DG Source Allocation by Fuzzy and Clonal Selection Algorithm for Minimum Loss in Distribution System

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ABSTRACT

Distributed Generation (DG) is a promising solution to many power system problems such as voltage regulation, power loss, etc. This article presents a new methodology using Fuzzy and Artificial Immune System (AIS) for the placement of Distributed Generators (DGs) in a radial distribution system 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, the *Fuzzy Set* approach is used to find the optimal DG locations and in the second stage, Clonal Selection algorithm of AIS is used to size the DGs corresponding to maximum loss reduction. This algorithm is a new, population based, optimization method inspired by the cloning principle of the human body immune system. The advantage of this algorithm is the population size is dynamic and it is determined by the fitness values of the population. The proposed method is tested on standard IEEE-33 based bus test system. Net, the results are compared with different approaches available in the literature. The proposed method outperforms the other methods in terms of the quality of solution and computational efficiency.

Keywords: *DG placement, Meta heuristic methods, Artificial Immune Systems, Clonal Selection algorithm, loss reduction, radial distribution system*

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 energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, the 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] or network stability. 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, DG is 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 [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.

Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) have been applied to DG placement [10-13] for either, sizing or location of DGs. This article presents a new methodology using Clonal selection algorithm [14-17] for the placement of DG in the radial distribution systems. The Clonal algorithm is a new population based meta heuristic approach inspired by the Clonal principle of immune system of human body. The advantage of this algorithm is that it does not require external parameters such as selection, cross over rate and mutation rate as in case of genetic algorithm (GA) and differential evolution and it is hard to determine these parameters *a priori*. The other advantage is that the global search ability in the algorithm is implemented by introducing hyper mutation which differs from mutation in GA in two ways. One is the mutation rate is very high that every solution is mutated here and the second one is the mutation is not a single bit mutation. A key advantage of Clonal algorithm is its dynamic population size.

In this article, the optimal locations of distributed generators are identified based on the Fuzzy method [18] and Clonal 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 Clonal 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.

THEORETICAL BACKGROUND

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

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

Here I_i is the magnitude of the branch current and R_i is the resistance of the i^{th} 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:

$$P_{La} = \sum_{i=1}^{n} I_{a\,i}^{2} Ri \tag{2}$$

$$P_{Lr} = \sum_{i=1}^{n} I_{r\,i}^{2} Ri \tag{3}$$

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, (a) the active component of branch currents is compensated and (b) losses due to active component of branch current are reduced. This article 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 size DGs for maximum real loss reduction.

OPTIMAL DG LOCATIONS USING FUZZY APPROACH

This article 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: (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. Then the Power Loss Index [18] value for i^{th} node can be obtained using Equation 4, given next.

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

These power loss reduction indices along with the Per-Unit* or P.U. nodal voltages are the inputs to the Fuzzy Inference System (FIS), which determines the nodes that are more suitable for DG installation.

Implementation of Fuzzy method

In this article, 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 Figure 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 Figure 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 Figure 3.

Editorial Note: In the power transmission field of electrical engineering, a Per-Unit system is the expression of system quantities as fractions of a defined base unit quantity. Calculations are simplified because quantities expressed as per-unit are the same regardless of the voltage level. Similar types of apparatus will have impedances, voltage drops and losses that are the same when expressed as a per-unit fraction of the equipment rating, even if the unit size varies widely. Conversion of per-unit quantities to volts, ohms, or amperes requires knowledge of the base that the per-unit quantities were referenced to.

A per-unit system provides units for power, voltage, current, impedance, and admittance. Only two of these are independent, usually power and voltage. All quantities are specified as multiples of selected base values. For example, the base power might be the rated power of a transformer, or perhaps an arbitrarily selected power which makes power quantities in the system more convenient. The base voltage might be the nominal voltage of a bus. Different types of quantities are labeled with the same symbol (pu or P.U.); it should be clear from context whether the quantity is a voltage, current, etc.

Per-unit is used primarily in power flow studies; however, because parameters of transformers and machines (electric motors and electrical generators) are often specified in terms of per-unit, it is important for all power engineers to be familiar with the concept.

