Optimal Sizing and Placement of Multiple Distributed Generation in Radial Distribution Networks considering Uncertainty in the Variation of Loads

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***Abstract*—This paper proposes the application of the firefly algorithm (FA) for optimal sizing and placement of Multiple Distributed Generation (DGs) in the radial distribution networks considering uncertainty in the variation of loads in order to minimize power losses and to improve the voltage profile. Uncertainty in the variation of loads is linearly changed in small steps of 1% from 50% to 150% of the base case. IEEE 33-bus test system is used to demonstrate the effectiveness of the proposed algorithm. The results are compared with Shuffled Frog Leaping Algorithm (SFLA) is also given.**

***Index Terms* —Radial distribution network; Load flow; Multiple Distributed Generation; Uncertainty in the variation of loads.**

1. INTRODUCTION

Distribution networks are generally radial in nature with single source feed. Conventional load flow programs used for the transmission networks are not suitable for the distribution networks as these networks are characterized by high R/X ratio, thus makes Jacobian matrix ill-conditioned and hence Newton-Raphson (NR) and Fast Decouple load flow (FDLF) methods are not suitable for solving such networks [1].

One of the most important motivation for the studies on integration of distributed resources to the grid is the exploitation of the renewable resources such as; hydro, wind, solar, geothermal, biomass and ocean energy, which are naturally scattered around the country and also smaller in size. Accordingly, these resources can only be tapped through integration to the distribution system by means of Distributed Generation (DG). DG which generally consists of various types of renewable resources can be defined as electric power generation within distribution networks or on the customer side of the system [1]. DG can be an alternative for industrial, commercial and residential applications. DG makes use of the latest modern technology which is efficient, reliable, and simple enough so that it can compete with traditional large generators in some areas [2, 3].

On account of achieving above benefits, the DG must be reliable, dispatchable, of the proper size and at the proper placement [4].

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 [5].

In this area, the most of studies have focused their research on the peak load level and so the uncertainty variations of loads have been considered [6, 7]. However, in the time horizon of a day, a month or a year, the active and reactive load values may experience severe changes and the operator have to consider these variations. As a result of uncertainty associated with the variation of loads during the day, the operation and control of distribution networks are very complex and can be modeled as a nonlinear optimization problem [8, 9].

According to the above discussion, in this work, the uncertainty in variation of loads is linearly changed from 50% to 150% of its nominal value in 1% steps.

In this paper DGs are considered as an active power source. The best sizing and placement of multiple DGs unit in the distribution system to minimize the total loss are fond by firefly algorithm. This will also improve the voltage profile.

2. LOAD FLOW

The calculation of the load flow of distribution system is different from that of transmission system because is radial in nature and has high R/X ratio. In the proposed method of load flow analysis the main aim is to reduce the data preparation and to assure computation for any size for distribution network. The proposed algorithm can know the topology of the grid, just by reading line and bus data. The voltage of each node is calculated by using a simple algebraic equation.

Although this method is based on the forward sweep. It calculates the power flow of simple and complex radial distribution networks.

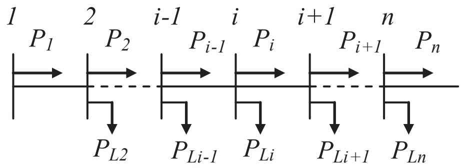

Fig.1. Single-line diagram of a radial distribution network.

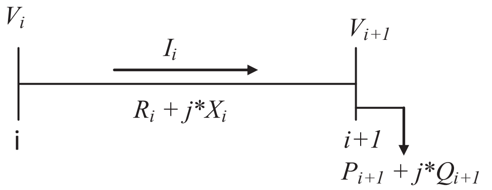

Fig.2. Electrical equivalent of Figure.1.

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

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

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

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

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

The Distributed Generation 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 DG can be modeled as negative power load model. The load at bus i with DG unit is to be modified as:

$$P_{Li} = P_{Load,i} - P_{DG,i} \quad (5)$$

The power loss of any line branch connecting bus i and $i+1$ can be computed as:

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

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:

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

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 [8]:

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.

