Application of Fuzzy and ABC Algorithm for DG Placement for Minimum Loss in Radial Distribution System

M. Padma Lalitha*, V.C. Veera Reddy** and N. Sivarami Reddy***

Abstract: Distributed Generation (DG) is a promising solution to many power system problems such as voltage regulation, power loss, etc. This paper presents a new methodology using Fuzzy and Artificial Bee Colony algorithm (ABC) for the placement of Distributed Generators (DG) in the radial distribution systems to reduce the real power losses and to improve the voltage profile. A two-stage methodology is used for the optimal DG placement. In the first stage, Fuzzy is used to find the optimal DG locations and in the second stage, ABC algorithm is used to find the size of the DGs corresponding to maximum loss reduction. The ABC algorithm is a new population based meta heuristic approach inspired by intelligent foraging behavior of honeybee swarm. The advantage of ABC algorithm is that it does not require external parameters such as cross over rate and mutation rate as in case of genetic algorithm and differential evolution and it is hard to determine these parameters in prior. The proposed method is tested on standard IEEE 33 bus test system and the results are presented and compared with different approaches available in the literature. The proposed method has outperformed the other methods in terms of the quality of solution and computational efficiency.

Keywords: ABC Algorithm, DG placement, Loss reduction, Meta Heuristic Methods, Radial Distribution System.

1 Introduction

Distributed or dispersed generation (DG) or embedded generation (EG) is small-scale power generation that is usually connected to or embedded in the distribution system. The term DG also implies the use of any modular technology that is sited throughout a utility's service area (interconnected to the distribution or sub-transmission system) to lower the cost of service [1]. The benefits of DG are numerous [2, 3] and the reasons for implementing DGs are an energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding sites for smaller generators, shorter construction times and lower capital costs of smaller plants and proximity of the generation plant to heavy loads, which reduces transmission costs. Also it is accepted by many countries that the reduction in gaseous emissions

(mainly CO_2) offered by DGs is major legal driver for DG implementation [4].

The distribution planning problem is to identify a combination of expansion projects that satisfy load growth constraints without violating any system constraints such as equipment overloading [5]. Distribution network planning is to identify the least cost network investment that satisfies load growth requirements without violating any system and operational constraints. Due to their high efficiency, small size, low investment cost, modularity and ability to exploit renewable energy sources, are increasingly becoming an attractive alternative to network reinforcement and expansion. Numerous studies used different approaches to evaluate the benefits from DGs to a network in the form of loss reduction, loading level reduction [6-8].

Naresh Acharya *et al* suggested a heuristic method in [9] to select appropriate location and to calculate DG size for minimum real power losses. Though the method is effective in selecting location, it requires more computational efforts. The optimal value of DG for minimum system losses is calculated at each bus. Placing the calculated DG size for the buses one by one, corresponding system losses are calculated and compared to decide the appropriate location. More over the heuristic search requires exhaustive search for all

possible locations which may not be applicable to more than one DG. This method is used to calculate DG size based on approximate loss formula may lead to an inappropriate solution.

In the literature, genetic algorithm and PSO have been applied to DG placement [10-13].In all these works both sizing and location of DGs are determined by these methods. This paper presents a new methodology using ABC algorithm [14-17] for the placement of DG in the radial distribution systems. The ABC algorithm is a new population based meta heuristic approach inspired by intelligent foraging behavior of honeybee swarm. The advantage of ABC algorithm is that it does not require external parameters such as cross over rate and mutation rate as in case of genetic algorithm and differential evolution and it is hard to determine these parameters in prior. The other advantage is that the global search ability in the algorithm is implemented by introducing neighborhood source production mechanism which is a similar to mutation process. The advantage of ABC algorithm is because of its simplicity it takes less computation time than PSO method.