For the DG allocation problem, rules are defined to determine the suitability of a node for DG 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 capacitor placement. These rules are summarized in the fuzzy decision matrix in Table 1. In the present work 25 rules are constructed.*

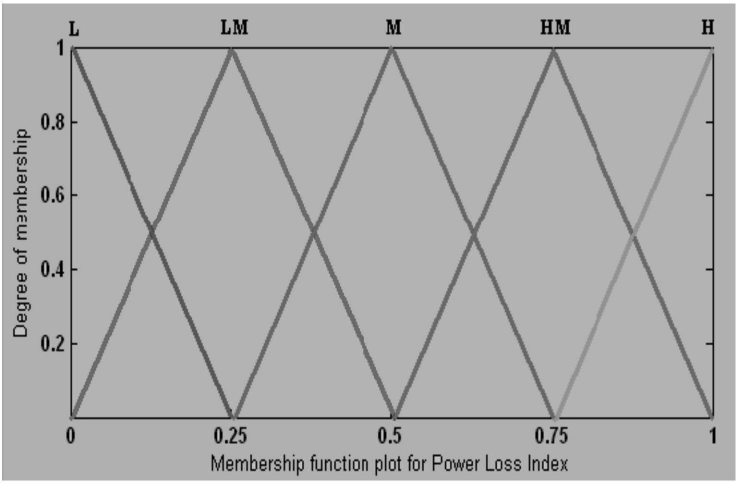

Figure 1. Membership function plot for PLI.

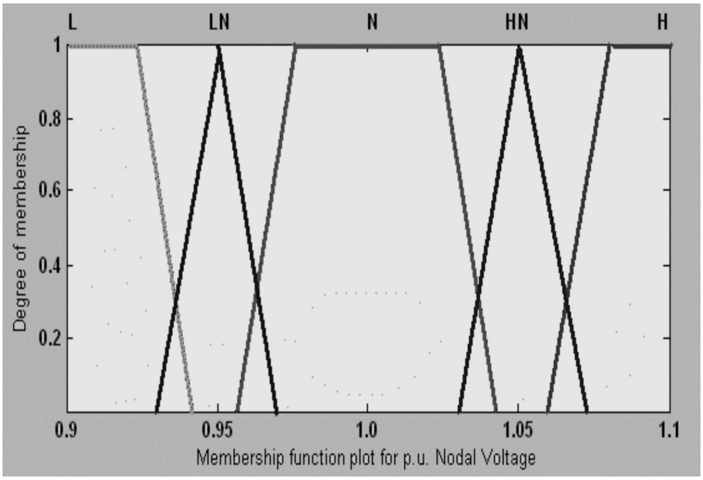

Figure 2. Membership function plot for voltage

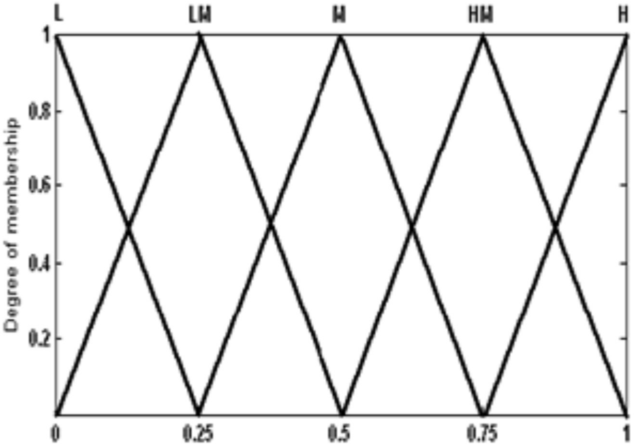

Figure 3. Membership function plot for DSI

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

IDENTIFICATION OF OPTIMAL DG SIZES BY CLONAL ALGORITHM

Introduction to the Artificial Immune System

The 'artificial immune system' is an approach which uses the natural immune system as a metaphor for solving computational problems, *not* modeling the immune system [14]. The main application domains of AIS are anomaly detection, pattern recognition, computer security, fault tolerance, dynamic environments, robotics, data mining, optimization, and scheduling. The 'immune system' (IS) can be considered to be a remarkably efficient and powerful information processing system which operates in a highly parallel and distributed manner. It contains a number of features which potentially can be adapted in computer systems; recognition, feature extraction, diversity, learning, memory, distributed detection, self-regulation, threshold mechanism, co-stimulation, dynamic protection, and probabilistic detection. It is unnecessary to replicate *all* of these aspects of the IS in a computer model, rather they should be used as general guidelines in designing a system.

There are a number of different algorithms that can be applied to many domains, from data analysis to autonomous navigation [14]. These immune algorithms were inspired by works on theoretical immunology and several processes that occur within the IS. The AISs lead to the development of different techniques, each one mapping a different mechanism of the system. For examples, the *Artificial Immune Networks* as proposed by Farmer et al. [15], the *Clonal Selection Algorithm* proposed by de Castro and Von Zuben [16], and the *Negative Selection Algorithm* introduced by Forrest et al. [17]. Immune network models are suitable to deal with dynamic environments and optimization problems, algorithms based upon the clonal selection principle are adequate to solve optimization and scheduling problems, and the negative selection strategies are successfully applied to anomaly detection.