A. Attractiveness

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

$$\beta_r = \beta_0 * \exp\left(-\gamma r_{ij}^m\right), \text{ with } m \geq 1 \quad (8)$$

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

B. Distance

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

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d}\left(x_{i,k} - x_{j,k}\right)^2} \quad (9)$$

Where x_i, k is the k_{th} component of the spatial coordinate x_i of the i_{th} firefly and d is the number of dimensions we have, for d = 2, we have :

$$r_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \quad (10)$$

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.

C. Movement

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

$$x_i = x_i + \beta_0 * \exp\left(-\gamma r_{ij}^2\right) * \left(x_j - x_i\right) + \alpha * \left(rand - \frac{1}{2}\right) \quad (11)$$

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. RESULTS AND DISCUSSION

The proposed method has been tested on the radial distribution system IEEE 33-bus as shown in Figure 3 [12, 13], has 32 branches. The total loads for this test system are 3.72 MW and 2.3 MVAr. 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 [9] and [10] respectively. The results of FA are compared with those obtained by the method Shuffled Frog Leaping Algorithm (SFLA) [12].

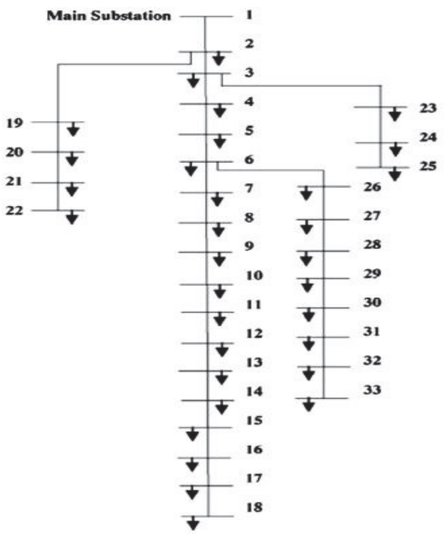

Fig.3.The schematic of a 33-bus radial distribution network.

The following four cases to study the impact of DGs installation on the system performance are considered:

Case 1: Calculate the distribution network losses and minimum voltage without DGs (Base case).

Case 2: Calculate the distribution network losses and minimum voltage with the one DG included once its optimal sizing and placement is determined.

Case 3: Calculate the distribution network losses and minimum voltage with the two DGs included once its optimal sizing's and placements are determined.

Case 4: Calculate the distribution network losses and minimum voltage with the three DGs included once its optimal sizing's and placements are determined.

For FA parameters, population size is 20. The maximum iteration for FA algorithm is 30. Minimum value of beta (attractiveness) is 0.2. The scaling parameter is 0.25. Gamma (absorption coefficient) is 1 [11]. The Figure 4. shows the bus voltages before and after installing DGs. The comparison studies of these four cases are tabulated in table 1.

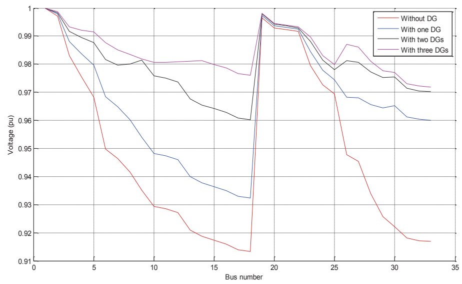

Fig. 4. Bus voltage before and after DGs Installation.

From the table 1, it can be seen that the result of location DG is similar with the Optimal Placement of DG in Radial Distribution Networks Using Shuffled Frog Leaping Algorithm (SFLA). For case two where the location for installing the DG is at bus 30, for case three the optimal placements are at bus 9 and 30 and for case four the optimal placements are at bus 14, 30 and 6 respectively. The total line power losses obtained by FA are lower than obtained by Shuffled Frog Leaping Algorithm (SFLA) [12].