In this paper, the optimal locations of distributed generators are identified based on the Fuzzy method [18] and ABC optimization technique which takes the number and location of DGs as input has been developed to determine the optimal size(s) of DG to minimize real power losses in distribution systems. The advantages of relieving ABC method from determination of locations of DGs are improved convergence characteristics and less computation time. Voltage and thermal constraints are considered. The effectiveness of the proposed algorithm was validated using 33-Bus Distribution System [19]. To test the effectiveness of proposed method, results are compared with different approaches available in the literature. The proposed method has outperformed the other methods in terms of the quality of solution and computational efficiency.

2 Theoretical Background

The total I^2R loss (P_L) in a distribution system having n number of branches is given by:

$$P_{Lt} = \sum_{i=1}^{n} I_i^2 R_i \tag{1}$$

here I_i is the magnitude of the branch current and R_i is the resistance of the ith branch respectively. The branch current can be obtained from the load flow solution. The branch current has two components, active component (I_a) and reactive component (I_r). The loss associated with the active and reactive components of branch currents can be written as:

$$P_{La} = \sum_{i=1}^{n} I_{ai}^2 R_i \tag{2}$$

$$P_{Lr} = \sum_{i=1}^{n} I_{ri}^2 R_i \tag{3}$$

Note that for a given configuration of a single-source radial network, the loss P_{La} associated with the active component of branch currents cannot be minimized because all active power must be supplied by the source at the root bus. However by placing DGs, the active component of branch currents are compensated and losses due to active component of branch current is reduced. This paper presents a method that minimizes the loss due to the active component of the branch current by optimally placing the DGs and thereby reduces the total loss in the distribution system. A two stage methodology is applied here. In the first stage optimum location of the DGs are determined by using fuzzy approach and in the second stage an analytical method is used to determine sizes of the DGs for maximum real loss reduction.

3 Identification of Optimal DG Locations using Fuzzy Approach

This paper presents a fuzzy approach to determine suitable locations for DG placement. Two objectives are considered while designing a fuzzy logic for identifying the optimal DG locations. The two objectives are: (i) to minimize the real power loss and (ii) to maintain the voltage within the permissible limits. Voltages and power loss indices of distribution system nodes are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to determine the DG placement suitability of each node in the distribution system. DG can be placed on the nodes with the highest suitability.

For the DG placement problem, approximate reasoning is employed in the following manner: when losses and voltage levels of a distribution system are studied, an experienced planning engineer can choose locations for DG installations, which are probably highly suitable. For example, it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of DG. Whereas a low loss section with good voltage is not ideal for DG placement. A set of fuzzy rules has been used to determine suitable DG locations in a distribution system.

In the first step, load flow solution for the original system is required to obtain the real and reactive power losses. Again, load flow solutions are required to obtain the power loss reduction by compensating the total active load at every node of the distribution system. The loss reductions are then, linearly normalized into a [0, 1] range with the largest loss reduction having a value of 1 and the smallest one having a value of 0. Power Loss Index [15] value for i^{th} node can be obtained using equation 4.

$$PLI(i) = \frac{(Lossreduction(i) - Lossreduction(min))}{(Lossreduction(max) - Lossreduction(min))} \tag{4}$$

These power loss reduction indices along with the p.u. nodal voltages are the inputs to the Fuzzy Inference

System (FIS), which determines the nodes that are more suitable for DG installation.

3.1 Implementation of Fuzzy Method

In this paper, two input and one output variables are selected. Input variable-1 is power loss index (PLI) and Input variable-2 is the per unit nodal voltage (V). Output variable is DG suitability index (DSI). Power Loss Index range varies from 0 to 1, P.U. nodal voltage range varies from 0.9 to 1.1 and DG suitability index range varies from 0 to 1.