Application of Clonal Algorithm to determine DG Unit Sizes

The clonal selection algorithm (CSA) is inspired by the immunological processes of *clonal selection* and *affinity maturation*. When an antigen is detected, those antibodies that best recognize this antigen will proliferate by cloning. This process is called *clonal selection principle* [6]. The clonal selection principle is used to explain how the IS 'fights' against an antigen. When a bacterium invades our organism, it starts multiplying and damaging our cells. One form the IS found to cope with this replicating antigen was by replicating the immune cells successful in recognizing and fighting against this disease-causing element. Those cells reproduce themselves asexually in a way proportional to their degree of recognition: the better the antigenic recognition, the higher the number of clones (offspring) generated. During the process of cell division (reproduction), individual cells suffer a mutation that allows them to become more adapted to the antigen recognized: the higher the affinity of the parent cell, the lower the mutation they suffer. The algorithm is given below.

> ***Initialization***: initialize a population of antibodies (feasible sizes of DG unit at predetermined locations). Each antibody represents a solution in the search space.
>
> ***Selection:*** All the antibodies are selected in optimization version
>
> ***Affinity Evaluation***: determine the affinity of selected antibodies (affinity = 1/Power Loss)
>
> ***Cloning or proliferation***: The selected antibodies will be cloned (reproduced) independently and proportionally to their affinities, generating a repertoire of clones: the higher the affinity, the higher the number of clones generated for each of the selected antibodies;
>
> ***Hyper-mutation***: The repertoire of clones is submitted to an affinity maturation process inversely proportional to the affinity, generating a population of matured clones: the higher the affinity, the smaller the mutation rate;
>
> ***Affinity evaluation:*** determine the affinity of matured clones
>
> ***Reselection:*** From this set of mature clones re-select the higher affinity clones
>
> Finally, replace the *d* lowest affinity antibodies from the population of the antibodies by new individuals generated randomly to maintain the diversity in population area selected for cloning and a number of clones are generated for each solution. Almost all clones will

be mutated to produce new feasible solutions for the next generation since '1—selection probability' would give a high mutation rate for each clone. But only new solutions with high affinity will be selected to replace the low affinity solutions in the current population. The process will be repeated until the stopping criteria are met. Note the main operators in CSA are *cloning, mutation and* re*selection*.

In our implementation, it was assumed that the *n* highest affinity antibodies were sorted in ascending order after Step 3, so that the amount of clones generated for all these *n* selected antibodies is given by Equation (5), as follows:

$$N_c = \sum_{i=1}^{n} round\left(\frac{\beta . N}{i}\right) \tag{5}$$

Where: *N*c is the total amount of clones generated, β is a multiplying factor, *N* is the total amount of antibodies and *round*(·) is the operator that rounds its argument towards the closest integer. Each term of this sum corresponds to the clone size of each selected antibody, e.g., for *N* = 100 and β= 1, the highest affinity antibody (*i* = 1) will produce 100 clones, while the second highest affinity antibody produces 50 clones, and so on.

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.

The locations determined by Fuzzy method for DG placement are 6, 15, 25, 32. With these locations, sizes of DGs are determined by using Clonal Algorithm described previously. 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 four 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.

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 case IV 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 Figure 4.

Table 5 shows % improvements in power loss due to active component of branch current, reactive component of branch current and total

Table 2. Buses with DSI Values

Bus No.	DSI
32	.92
30	.7982
31	.75
18	.75

Table 3. Results of IEEE 33 Bus System

Case	bus 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					

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

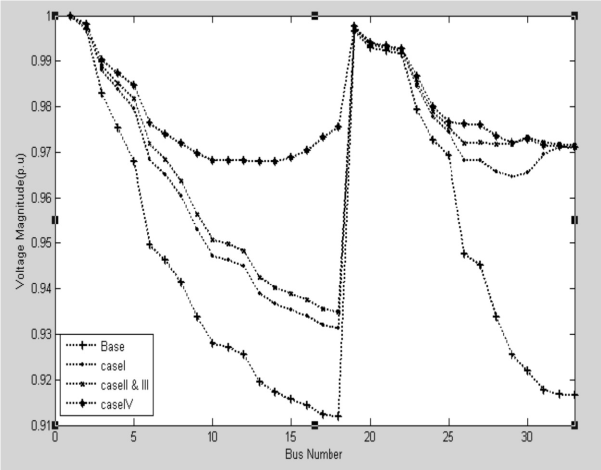

Figure 4. Voltage Profile with and without DG Placement for All Cases

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 IV.

The convergence characteristics of the solution of Clonal selection algorithm for all the four cases are shown in Figure 5. Table 6 shows the minimum, average and maximum values of total real power loss from 100 trials of Clonal selection algorithm. The average number of iterations and average CPU time are also shown.

