Optimal Distributed Generation Allocation in Distribution Systems Employing Modified Artificial Bee Colony Algorithm to Reduce Losses and Improve Voltage Profile

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Abstract— **One of the modern and important techniques in electrical distribution systems is to solve the networks problem of service availability, high loss and low voltage stability by accommodating small scaled de-centralized generating units in these networks, which is known as distributed generation (DG).This paper presents a new methodology using a new population based meta heuristic approach namely Modified 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 improves supply quality and reliability, reduces green house effects, improves voltage profile in radial distribution system, reduces line loss and environment impact. The modification is in the neighbouring search of the artificial bee colony (ABC) algorithm. The suggested method is programmed under MATLAB software and is tested on IEEE 33-bus test system and the results are presented. The method is found to be effective and applicable for practical network**

Keywords-component; **Distributed Generation, Power Loss Reduction, Artificial Bee Colony Algorithm**

I. INTRODUCTION

Distributed generation 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 to lower the cost of service [1]. Numerous studies used different approaches to evaluate the benefits from DGs to a network in the form of loss reduction, loading level reduction [6-7].

Optimization tools have been employed to solve different DG-unit problems. These include Genetic Algorithm (GA), Evolutionary Programming (EP) and Particle Swarm Optimization (PSO.) Some of those techniques have been modified to enhance their performance or to overcome other limitations.

Minimizing power loss by finding the optimal size, location and operation point of DG-unit was suggested in [4]. The authors of [5] employed the GA for Optimal Power Flow (OPF) to minimize the DG-unit's active and reactive power costs. Two examples of DG-unit optimization cases were considered, with and without reactive power injection. Significant reduction in the search space was attained by eliminating the DG-unit size. However, DG-unit dispatching can cause operational problems in the distribution feeders. An algorithm was offered in [6] to maximize the reduction of load supply costs as well as operational schedules for all feeder load levels exploiting EP. The optimal solution was selected based on maximum cost reduction, which was attained through evaluating the cost of DG-unit supply scenarios based on the base case.

In this paper, a modified artificial bee colony (ABC) algorithm is proposed to solve the DG-unit application problem. The ABC algorithm is a new meta-heuristic approach inspired by the intelligent foraging behaviour of honey-bee swarm. 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 algorithm was tested on 33-Bus Distribution System [9].To demonstrate the effectiveness of proposed method, results are compared with different approaches available in the literature. The results demonstrate that the proposed modification improves the solution quality and efficiency of the ABC algorithm.

II. FORMULATION OF OPTIMIZATION MODEL FOR LOSS MINIMIZATION

A new method is introduced to minimize the losses associated with the absolute value of branch currents by optimally placing DG units. The problem of DG unit placement consists of determining the size, location and number of DG units to be installed in a distribution system such that maximum benefits are achieved while operational constraints at different loading levels are satisfied. The total power loss in a distribution system having 'n' number of branches is given by

$$P_{TL} = \sum_{i=1}^{n} I_i^2 R_i \qquad (1)$$

I_i is the current magnitude and R_i is the resistance. I_i can be obtained from load flow study. The branch current has two components: active component I_a and reactive component I_r.

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The total losses associated with these two components can be written as

$$P_{TL} = P_{La} + P_{Lr} \tag{2}$$

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

For a given configuration of a single source radial distribution network, the losses P_{La} associated with the active component of branch current cannot be minimized because all the active power must be supplied by the source at the root bus. This is not true if DG units are to be placed at different locations for loss reduction that is real power can be supplied locally by using DG units of optimum size to minimize P_{La} associated with the active component of branch current. However there is significant change in reactive power loss with DG unit in distribution system.

A. Identification of Optimal DG Location

This algorithm determines the optimal size and location of DG units that should be placed in the system to minimize loss. First optimum sizes of DG units for all nodes are determined for base case and best one is chosen based on the maximum loss saving. This process is repeated if multiple DG locations are required by modifying the base system by inserting a DG unit into the system one-by-one.