Five membership functions are selected for PLI. They are **L, LM, M, HM and H**. All the five membership functions are triangular as shown in Fig. 1. Five membership functions are selected for Voltage. They are **L, LN, N, HN and H**. These membership functions are trapezoidal and triangular as shown in Fig. 2. Five membership functions are selected for DSI. They are **L, LM, M, HM** and **H**. These five membership functions are also triangular as shown in Fig. 3.
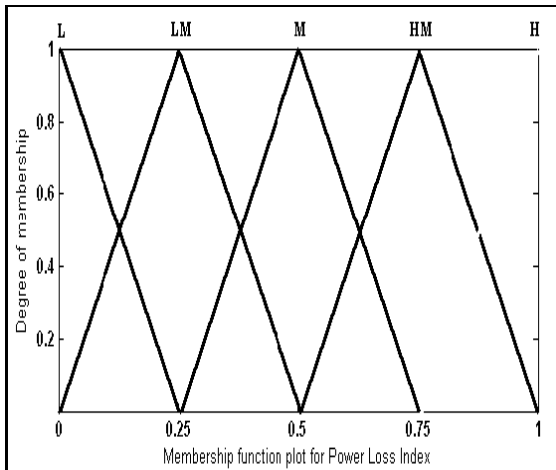

Fig. 1 Membership function plot for PLI.

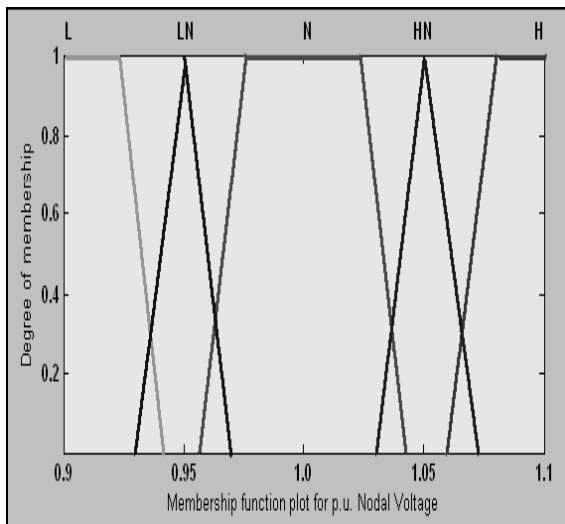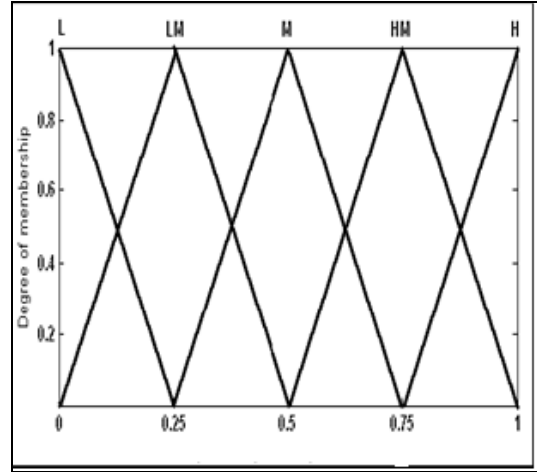**Fig. 2** Membership function plot for voltage.

Fig. 3 Membership function plot for DSI.

For the DG allocation problem, rules are defined to determine the suitability of a node for capacitor installation. Such rules are expressed in the following form: IF premise (antecedent), THEN conclusion (consequent).

For determining the suitability of DG placement at a particular node, a set of multiple-antecedent fuzzy rules has been established. The inputs to the rules are the voltage and power loss indices and the output is the suitability of DG placement. The rules are summarized in the fuzzy decision matrix in Table 1. In the present work 25 rules are constructed.

Table 1 Fuzzy Decision Matrix.