TABLE I
Comparison Results Of The 33-Bus Network Between Firefly Algorithm And Shuffled Frog Leaping Algorithm For Four Cases

		Real power losses (MW)	Minimum bus voltage		Optimal sizing and placement	
			Bus number	*voltage (pu)*	*Sizing (MW)*	*Placement*
Case 1	Without DGs	0.2019	18	0.9134	-	-
Case 2	FA	0.1179	18	0.9324	1.1922	30
	SFLA	0.1182	18	0.9384	1.1999	30
Case 3	FA	0.0857	18	0.9587	1.0822	09
					1.0131	30
	SFLA	0.0920	18	0.9617	1.1623	09
					1.0311	30
Case 4	FA	0.0761	33	0.9719	0.6270	14
					0.7770	30
					1.1170	06
	SFLA	0.0774	33	0.9700	0.6022	14
					0.7500	30
					1.0981	06

In this paper firstly without installing any DGs, the uncertainty in variation of loads (μ) are changed linearly from 50% to 150% of base case with 1% steps. When the load is increased by 50%, Pup and Qup are increased by 50%. Also, when the load is decreased by 50%, Pup and Qup are decreased by 50%. In addition, second case, third case and ford case consider one DG, two DGs and three DGs, respectively.

A. Without installing DGs

As mentioned before, the feeder loads are linearly changed from 50% to 150% in 1% steps. The simulation results of variation in losses, upstream power and minimum value of voltage for three different loading levels: base load value, increased by 50% and decreased by 50% is shown in table 2. Figure.5 shows the voltage profile under different load levels. As it can be seen in this figure, load increase has a negative effect on the voltage profile. The worst voltage profile is experienced by 50% increase. In this situation, the minimum voltage level is at bus 18, which is equal to 0.8642 pu. On the other hand, as the load is decreased, the voltage profile is enhanced. Therefore, the best voltage profile has happened for the case of 50% decrease in the load. Here again, the minimum magnitude of the voltage is at bus 18, which is equal to 0.9583 pu. The active and reactive power losses under different loading levels are shows in Figure. 6. By curve fitting technique, the amount of power losses can be approximated, as follows:

$$Ploss(MW) = 0.27216\mu^2 - 0.09844\mu + 0.02817 \quad (12)$$

$$Qloss(MVAr) = 0.18236\mu^2 - 0.06686\mu + 0.01914 \quad (13)$$

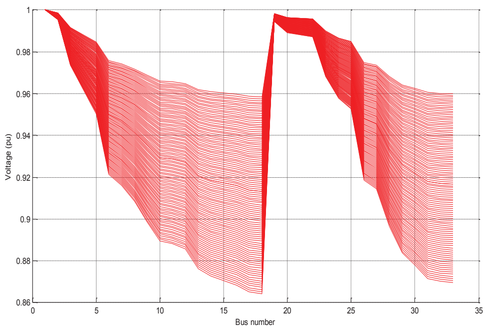

Fig.5. Bus voltage in 33-bus system with uncertainty in the variation of loads without installing DG.

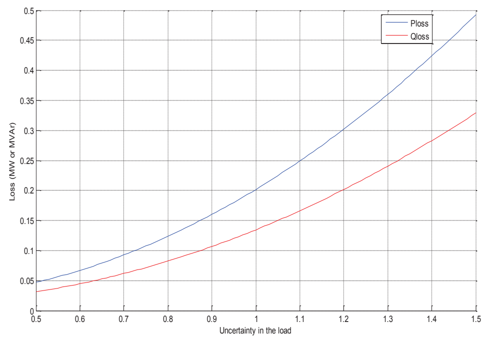

Fig. 6. Losses variations in 33-bus system with uncertainty in the variation of loads without installing DG.

$$Pup(MW) = 3.7200\mu \quad (14)$$

$$Qup(MVAr) = 2.3000\mu \quad (15)$$

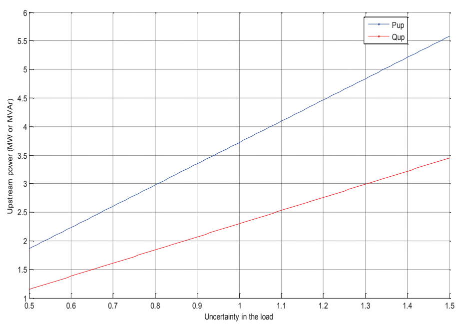

Fig.7. Upstream power variation in 33-bus system with uncertainty in the variation of loads without installing DG.