A. 1 Methodology

Consider RDN with 'n' branches. Let a DG unit be placed at bus 'm' and 'β' be a set of branches connected between the source and DG unit. If the DG unit is placed at bus 'X' then 'β' consists of branches $X_1, X_2\ X_3$ ...., X_n. The DG unit supplies active component of current I_{DG} and for radial distribution network it changes only the active component of current of branch set 'β'. The current of other branches is not affected by the DG unit. Thus new active current I_{ai}^{new} of the i^{th} branch is given by

$$I_{ai}^{new} = I_{ai} + DG_i I_{DG} \tag{4}$$

Where DG_i =1; if branch $i \in \beta$

=0; otherwise

I_{ai} is the active component of current of i^{th} branch in the original system obtained from the load flow solution. The P_{La}^{com} is associated with the active component of branch currents in the compensated system. For a DG unit placed at node 'k', the system losses are

$$P_{La}^{com} = \sum (I_{ai} + DG_i I_{DG})^2 R_i + \sum_{k+1}^{n} I_{ai}^2 R_i + \sum_{i=1}^{n} I_{ri}^2 R_i \tag{5}$$

The power saving, S is the difference between equation 8 and 10 due to the introduction of DG unit at node 'k' is given by

$$S = P_{La} - P_{La}^{com}$$

$$= -2I_{DG} \sum_{i=1}^{n} DG_i I_{ai} R_i - I_{DG}^2 \sum_{i=1}^{k} DG_i R_i \tag{6}$$

The DG current I_{DG} that provides maximum saving can be obtained from

$$\frac{\delta S}{\partial I_{DG}} = -2\sum_{i=1}^{n} DG_i I_{ai} R_i - I_{DG} \sum_{i=1}^{k} DG_i R_i = 0 \tag{7}$$

The DG current for maximum saving is

$$I_{DG} = -\frac{\sum_{i=1}^{k} DG_i I_{ai} R_i}{\sum_{i=1}^{k} DG_i R_i}$$

$$I_{DG} = -\frac{\sum_{i \in \beta} I_{ai} R_i}{\sum_{i \in \beta} R_i} \tag{8}$$

The corresponding DG size is

$$P_{DG} = V_k I_{DG} \tag{9}$$

V_k is the magnitude of voltage at bus k. The optimum size of DG at each bus is determined using eqn (9). Then saving for each DG is determined using eqn (6).The DG with highest saving is the candidate location for DG placement. When the candidate bus is identified and DG is placed, the load flow is carried out to calculate the new loss and new voltage.

An advantage of deploying DG-units in distribution networks is to minimize the total system real power loss while satisfying certain operating constraints. The power flow algorithm offered in [8] is applied in this paper.

The mathematical formulation of the mixed integer nonlinear optimization problem for the DG-unit application is as follows:

1. The objective function is minimizing the total system real power loss as follows:

$$Obj.Fun. = \min \sum_{i=1}^{n} I_i^2 R_i \tag{10}$$

2. The inequality constraints are the system's voltage limits i.e., ±5% of the nominal voltage value.

$$|V_{\min}^{spec}| \le |V_i^{sys}| \le |V_{\max}^{spec}| \qquad i = 1, 2, 3\ldots.n \tag{11}$$

3. In addition, the thermal capacity limits of the network's feeder lines are treated as inequality constraints:

$$S_{i,i+1}^{sys} \le S_{i,i+1}^{rated} \ge S_{i+1,i}^{sys} \qquad i = 1, 2, \ldots..n \tag{12}$$

4. The boundary (discrete) inequality constraints are the DG-unit' size (kVA) as follows:

$$|S_{DG}^{\min}| \leq |S_{DG}| \leq S_{DG}^{\max} \qquad i = 1, 2, 3 \ldots\ldots\ldots n \qquad (13)$$

Since the DGs are added to the system one by one, the sizes obtained by single DG placement algorithm are local optima not global optimum solution. The global optimal solution is obtained if multiple DGs are simultaneously placed in the system by using ABC algorithm. This method is explained in next section.