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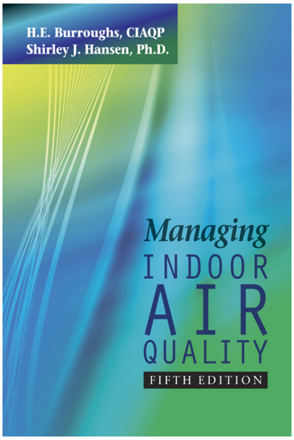

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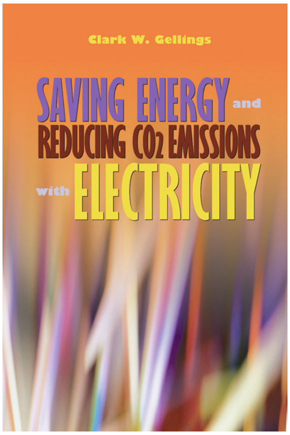

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Table 5. Loss Reduction by DG Placement

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

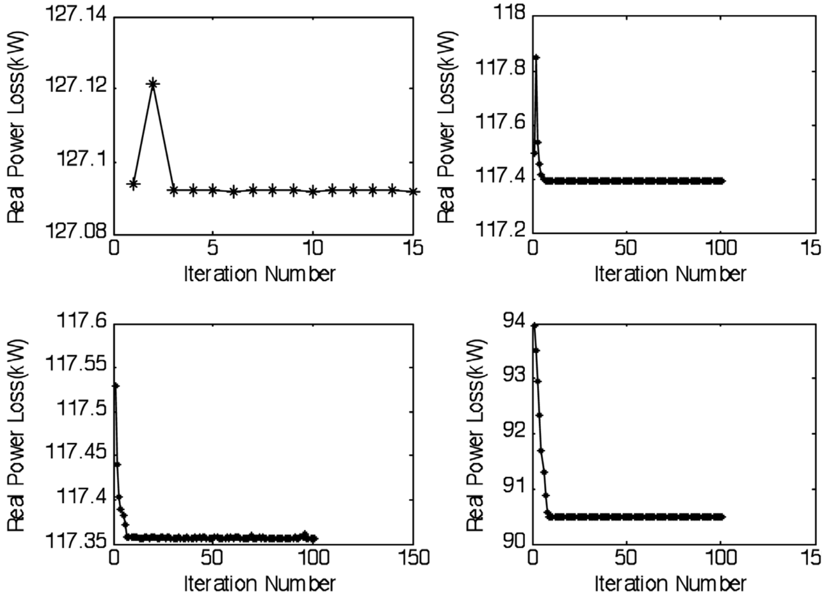

Figure 5. Convergence characteristic of Clonal selection algorithm for 33 bus test system.

Table 6. Performance of Clonal Selection algorithm for IEEE 33 Bus System

Total real power loss (kW)	**Case I**	**Case II**	**Case III**	**Case IV**
Min	104.813	89.752	79.012	66.029
Average	105.023	89.9619	79.2515	66.5892
Max	105.424	90.12	79.856	66. 759
No. of Antibodies	50	50	50	50
Avg. No. of iterations	8.257	24.384	62.896	67.903
Average Time (Sec.)	1.563	9	21.25	28.937

Comparison Performance

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

From Table 7 it is clear that the proposed method is producing the results that matches with those of existing method or even slightly better results. To demonstrate the supremacy of the proposed method the convergence characteristics are compared with that of PSO algorithm as shown in Table 8. Both the number of iterations and computation time are less for Clonal selection algorithm. The only disadvantage of the proposed method is, it is producing slightly different results for each run.

CONCLUSIONS

In this article, 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 Clonal Selection 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 demonstrate that the proposed 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 continuing work.

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Table 7. Comparison of results of IEEE 33-bus system by proposed method and the PSO method.

Case	Bus locations	sizes(Mw)		Total Size(Mw)		saving(Kw)	
		Clonalg	PSO	Clonalg	PSO	Clonalg	PSO
1	32	1.2931	1.2931	1.1883	1.1883	76.8169	76.3619
2	32	0.3835	0.3836	1.416	1.416	86.5142	86.0246
	30	1.1509	1.1506				
3	32	0.2703	0.2701	1.416	1.416	86.5529	86.0628
	30	1.1130	1.1138				
	31	0.1503	0.1503				
4	32	0.2642	0.27006	1.86176	1.86176	113.4292	113.4294
	30	0.8413	0.8432				
	31	0.1508	0.1503				
	18	0.5992	0.5982				

Table 8. Comparison of results of Clonal Selection Algorithm and PSO algorithms

	Case I		Case II		Case III		Case IV	
	Clonalg	PSO	Clonalg	PSO	Clonalg	PSO	Clonalg	PSO
Swarm Size	50	50	50	50	50	50	50	50
Avg. No. of iterations	8.257	123.48	24.384	126.97	62.896	141.29	67.903	149.31
Avg. time(sec.)	1.563	40.02	9	53.4	21.25	58.938	28.937	63.78

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