TABLE II
Results Of Load Uncertainty (Without Using DGs)

IEEE 33 bus	Loads decreased by 50 %	Base case	Loads increased by 50 %
P_{up} (MW)	1.8600	3.7200	5.5800
Q_{up} (MVAr)	1.1500	2.3000	3.4500
P_{loss} (MW)	0.0470	0.2019	0.4929
Q_{loss} (MVAr)	0.0313	0.1346	0.3291
V_{min} (pu)@Bus	0.9583@18	0.9134@18	0.8642@18
V_{max} (pu)@Bus	1.0000@1	1.0000@1	1.0000@1

Once the load is decreased, the slope of the loss reduction curve is reduced, as well. For example, when the load is increased about 50% of its base value, the active and reactive power losses are increased by 144.13% and 144.50%, respectively. Nevertheless, as the load is decreased by 50%, the active and reactive power losses are reduced by 76.72% and 76.74%, respectively. Figure.7 shows the active and reactive powers (Pup and Qup) supplied by the upstream network, respectively.

B. *With one DG*

The load flow analysis shows that the percentage of loss reduction. In TABLE III, the proposed method results for three states of loads (decreased by 50%, increased by 50% and the base case) are summarized. Figure. 8 shows the voltage profile under different loading levels. By comparing the results of Figure. 5 with that of Figure. 8, it can be said that utilization of DG in the system has improved the voltage profile effectively. In the case of the load growth, the minimum voltage magnitude has occurred at bus 18, which is 0.8960 pu. For 50% load increase. On the other hand, as the load is decreased, the minimum voltage magnitude is 0.9670 pu at bus 18 for a 50% decrease. Figure. 9 shows the active and reactive power losses under different loading levels after installation of one DG. By curve fitting technique, the optimal losses can be written as follows:

$$Ploss(MW) = 0.13619\mu^2 - 0.02537\mu + 0.00709 \quad (16)$$

$$Qloss(MVAr) = 0.094188\mu^2 - 0.018187\mu + 0.0050854 \quad (17)$$

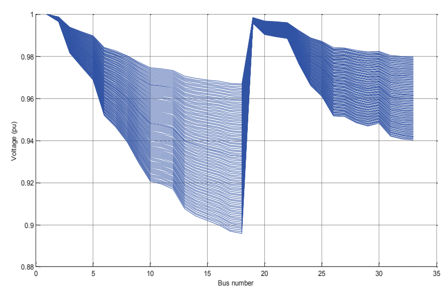

Fig. 8. Bus voltage in 33-bus system with uncertainty in the variation of loads after installation of one DG.

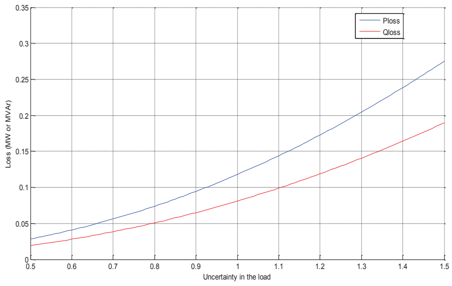

Fig. 9. Losses variations in 33-bus system with uncertainty in the variation of loads after installation of one DG.

Figure.10 shows the active and reactive powers (Pup and Qup) supplied by the upstream network, respectively.

$$Pup(MW) = 2.5278\mu \quad (18)$$

$$Qup(MVAr) = 2.3000\mu \quad (19)$$

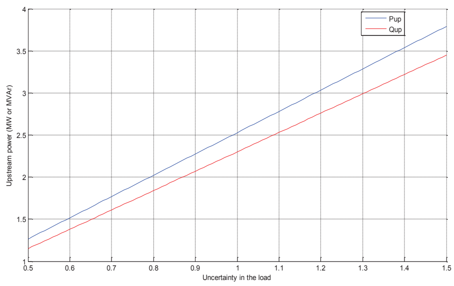

Figure 10. Upstream power variation in 33-bus system with uncertainty in the variation of loads after installation of one DG.

