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Optimal Placement of DG Units for Loss Reduction in Distribution Systems Using One Rank Cuckoo Search Algorithm

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Abstract

This paper presents a hybrid method to determine the optimal locations and sizes of DG units in distribution networks using Fuzzy and one rank cuckoo search Algorithm (ORCS). The main objective functions are to reduce total power losses and to improve voltage profiles of power distribution networks. As major power losses are occurring on distribution networks, Keen interest is evinced to reduce them. Due to the increasing interest on renewable sources in recent times, the studies on integration of distributed generation to the power grid have rapidly increased. The Distributed Generation (DG) sources are added to the networks mainly to reduce the power losses by supplying a net amount of power. In order to minimize the line losses of power systems, it is equally important to define the size and location of local generation. In this paper fuzzy approach is used to find the optimal DG locations and one rank cuckoo search algorithm is used for optimal sizes of the DG units. The proposed method is tested on IEEE 15-bus, 33-bus and 69-bus test systems and the results are presented.

Keywords: *Loss reduction, one rank cuckoo search algorithm, Fuzzy, radial distribution systems, DG unit*

1. Introduction

Reduction of total power loss in distribution system is very essential to improve the overall efficiency of power delivery. This can be achieved by placing the optimal value of Distributed Generators at proper locations in radial distribution systems. DG units placed at optimal locations with optimum sizes to reduce the losses and to improve the voltages within the limits.

Application of Distributed Generators to the primary distribution feeders is a common practice in most of the countries. The objective of the Distributed Generators placement problem is to determine the locations and sizes of the Distributed Generators so that the power loss is minimized and annual savings are maximized.

Distributed generation has been a topic of research for the past few decades. A lot of study is carried out in this area. Dugan, R.C and Mc Dermott, T.E [1] defined the distributed generation as follows. Distributed generators that are interconnected to with utility distribution systems will generally be units smaller than 10 MW. Larger units are generally connected directly to transmission facilities and will most likely be commercial power producers. The units installed on distribution systems will typically be no larger than 1 or 2 MW. These would be installed mostly by the utility itself or by end users. This method of generation is commonly referred to as distributed generation (DG).

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In paper [2-3] the authors Celli and Pilo, discuss the necessity of knowing the power system impacts with DG and hence proposes a new software procedure, based on a genetic algorithm, capable of establishing the optimal distributed generation allocation on an existing MV distribution network, considering all the technical constraints, like feeder capacity limits, feeder voltage profile and three-phase short circuit current in the network nodes.

X. S. Yang and Suash Deb [4] developed an optimization technique. This algorithm is inspired by some species of a bird family called cuckoo because of their special life-style and aggressive reproduction strategy.

Multiple DG units were used by Naveen Jain [5] to minimize the power losses and evaluating the network capacity. The authors in [6] proposed a hybrid method *i.e.* Combined particle swarm optimization (PSOGA) to improve the voltage stability.Teaching Learning Based Optimization (TLBO) was proposed by Ravipudi venkata Rao [7] for solving continuous non-linear optimization problems. Optimal DG Placement and sizing by using index vector method and Flower pollination algorithm [8] to reduce the maximum power loss was proposed by dinakara Prasad reddy *et al.* Effect of load models in distribution system was presented in [9]. Comparison of different sensitivity based DG placement were proposed[10] by Murthy *et al.* An analytical approach based on exact loss formula has been presented in [11] to find the optimal size and location of DG however, voltage constraint has not been considered.

The authors in [12-15] uses new optimization algorithms like ant lion, whale optimization algorithms for DG allocation. The authors [16] in this paper uses particle swarm optimization algorithm is used for DG allocation. A new MLPSO was used in [17] for power loss reduction. A novel combined GA/PSO is presented in [18] for optimal DG placement on distribution systems.

In this paper, a novel method of optimal DG allocation using Fuzzy and new optimization algorithm called one rank Cuckoo search algorithm [19-20] is proposed for finding DG location and sizes. The results clearly indicate that DG reduces the electrical line loss.