AND		Voltage				
		LL	LN	NN	HN	HH
DSI	L	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	L

4 Identification of Optimal DG Sizes by ABC Algorithm

4.1 Introduction to ABC Algorithm

In the ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. A bee waiting on the dance area for making decision to choose a food source is called an onlooker and a bee going to the food source visited by it previously is named an employed bee. A bee carrying out random search is called a scout. In the ABC algorithm, first half of the colony consists of employed artificial bees and the second half constitutes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source is exhausted by the employed and onlooker bees becomes a scout. In

the ABC algorithm, each cycle of the search consists of three steps: sending the employed bees onto the food sources and then measuring their nectar amounts; selecting of the food sources by the onlookers after sharing the information of employed bees and bees come in to the hive and share the nectar information of the sources with the bees waiting on the dance area within the hive. At the second stage, after sharing the information, every employed bee goes to the food source area visited by her at the previous cycle since that food source exists in her memory, and then chooses a new food source by means of visual information in the neighborhood of the present one. At the third stage, an onlooker prefers a food source area depending on the nectar information distributed by the employed bees on the dance area. As the nectar amount of a food source increases, the probability with which that food source is chosen by an onlooker increases, too. Hence, the dance of employed bees carrying higher nectar recruits the onlookers for the food source areas with higher nectar amount. After arriving at the selected area, she chooses a new food source in the neighborhood of the one in the memory depending on visual information. Visual information is based on the comparison of food source positions. When the nectar of a food source is abandoned by the bees, a new food source is randomly determined by a scout bee and replaced with the abandoned one. In our model, at each cycle at most one scout goes outside for searching a new food source and the number of employed and onlooker bees were equal. The probability P_i of selecting a food source i is determined using the following expression:

$$P_i = \frac{fit_i}{\sum_{n=1}^{S_N} fit_n} \qquad (5)$$

where fit_i is the fitness of the solution represented by the food source i and S_N is the total number of food sources. Clearly, with this scheme good food sources will get more onlookers than the bad ones. After all onlookers have selected their food sources, each of them determines a food source in the neighborhood of his chosen food source and computes its fitness. The best food source among all the neighboring food sources determined by the onlookers associated with a particular food source i and food source i itself, will be the new location of the food source i. If a solution represented by a particular food source does not improve for a predetermined number of iterations then that food source is abandoned by its associated employed bee and it becomes a scout, i.e., it will search for a new food source randomly. This tantamount to assigning a randomly generated food source (solution) to this scout and changing its status again from scout to employed. After the new location of each food source is determined, another iteration of ABC algorithm begins. The whole process is repeated again and again till the termination condition is satisfied. The food source in the

determining the nectar amount of the foods; determining the scout bees and then sending them onto possible food sources. At the initialization stage, a set of food source positions are randomly selected by the bees and their nectar amounts are determined. Then, these neighborhood of a particular food source is determined by altering the value of one randomly chosen solution parameter and keeping other parameters unchanged. This is done by adding to the current value of the chosen parameter the product of a uniform variate in [-1, 1] and the difference in values of this parameter for this food source and some other randomly chosen food source. Formally, suppose each solution consists of d parameters and let $X_i = (X_{i1}, X_{i2}, X_{i3}, ..., X_{id})$ be a solution with parameter values $X_{i1}, X_{i2}, X_{i3}, ..., X_{id}$. In order to determine a solution v_i in the neighborhood of X_i, a solution parameter j and other solution $X_k=(X_{k1}, X_{k2}, X_{k3}, ..., X_{kd})$ are selected randomly. Except for the values of the selected parameter j, all other parameter values of v_i are same as X_i, i.e., $vi=(X_{i1}, X_{i2} ... X_{i(j-1)}, X_{ij}, X_{i(j+1)}, ... X_{id})$. The value v_i of the selected parameter j in v_i is determined using the following formula:

$$v_{ij} = x_{ij} + u(x_{ij} - x_{kj}) \qquad (6)$$

where u is an uniform variate in [-1, 1]. If the resulting value falls outside the acceptable range for parameter j, it is set to the corresponding extreme value in that range.

4.2 Problem Formulation

$$Min\left\{ P_{Lt} = \sum_{i=1}^{n} \left| I_i \right|^2 R_i \right\} \qquad (7)$$

Subject to voltage and current constraints:

$$\left| V_{imin} \right| \le \left| V_i \right| \le \left| V_{imax} \right| \qquad (8)$$

$$\left| I_{ij} \right| \le \left| I_{ijmax} \right| \qquad (9)$$

where I_i is the current flowing through the ith branch which is dependent on the locations and sizes of the DGs. Locations determined by fuzzy method are given as input. So the objective function is now only dependent on the sizes of the DGs at these locations.