III.ARTIFICIAL BEE COLONY (ABC) ALGORITHM

The artificial bee colony (ABC) algorithm was introduced in 2005 by Karaboga [10]. Initially, it was proposed for unconstrained optimization problems. Then, an extended version of the ABC algorithm was offered to handle constrained optimization problems [11]. Furthermore, the performance of the ABC algorithm was compared with those of some other well-known population-based optimization algorithms, and the results and the quality of the solutions were outperformed or matched those obtained using other methods [11-12].

The probability of selecting a food-source p_i by onlooker bees is calculated as follows:

$$p_i = \frac{fitness_i}{\sum_{i=1}^{E_b} fitness_i} \qquad (14)$$

where, $fitness_i$ is the fitness value of a solution i, and E_b is the total number of food-source positions (solutions) or, in other words, half of the colony size. Clearly, resulting from using eq. (14), a good food source (solution) will attract more onlooker bees than a bad one. Subsequent to onlookers selecting their preferred food-source, they produce a neighbour food-source position $i+1$ to the selected one i, and compare the nectar amount (fitness value) of that neighbour $i+1$ position with the old i position. The same selection criterion used by the employed bees is applied to onlooker bees as well. This sequence is repeated until all onlookers are distributed. Furthermore, if a solution i does not improve for a specified number of times (limit), the employed bee associated with this solution abandons it, and she becomes a scout and searches for a new random food-source position. Once the new position is determined, another ABC algorithm cycle MCN starts. The same procedures are repeated until the stopping criteria are met.

In order to determine a neighbouring food-source position (solution) to the old one in memory, the ABC algorithm alters one randomly chosen parameter and keeps the remaining parameters unchanged. In other words, by adding to the current chosen parameter value the product of the uniform variant [-1, 1] and the difference between the chosen parameter value and other "random" solution parameter value, the neighbour food-source position is created according to the following expression:

$$x_{ij}^{new} = x_{ij}^{old} + u(x_{ij}^{old} + x_{kj})` \qquad (15)$$

where, $k \neq i$ and both ∈ {1, 2, ... E_b }. The multiplier u is a random number between [-1, 1] and $j \in$ {1, 2, ...D}. When the food-source position has been abandoned, the employed bee associated with it becomes a scout. The scout produces a completely new food-source position as follows:

$$x_i^{j(new)} = \min x_i^j + u(\max x_i^j - \min x_i^j) \quad (16)$$

where, eq. (11) applies for all j parameters and u is a random number between [-1,1]. If a parameter value produced using (10) and/or (11) exceeds its predetermined limit, the parameter can be set to an acceptable value [58]. In this paper, the value of the parameter exceeding its limit is forced to the nearest (discrete) boundary limit value associated with it. Furthermore, the random multiplier number u is set to be between [0, 1] instead of [-1, 1].

IV ABC ALGORITHM FOR DG APPLICATION PROBLEM

The solution steps of the proposed ABC algorithm for DG-unit application are described as follows:

Initialize the food-source positions x_i (solutions population), where $i = 1, 2, 3 \ldots\ldots E_b$.

Calculate the nectar amount of the population by means of their fitness values using:

$$fitness_i = 1/(1 + Obj.Fun._i) \qquad (17)$$

Where, $Obj.Fun._i$ represents the response of eq. (1) at solution i.