2. Problem Formulation

The problem of DG allocation and sizing should be approached with caution. If DG units are connected at non-optimal locations, the system losses may increase. Studies have indicated that inappropriate locations or sizes of DG may lead to greater system losses than the ones in the existing network.

In this paper different methodologies to determine optimal locations and sizes of DG units to minimize the system real power loss are used. In achieving this objective some system constraints have to be satisfied. The distribution system considered is a balanced radial distribution system. The problem statement can be defined as

$$\text{Objective Function}=\text{Min (TLP)} \quad (1)$$

Where $TLP = \sum_{i=1}^{n} I_i^2 R_i$ is the total real power loss of the radial distribution system. Subject to voltage constraint

$$|V_{i\min}| \le |V_i| \le |V_{i\max}|$$

Where I_i is the current flowing through the i^{th} branch. R_i is the resistance of the i^{th} branch and n is the number of branches in the system. V_{imax} and V_{imin} are the upper and lower limits on i^{th} bus voltage.

3. Optimal Dg Placement Using Fuzzy Approach

This paper presents a fuzzy approach for determining optimal locations for DG units.

Two objectives are considered while designing a fuzzy logic for identifying the optimal Distributed Generators 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 set of rules are used in fuzzy inference system (FIS) for determining optimal DG unit locations. DG units are placed on the nodes with the highest suitability.

In distribution system with high losses and low voltage is highly ideal for placement of DG units. Whereas a low loss section with good voltage is not ideal for Distributed Generators placement. A set of fuzzy rules has been used to determine suitable Distributed Generators locations in a distribution system.

The real and reactive power losses are obtained from the base load flow. From this the loss sensitivity factor (LSF) values $\left(\frac{\partial P_{lineloss}}{\partial Q_{eff}}\right)$ can be calculated with the following equation.

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{\left(2\times Q_{eff}(j)\times R(k)\right)}{\left(V(j)\right)^2} \tag{2}$$

Where $Q_{eff}(j)$ is the total effective reactive power supplied beyond the bus ‘j’. These LSF values are linearly normalized into a [0, 1] range with the largest loss Sensitivity Factors having a value of 1 and the smallest one having a value of 0. Loss sensitivity factor index (LSFI) value for n^{th} node can be obtained using below equation.

$$LSFI(n) = \frac{LSF(n) - LSF(min)}{LSF(max) - LSF(min)} \tag{3}$$

These LSFI values along with the p.u. nodal voltages are the inputs to the Fuzzy Inference System (FIS), which determines the node more suitable for DG unit placement.

In this work, two input and one output variables are selected. Input variable-1 is LSFI and Input variable-2 is the per unit nodal voltage (V). Output variable is Distributed Generator suitability index (DSI).

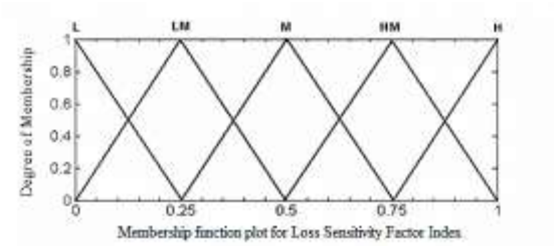

Figure 1. Membership Function Plot for LSFI

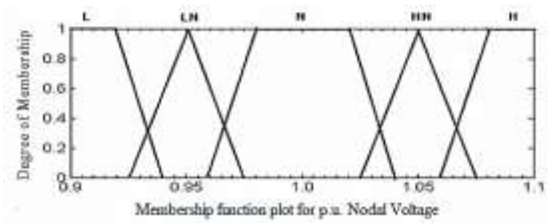

Figure 2. Membership Function Plot for p.u. Nodal Voltage

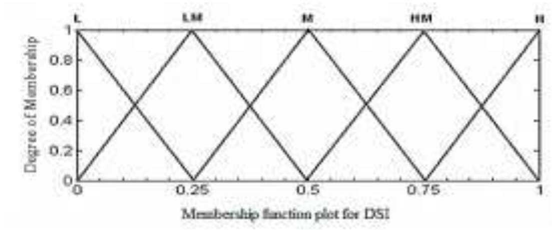

Figure 3. Membership Function plot for DSI

For the Distributed Generator allocation problem, rules are defined to determine the suitability of a node for Distributed Generator installation. Such rules are expressed in the following form:

IF premise (antecedent), THEN conclusion (consequent) for determining the suitability of Distributed Generator placement at a particular node, a set of multiple antecedent fuzzy rules has been established.