TABLE III
Results Of Load Uncertainty (With One DG)

IEEE 33 bus	Loads decreased by 50 %	Base case	Loads increased by 50 %
P_{up} (MW)	1.2639	2.5278	3.7917
Q_{up} (MVAr)	1.1500	2.3000	3.4500
P_{loss} (MW)	0.0284	0.1179	0.2754
Q_{loss} (MVAr)	0.0195	0.0811	0.1897
V_{min} (pu)@Bus	0.9670@18	0.9324@18	0.8960@18
V_{max} (pu)@Bus	1.0000@1	1.0000@1	1.0000@1

C. With two DGs

The load flow analysis shows that the loss reduction. Figure.11 shows the voltage profile under different loading levels. By comparing the results of Figures.5, Figure. 8, Figure. 11, it can be said that the installation of two DGs has a remarkable influence on the voltage profile among of one DG unit. Figure. 12 illustrates the real and reactive power losses under different loading levels at the presence of two DGs. By curve fitting, the following equations can be written:

$$Ploss(MW) = 0.0925522\mu^2 - 0.0093554\mu + 0.002457 \quad (20)$$

$$Qloss(MVAr) = 0.063191\mu^2 - 0.0067187\mu + 0.0018321 \quad (21)$$

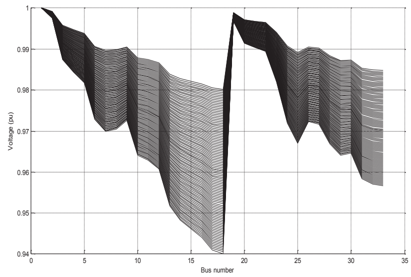

Fig. 11. Bus voltage in 33-bus system with uncertainty in the variation of loads after installation of two DGs.

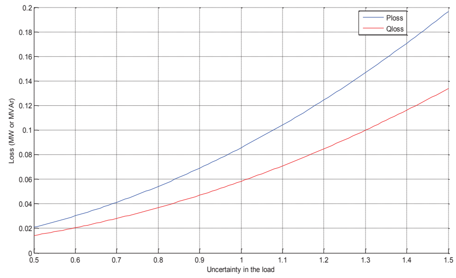

Fig.12. Losses variations in 33-bus system with uncertainty in the variation of loads after installation of two DGs.

Figure.13 shows the active and reactive powers (Pup and Qup) supplied by the upstream network, respectively.

$$Pup(MW) = 1.6247\mu \quad (22)$$

$$Qup(MVAr) = 2.3000\mu \quad (23)$$

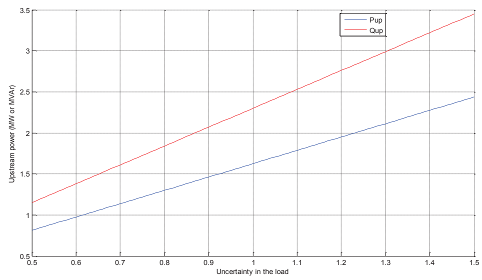

Fig. 13. Upstream power variation in 33-bus system with uncertainty in the variation of loads after installation of two DGs.

TABLE IV
Results Of Load Uncertainty (With Two DGs)

IEEE 33 bus	Loads decreased by 50 %	Base case	Loads increased by 50 %
P_{up} (MW)	0.8123	1.6247	2.4370
Q_{up} (MVAr)	1.1500	2.3000	3.4500
P_{loss} (MW)	0.0210	0.0857	0.1967
Q_{loss} (MVAr)	0.0143	0.0583	0.1339
V_{min} (pu)@Bus	0.9795@18	0.9587@18	0.9378@18
V_{max} (pu)@Bus	1.0000@1	1.0000@1	1.0000@1