R_i is the resistance of the ith branch. V_{imax} and V_{imin} are the upper and lower limits on i^{th} bus voltage. I_{ijmax} is the maximum loading on branch ij. The important operational constraints on the system are addressed by equations 8 and 9.

4.3 Assigned Values for Various Parameters of ABC Method

The assigned values for various parameters of ABC method are as follows.

- Number of Total Bees = 40
- Number of Employed bees = 20
- Number of Onlooker bees = 20
- Number of Scout Bee = 1

- Stopping Criterion --- (Maximum Fitness – Average Fitness) < 10^{-12}

4.4 Algorithm to Find the DG Sizes at Desired Locations using ABC Algorithm

The proposed ABC algorithm for finding sizes of DGs at selected locations to minimize the real power loss is summarized as follows:

1. Read the input data; Initialize MNC (Maximum Iteration Count) and base case as the best solution.
2. Construct initial Bee population (solution) x_{ij} as each bee is formed by the sizes of DG units and the number of employed bees are equal to onlooker bees.
3. Evaluate fitness value for each employed bee by using the following the formula

$$\text{fitness} = \frac{1}{1 + \text{PowerLoss}} \quad (10)$$

4. Initialize iteration = 1.
5. Generate new population (solution) v_{ij} in the neighborhood of x_{ij} for employed bees using equation (6) and evaluate them.
6. Apply the greedy selection process between x_i and v_i.
7. Calculate the probability values P_i for the solutions x_i by means of their fitness values using the equation (5).
8. Produce the new populations v_i for the onlookers from the populations x, selected depending on P_i by applying roulette wheel selection process, and evaluate them.
9. Apply the greedy selection process for the onlookers between x_i and v_i.
10. Determine the abandoned solution, if exists, and replace it with a new randomly produced solution x_i for the scout bees using the following equation

$$x_{ij} = \min_j + \text{rand}(0,1) * (\max_j - \min_j) \quad (11)$$

11. Memorize the best solution achieved so far. If the difference between two successive values is less than specified value, go to step 14.
12. Increase the iteration number by one.
13. If iterations are less than MIC, go to step 5, otherwise go to step 14.
14. Stop.

5 Results and Discussion

First load flow is conducted for IEEE 33 bus test system [7]. The power loss due to active component of current is 136.9836 kW and power loss due to reactive component of the current is 66.9252 kW. Optimal DG locations are identified based on the DSI values. For this 33 bus system, four optimal locations are identified. The candidate locations with their DSI values are given in Table 2.

Table 2 Buses with DSI values.

Bus No.	DSI
32	0.92
30	0.7982
31	0.75
18	0.75

The locations determined by Fuzzy method for DG placement are 32,30,31,18. With these locations, sizes of DGs are determined by using ABC Algorithm described in section 4. The sizes of DGs are dependent on the number of DG locations. Generally it is not possible to install many DGs in a given radial system. Here 4 cases are considered. In case I only one DG installation is assumed. In case II two DGs, in case III three DGS and in the last case four DGs are assumed to be installed. DG sizes in the four optimal locations, total real power losses before and after DG installation for four cases are given in Table 3.

Table 3 Results of IEEE 33 bus system.