The inputs to the rules are the voltage and LSF indices and the output is the Distributed Generator suitability index. The rules are formed as shown in Table1. Here five membership functions are selected for LSFI. They are **L, LM, M, HM and H**. Five membership functions are selected for Voltage. They are **L, LN, N, HN and H**. Five membership functions are selected for DSI. They are **L, LM, M, HM and H**. These membership functions are shown in above Figures.

Table 1. Decision Matrix for Determining the Optimal DG Locations

AND		Voltage Magnitudes				
		L	LN	N	HN	H
LSFI	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	LM

For finding best DG locations the output variable *i.e.* DSI values from FIS are arranged in descending order with corresponding bus numbers. Higher the DSI value, higher the probability of the best suitable location. The first ten DSI values with corresponding bus numbers are shown in Table 2.

Table 2. DSI Values in Descending Order

S. No	IEEE 15 bus system		IEEE 33 bus system		IEEE 69 bus system	
	DSI Values	Bus no	DSI Values	Bus no	DSI Values	Bus no
1.	0.5509	6	0.7646	6	0.7500	57
2.	0.5016	3	0.7622	28	0.7500	58
3.	0.5000	11	0.7500	29	0.5793	61
4.	0.2586	2	0.6209	30	0.4783	60
5.	0.2500	14	0.5223	9	0.4104	59
6.	0.2500	7	0.5077	13	0.3398	64
7.	0.2500	13	0.5029	10	0.2843	65
8.	0.2500	15	0.5000	3	0.2749	63
9.	0.2500	8	0.4678	8	0.2692	62
10.	0.2500	4	0.4267	5	0.2500	17

Optimal DG locations are identified based on DSI values. For 15 bus system, nodes having DSI value greater than or equal to 0.5 are considered for optimal DG placement. Three candidate notes are selected for optimal DG placement. These nodes are 6, 3 and 11. For 33 bus system, nodes having DSI value greater than or equal to 0.6 are considered for optimal DG placement. Four candidate notes are selected for optimal DG placement. These nodes are 28, 6, 29 and 30. For 69 bus system, nodes having DSI value greater than or equal to 0.5 are considered for optimal DG placement. Three candidate notes are selected for optimal DG placement. These nodes are 57, 58 and 61.

4. One Rank Cuckoo Search (ORCS) Algorithm

Cuckoo Search algorithm [20] is inspired by some species of a bird family called cuckoo. Cuckoos lay their eggs in the nests and remove the existing eggs to increase the hatching probability of their eggs. On the other hand, some of the host birds are able to find the alien eggs and throw them out of their nests or build their new nests in new locations.

The following three idealized rules are considered

1. Each Cuckoo lays one egg at a time, and dumps it in a randomly chosen nest.
2. The best nests with high quality of eggs are carried over to the next generations.
3. The number of available host nests is constant, and the egg which is laid by a Cuckoo is discovered by the host bird with a probability of pa in the range of [0, 1]. If a cuckoo's egg is very similar to a host's egg, then this cuckoo's egg is less likely to be discovered.

The one rank/combined evaluation and bound by best solution functionalities, have been added to the original cuckoo search algorithm, and used to draw the basic one rank cuckoo search algorithm. The proposed ORCS algorithm introduced one more parameter, one rank ratio update trigger t_{or}, in addition to the two parameters employed by the original CS algorithm, population size and abandon rate p_a.