D. With three DGs

The load flow analysis Figure. 14 shows the voltage profile under different loading levels. By comparing the results of Figure. 5, Figure. 8, Figure. 11, Figure. 14, it can be said that the installation of the three DG has a remarkable influence on the voltage profile among all number of DGs unit. Figure. 15 illustrates the real and reactive power losses under different loading levels at the presence of three DGs. By curve fitting, the following equations can be written:

$$Ploss(MW) = 0.0808608\mu^2 - 0.006557\mu + 0.0017607 \quad (24)$$

$$Qloss(MVAr) = 0.0563516\mu^2 - 0.004819\mu + 0.0012963 \quad (25)$$

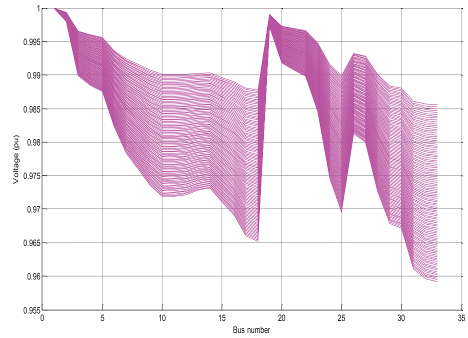

Fig. 14. Bus voltage in 33-bus system with uncertainty in the variation of loads after installation of three DGs.

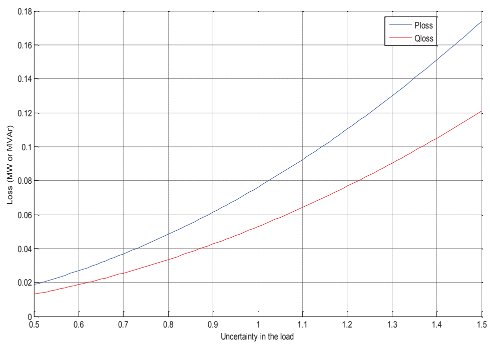

Fig. 15. Losses variations in 33-bus system with uncertainty in the variation of loads after installation of three DGs.

Figure.16 shows the active and reactive powers (Pup and Qup) supplied by the upstream network, respectively.

$$Pup(MW) = 1.1990\mu \quad (26)$$

$$Qup(MVAr) = 2.3000\mu \quad (27)$$

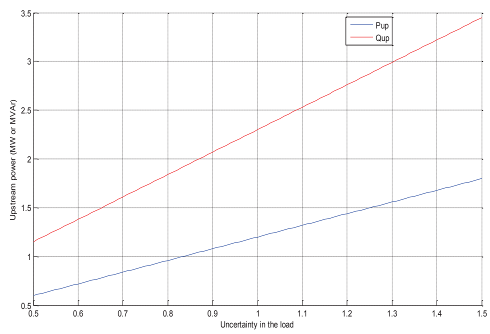

Fig. 16. Upstream power variation in 33-bus system with uncertainty in the variation of loads after installation of three DGs.

TABLE V
Results Of Load Uncertainty (With Three DGs)

IEEE 33 bus	Loads decreased by 50 %	Base case	Loads increased by 50 %
P_{up} (MW)	0.5995	1.1990	1.7985
Q_{up} (MVAr)	1.1500	2.3000	3.4500
P_{loss} (MW)	0.0187	0.0761	0.1738
Q_{loss} (MVAr)	0.0130	0.0528	0.1208
V_{min} (pu)@Bus	0.9855@33	0.9719@33	0.9592@33
V_{max} (pu)@Bus	1.0000@1	1.0000@1	1.0000@1

5. CONCLUSION

In this paper, a firefly algorithm (FA) for optimal sizing and placement of multiple DGs is efficiently minimizing the total active and reactive power losses effectively when the voltage profile of the system has been also improved. The proposed method was tested on IEEE 33-bus distribution system with four cases, without DG, with one DG, two DGs and three DGs included in the system. The performance of FA is good for solving the optimal sizing and placement problem in the distribution system. The results show that incorporating the multiple DGs 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 three DGs integrated in the system are better than the case without, with one and two DGs. The comparison with Shuffled Frog Leaping Algorithm (SFLA) also has been conducted to see the performance of FA in solving the optimal sizing and placement of multiple DGs problems. The uncertainty in variation of loads is linearly changed from 50% to 150% of its nominal value in 1% steps of four cases.

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