Case	DG locations	DG sizes (MW)	Total Size (MW)	Losses before DG installation (kW)	Loss after DG installation (kW)	Saving (kW)	Saving/DG size
I	32	1.2931	1.2931	203.9088	127.0919	76.817	59.405
II	32	0.3836	1.5342	203.9088	117.3946	86.5142	56.39
	30	1.1506					
III	32	0.2701	1.5342	203.9088	117.3558	86.553	56.41
	30	1.1138					
	31	0.1503					
IV	32	0.2701	1.8423	203.9088	90.292	113.6166	61.67
	30	0.8233					
	31	0.1503					
	18	0.5986					

The last column in Table 3 represents the saving in kW for 1 MW DG installation. The case with greater ratio is desirable. As the number of DGs installed is increasing the saving is also increasing. In case4 maximum saving is achieved but the number of DGs is four. Though the ratio of saving to DG size is maximum

of all cases which represent optimum solution but the number of DGs involved is four so it is not economical by considering the cost of installation of 4 DGs. But in view of reliability, quality and future expansion of the system it is the best solution.

Table 4 shows the minimum voltage and % improvement in minimum voltage compared to base case for all the four cases. In all the cases voltage profile is improved and the improvement is significant. The voltage profile for all cases is shown in Fig. 4.

Table 4 Voltage improvement with DG placement.

Case No.	Bus No.	Min Voltage	% Change
Base Case	18	0.9118	
Case1	18	0.9314	2.149
Case2	18	0.9349	2.533
Case3	18	0.9349	2.533
Case4	14	0.9679	6.153

Table 5 shows % improvements in power loss due to active component of branch current, reactive component of branch current and total active power loss of the system in the four cases considered. The loss due to active component of branch current is reduced by more than 68% in least and nearly 96% at best. Though the aim is reducing the P_{La} loss, the P_{Lr} loss is also reducing due to improvement in voltage profile. From Table 5 it is observed that the total real power loss is reduced by 48.5% in case 1 and 67% in case 4.

The convergence characteristics of the solution of ABC algorithm for all the four cases are shown in Fig. 5.

Table 6 shows the minimum, average and maximum values of total real power loss from 100 trials of ABC algorithm. The average number of iterations and average CPU time are also shown.

5.1 Comparison Performance

To demonstrate the validity of the proposed method the results of proposed method are compared with an existing PSO method [20]. The comparison is shown in Table 7.

From the above tables it is clear that the proposed method is producing the results that match with those of existing method. The two methods are tested on four IEEE standard test systems viz. 15 Bus, 34 Bus, 69 Bus and 85 Bus system. The results of these two methods for all the test system are identical. To demonstrate the supremacy of the proposed method the convergence characteristics are compared with that of PSO algorithm as shown in Table 8. Though the number of iterations is more for ABC algorithm it takes less computation time because of its simplicity when compared to PSO method.

The convergence characteristics of the proposed ABC method and PSO methods for remaining test system are given in Table 9.

From the above table it is clear that the time taken for one iteration is very small for ABC compared to PSO method. For small systems the convergence characteristics of ABC method are better than PSO method. For large systems for less number of DG units the convergence characteristics of ABC Method are better than PSO method. When four DG units are to be placed in the system then PSO method is taking less time than ABC method. But generally it is very rare case.
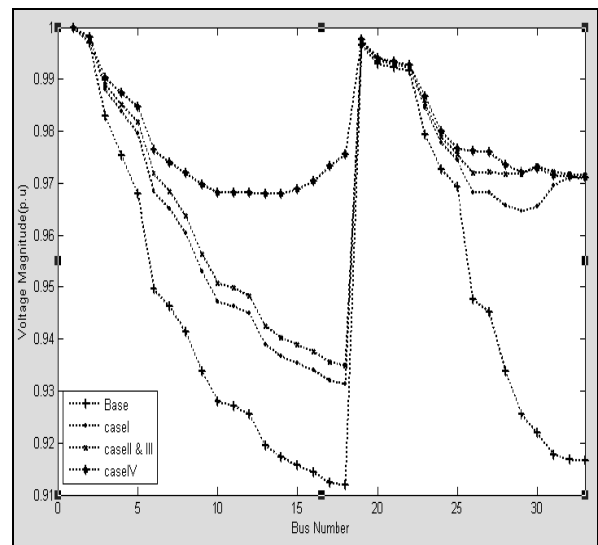

Fig. 4 Voltage profile with and without DG placement for all Cases.