In the proposed algorithm one rank/combined evaluation is used to generate new solutions using Levy flights, replaces a fraction of them, and finally evaluates and ranks their fitness at once. A one rank ratio r_{or} is initiated by 1, to allow the proposed algorithm to combine all the explorations and exploitations, until it fails to find better nests for t_{or} iterations, to trigger a gradual decrease of the one rank ratio as shown below, where t is the iteration number and D is the number of objective function dimension.

$$r_{or}^{t+1} = r_{or}^{t} \times 1 - 0.5 / D \quad (4)$$

The proposed algorithm enforces the integrity over an out of constraints solution by replacing its invalid dimensions by the corresponding dimensions drawn from randomly selected solutions among the current best solutions by using Bound by Best Solutions. A ratio of the replaced dimensions is utilizing the current best solutions found so far, and the rest is being randomly drawn by further exploring the search space. A bound by best ratio is defined as below equation.

$$r_{bbb} = 1 - 1/\sqrt{D} \quad (5)$$

Algorithm for DG Placement and Sizing Using Fuzzy Approach and one rank CS Algorithm

1. Initialize all the parameters and control parameters of CS algorithm. They are DG_{min}=60 kVA, DG_{max}= 3000 kVA, population nop=15, number of dg units ndg, discovery rate of alien egss/solutions probability p_a = 0.25, t_{or}=0.1.

2. Initially [pop x ndg] population is generated randomly within the limits.
   Nest (i, :) =DG_{min}+ (DG_{max}-DG_{min}).*rand (size (DG_{min}))

3. By placing all the nests at the respective DG location and find the fitness *i.e.* total real power loss. The same procedure is repeated for the pop number of nests. Get the current best of fitness function.
4. Start iterations
5. Generate new set of nests or solutions randomly but keep the current best

   Nest (i, :) = Nest (i, :) + step size.*randn (size(s))
6. A fraction of worse nests are replaced with the probability p_a and new nest is discovered by

   K=rand (size (Nest))>pa

   Step size=rand*(Nest (rand (n), :)-Nest (rand (n),))

   New_nest=Nest + stepsize.*K
7. Evaluate new population obtained from bound by best solution procedure and find out fitness value.
8. Find the best nest corresponding to best fitness value so far.
9. Increment Iterations.
10. The DG unit sizes corresponding to minimum fitness (Best Nest) gives the optimal DG unit sizes. Repeat till end of iterations and get the best solution.

5. Results

The proposed algorithm is applied to IEEE 15, 33 and 69 bus systems. Optimal DG locations are identified based on the DSI values. The optimal locations for 15, 33 and 69-bus system are three, four and three locations respectively. Distributed Generator sizes in optimal locations, total real power losses before and after compensation are shown in Tables 3, 4 and 5.

Table 3. Results of 15-Bus System

Bus No.	DG unit size in kVA
6	546
3	769
11	364
Minimum Bus Voltage in p.u. (before)	0.9445
Minimum Bus Voltage in p.u. (after)	0.9923
Total power loss in kW (before)	61.7933
Total power loss in kW (after)	4.6687
% of loss reduction	92.44

Table 4. Results of 33-Bus System

Bus No.	DG unit size in kVA
6	1764
28	91
29	139
30	1724
Minimum Bus Voltage in p.u. (before)	0.8785
Minimum Bus Voltage in p.u. (after)	0.9621
Total power loss in kW (before)	369.2543
Total power loss in kW (after)	64.0354
% of loss reduction	82.66

Table 5. Results of 69-Bus System

Bus No.	DG unit size in kVA
57	342
58	92
61	1927
Minimum Bus Voltage in p.u. (before)	0.9092
Minimum Bus Voltage in p.u. (after)	0.9727
Total power loss in kW (before)	225.0225
Total power loss in kW (after)	26.7244
% of loss reduction	88.12

The results show that 92.44 % reduction in power loss for 15-bus system, 82.66 % reduction in power loss for 33-bus system and 88.12% reduction in power loss for 69-bus system is possible as shown in tables and bus voltages are also improved substantially.

6. Conclusions

In this paper a new two stage methodology is proposed for DG placement problem. In stage I candidate locations for DG unit placement are determined and in stage II sizes of DG units at these locations are determined for minimum power loss. To determine the locations Fuzzy approach is developed. The proposed fuzzy approach is capable of determining the optimal DG locations based on the fuzzy rule base. The proposed one rank CS Algorithm method iteratively searches the optimal DG sizes at these locations effectively for the maximum power loss reduction. The validity of the proposed method is proved from the comparison of the results of the proposed method with and without DG. 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.

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