3. Produce neighbour solutions x_{ij}^{new} for the employed bees by using eq. (10) and evaluate them as indicated in step 2.
4. Apply the selection process.
5. If all onlooker bees are distributed, go to step 9. Otherwise, go to the next step.
6. Calculate the probability values p_i for the solutions x_{ij}^{new} using eq. (9)
7. Produce neighbour solutions x_{ij}^{new} for the selected onlooker bee, depending on the p_i value, using eq. (10) and evaluate them as step 2 indicates.
8. Follow step 4.
9. Determine the abandoned solution for the scout bees, if it exists, and replace it with a completely new solution $x_i^{j(new)}$ using eq. (11) and evaluate them as indicated in step 2.
10. Memorize the best solution attained so far.

11. If $cycle = MCN$, stop and print result. Otherwise follow step 3.

A. The Proposed Modified ABC Algorithm

The proposed neighboring search takes place during the onlooker search cycle. In other words, once the solution with high probability value is determined, all O_b recruit to search positions in the neighbourhood of the selected solution (food source), and then compare these neighbour nectar amounts with the old (selected) one, after that apply the selection process. This search cycle is repeated O_b times. The features of the proposed process are as follows: 1) it reduces the MCN and CS with insignificant impact on the solution quality resulting in accelerating the algorithm performance and, 2) it has good potential for problems with large (high-dimensional) decision space.

V. RESULTS AND DISCUSSION

The total loads of the 33-bus system are 3720 kW and 2300 kVar. Data of this system is given in [9].

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 I

Case	Bus Location	DG Sizes(MW)	Total Size (MW)
I	6	2.59	2.59
II	6	1.9589	2.56
	14	0.6063	
III	6	1.1891	2.52
	14	0.6469	
	31	0.6863	
IV	6	0.9261	3.22
	14	0.6469	
	31	0.6863	
	24	0.9672	

Table II

Case	Losses after DG (KW)	Losses before DG (KW)	Saving (KW)	Loss Reduction %
I	111.10	210.84	98.94	46.92
II	92.29		118.55	56.22
III	73.757		137.08	65.01
IV	68.611		142.22	67.45

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 case4 is optimal 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 III: Comparison of Voltage improvement

Case No.	Proposed Method Minimum Voltage	Proposed Method % Improvement	Method [12] % Improvement
Base Case	0.9038		
Case-I	0.94661	4.52	2.149
Case-II	0.9533	5.19	2.533
Case-III	0.97503	7.30	2.533
Case-IV	0.97523	7.32	6.175

Thus it can be seen that the proposed method has greater improvement in voltage profile and the method [12].

The voltage profile for all cases is shown in Figure 1, Figure 2, Figure 3 and Figure 4. In all the cases voltage profile is improved and the improvement is significant.

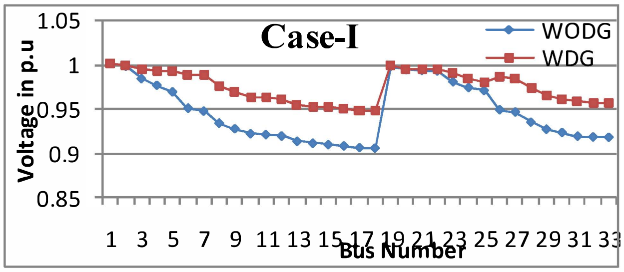

Figure 1

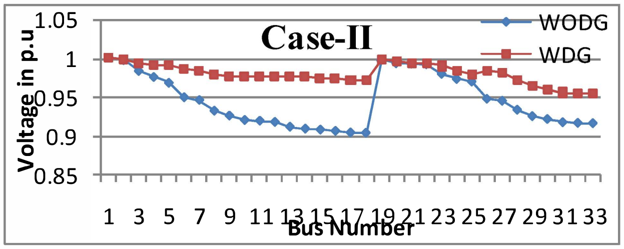

Figure 2

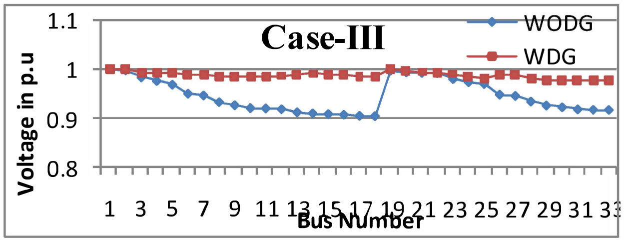

Figure 3

Table IV

Methods	Optimum	Optimum DG size	Power Loss

	location	(MW)	Without DG	With DG
[7]	Bus 6	2.49	211.20	111.24
Proposed Method	Bus 6	2.59	210.84	111.10