Table 5 Loss reduction by DG placement.

Case No.	P_{La} (kW)	% Saving	P_{Lr} (kW)	% Saving	P_{Lt} (kW)	% Saving
Base case	136.9836	----	66.9252	----	203.9088	----
Case1	62.7085	54.22	64.3834	3.7979	127.0919	37.45
Case2	53.6323	60.847	63.7623	4.726	117.3946	42.43
Case3	53.5957	60.874	63.7601	4.729	117.3558	42.45
Case4	27.7143	79.768	62.5779	6.4957	90.292	55.72

Table 6 Performance of ABC algorithm for IEEE 33 Bus System.

Total real power loss (kW)	Case I	Case II	Case III	Case IV
Min	105.023	89.9619	79.2515	66.5892
Average	105.023	89.9619	79.2515	66.5892
Max	105.023	89.9619	79.2515	66.5892
Bee swarm Size	40	40	40	40
Avg. No. of iterations	93.45	118.73	196.75	256.34
Average Time (Sec.)	3.344	4.89	7.89	10.14

Table 7 Comparison of results of IEEE 33-bus system by proposed method and other existing method.

Case	Bus Locations	Sizes (MW)		Total Size (MW)		Saving (kW)	
		ABC	PSO	ABC	PSO	ABC	PSO
1	32	1.2931	1.2931	1.1883	1.1883	76.3619	76.3619
2	32	0.3836	0.3836	1.416	1.416	86.0246	86.0246
	30	1.1506	1.1506				
3	32	0.2701	0.2701	1.416	1.416	86.0628	86.0628
	30	1.1138	1.1138				
	31	0.1503	0.1503				
4	32	0.27006	0.2700	1.86176	1.86176	113.4294	113.4294
	30	0.8432	0.8432				
	31	0.1503	0.1503				
	18	0.5982	0.5982				

Table 8 Comparison of results of ABC and PSO algorithms.

	Case I		Case II		Case III		Case IV	
	ABC	PSO	ABC	PSO	ABC	PSO	ABC	PSO
Swarm Size	40	30	40	30	40	30	40	30
Avg. No. of iterations	93.45	98.26	118.73	127.06	196.75	145.81	256.54	171.69
Avg. time(sec.)	3.344	5.234	4.89	6.39	7.89	8.688	10.14	10.78

Table 9 Comparison of convergence characteristics of ABC and PSO algorithms.

