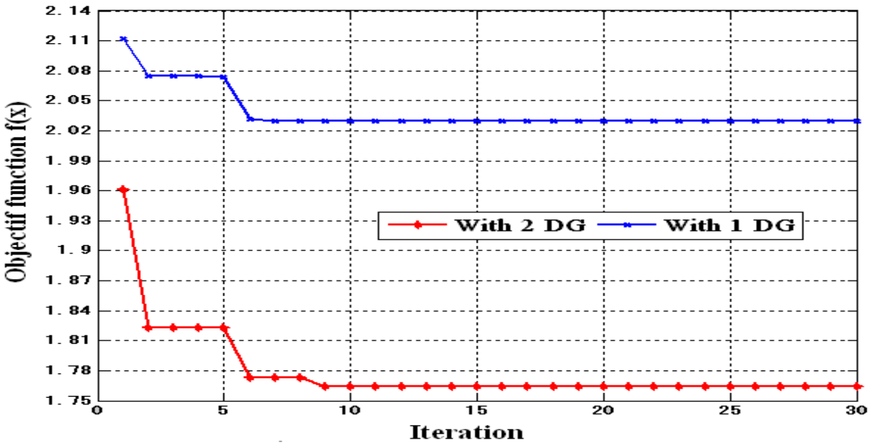

Figure 9.Firefly Convergence Characteristic in 69 Bus System

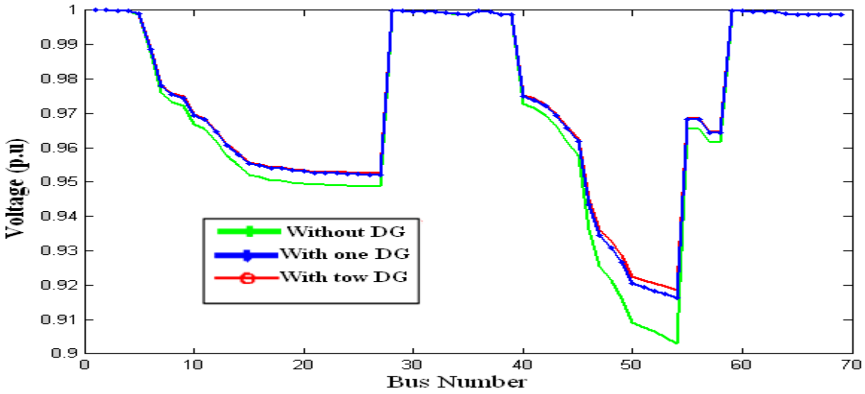

Figure 10. Bus Voltage Before and After DG Installation in 69 Bus System

5. Conclusion

In this paper an application of the algorithm Firefly (FA) and a load flow approach were presented with the objective of determining the optimal location and size of distributed generation (DG) in radial distribution network. The proposed method was tested on IEEE 69-bus and IEEE 33-bus distribution systems with three cases, without DG and with one and two DG included in the system. The performance of FA is good for solving the optimal location and sizing problem in the distribution system. The results show that incorporating the DG in the distribution system can reduce the total line power losses and improve the voltage profile.

The total losses of the system in case with two DG integrated in the system are better than the case without and with one DG. The comparison with genetic algorithm applied to IEEE 69-bus [10] and Shuffled Frog Leaping Algrithm (SFLA) [13] applied to IEEE 33-bus also has been conducted to see the performance of FA in solving the optimal allocation and sizing problems.

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