Table IV shows the comparison of our result with [7] and show that loss is minimum as compare to [7]

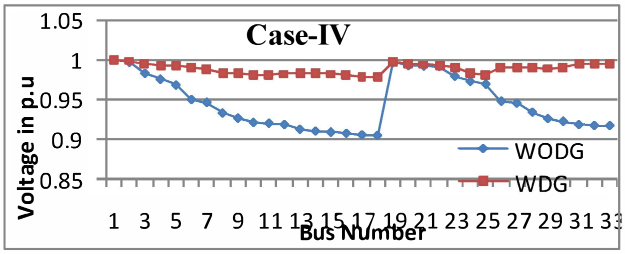

Figure 4

The convergence characteristics of ABC algorithm for all cases are shown in figure 5, figure 6, figure 7 and in figure 8

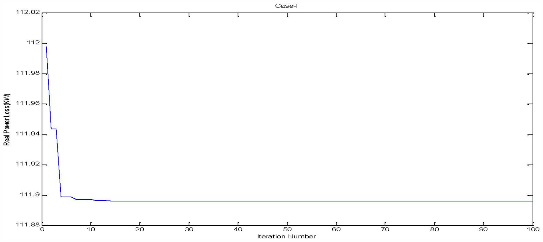

Figure 5

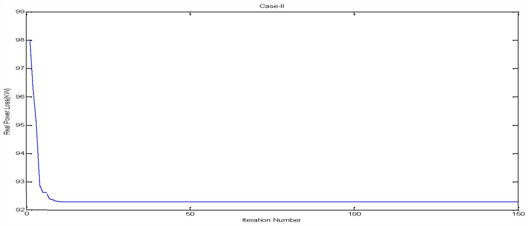

Figure 6

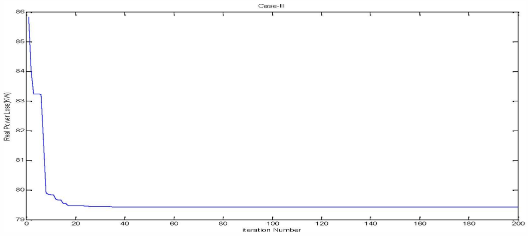

Figure 7

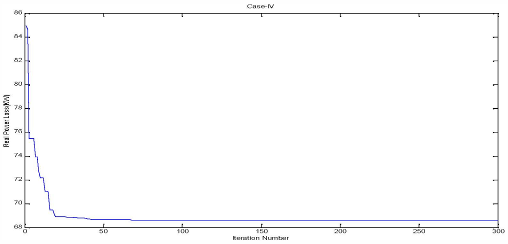

Figure 8

VI. CONCLUSION

In this paper, a modification to the new meta-heuristic population-based artificial bee colony algorithm (ABC) has BEEN PROPOSED. Simulations were conducted on the IEEE 33-bus radial feeder systems. The proposed modified ABC algorithm successfully achieved the optimal solutions at different cases with advantages of less CPU time-consumption and high solution quality. In addition, the results of the proposed algorithm were either matched or outperformed those attained by other methods. The outcomes of the proposed modified ABC algorithm were encouraging to exploit it in large dimensional optimization problems for future research.

Evidently as Figures 5, 6, 7 and figure 8 demonstrated, the modified ABC algorithm has excellent solution quality and convergence characteristics. The performance of the proposed algorithm shows its superiority and potential for solving complex power system problems in future publications.

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