| System	Average Computation Time		Average No. of Iterations		Swarm Size	
	ABC	PSO	ABC	PSO	ABC	PSO
15 Bus	2.047	1.328	90.78	91.84	40	30
	2.252	2.141	102.8	146.29		
33 Bus	5.187	3.61	108.38	93.37		
	6.486	5.797	115.89	150.21		
	6.8386	8.734	120.93	227.83		
	7.515	10.75	128.19	278.19		
69 Bus	14.81	9.047	100.25	98.16		
	15.17	14.624	114.79	161.65		
	15.36	19.672	119.32	212.72		
	14.36	20.765	124.86	229.41		
85 Bus	23.31	10.717	126.91	81.96		
	23.97	17.35	128.48	129.04		
	25.63	33.016	137.43	248.81		
	29.97	35.047	158.62	263.84		
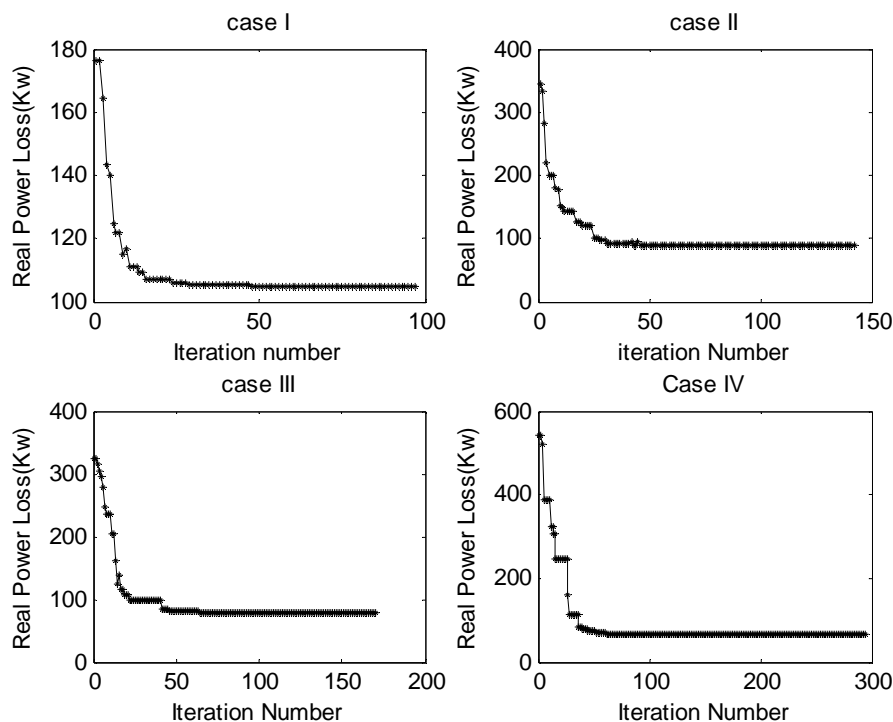
Fig. 5 Convergence characteristic of ABC algorithm for 33 bus test system.

6 Conclusion

In this paper, a two-stage methodology of finding the optimal locations and sizes of DGs for maximum loss reduction of radial distribution systems is presented. Fuzzy method is proposed to find the optimal DG locations and a ABC algorithm is proposed to find the optimal DG sizes. Voltage and line loading constraints are included in the algorithm.

The validity of the proposed method is proved from the comparison of the results of the proposed method with other existing methods. The results proved that the ABC algorithm is simple in nature than GA and PSO so it takes less computation time. By installing DGs at all the potential locations, the total power loss of the system has been reduced drastically and the voltage profile of the system is also improved. Inclusion of the real time constrains such as time varying loads and different types of DG units and discrete DG unit sizes into the proposed algorithm is the future scope of this work.

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M. Padma Lalitha is pursuing Ph.D and is a graduate from JNTU, Anathapur in Electrical & Electronics Engineering in the year 1994. Obtained Post graduate degree in PSOC from S.V.U, Tirupathi in the year 2002. Having 14 years of experience in teaching in graduate and post graduate level. Has 10 international journal publications and 10 international and national conferences to her credit. Presently working as Professor and HOD of EEE department in AITS, Rajampet. Areas of interest include radial distribution systems, artificial intelligence in power systems, ANN.
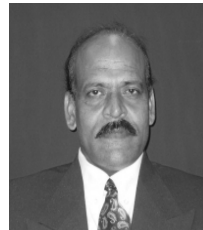
V. C. Veera Reddy presently working as a professor in EEE department of S.V.U. College of Engineering, Tirupathi. He awarded Ph.D for his work **"**Modeling & Control of Load frequency using New Optimal Control strategy" from S.V.U. in the year 1999.Have 28 years of experience in teaching and worked in various levels. Guided a number of research scholars. Attended a number of national & international conferences. Areas of interest include Distribution systems, Genetic Algorithms, Fuzzi Systems, ANN.

N. Sivarami Reddy is pursuing Ph.D and is a graduate from SRKREC, Bimavaram in Mechanical Engineering in the year 1989. Obtained Post graduate degree in Advanced Manufacturing Systems from NIT, Suratkal in the year 1992. Having 18 years of experience in teaching in graduate and post graduate level. Presently working as Professor and HOD of ME department in AITS, Rajampet. Areas of interest include Flexible Manufacturing systems, Soft computing techniques in FMS.