



OPTIMAL PLACEMENT OF DG UNITS USING FUZZY AND REAL CODED GENETIC ALGORITHM

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ABSTRACT

This paper presents a new methodology using Fuzzy and Real Coded Genetic Algorithm (RCGA) for the placement of DG units in electrical distribution systems to reduce the power losses and to improve the voltage profile. Electrical energy is vital in every aspect of day-to-day life. Keen interest is taken on all possible sources of energy from which it can be generated and this led to the encouragement of generating electrical power using renewable energy resources such as solar, tidal waves and wind energy. 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 network 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. There have been many studies, to define the optimum location of distributed generation. In this paper, Fuzzy approach is used to find the optimal locations of DG units and Real Coded Genetic Algorithm (RCGA) is used to find the optimal sizes of DG units. The suggested method is programmed under MATLAB software and is tested on 15-bus, 33-bus, 69-bus and 85-bus test systems and the results are presented.

Keywords: *Distributed generation allocation, Power losses, Loss Sensitivity Factors, Voltage Profile, Fuzzy Approach and Real Coded Genetic Algorithm.*

1. INTRODUCTION

“Distributed generation”, [1] is defined as small-scale generation located at or near the load centers. It has also been called as on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy. Distributed generation is done through various small-scale power generation technologies. Distributed energy resources (DER) refers to a variety of small, modular power-generating technologies that can be combined with energy management and storage systems and used to improve the operation of the electricity distribution system, whether or not those technologies are connected to an electricity grid.

Distributed generation is a technology which reduces the amount of energy lost in transmitting electricity because the electricity is generated very near load centre, perhaps even in the same building. This also reduces the size and number of power

lines that must be constructed. Much analysis's has been done on DG unit Placement.

This paper presents a methodology to find the optimal DG locations and sizes. A Fuzzy [2] approach has been used in finding the locations of DG Units. Real coded Genetic Algorithm [3] has been used in finding the Optimal Sizes of DG Units.

2. LOAD FLOW STUDY

A simple and efficient algorithm [4] is used to solve radial distribution networks (RDN). It solves the simple algebraic recursive expression of voltage magnitude and all the data are stored in vector form. The algorithm uses the basic principle of circuit theory and can be easily understood.

2.1. Circuit Model

In this section, a circuit model of a radial distribution network (RDN) is presented. It is assumed that a three-phase RDN is balanced and can be represented by equivalent single line diagram. Line shunt capacitance at distribution voltage level is negligibly small. Fig. 1 shows single line diagram of a sample radial distribution network.

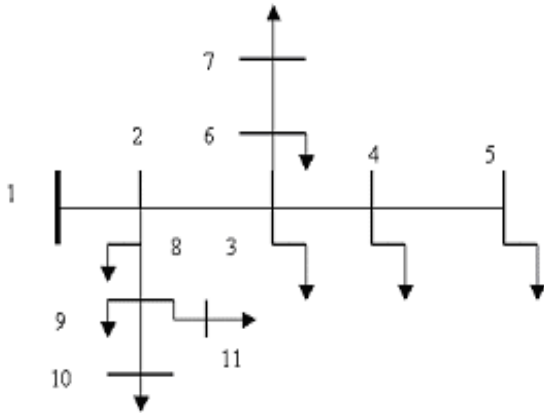


Fig.1. Sample radial distribution networks

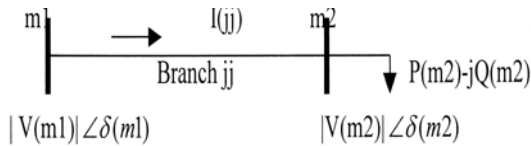


Fig. 2. Electrical equivalent of one branch of fig 1

2.2. Mathematical model of radial distribution network

A mathematical model of radial distribution networks can easily be derived from

$$I(jj) = \frac{|V(m1)| \cdot \delta(m1) - |V(m2)| \cdot \delta(m2)}{Z(jj)} \quad (2.1)$$

$$P(m2) - jQ(m2) = V(m2) \cdot I(jj) \quad (2.2)$$

Where $Z(jj) = R(jj) + jX(jj)$, And $m1$ and $m2$ are the sending and receiving end nodes respectively.

$$m1 = ISS(jj) \text{ and } m2 = IRR(jj)$$

$$P(m2) = \sum_{i=2}^{NB} PL(i) + \sum_{i=2}^{NB-1} LP(i) \quad (2.3)$$

$$Q(m2) = \sum_{i=2}^{NB} QL(i) + \sum_{i=2}^{NB-1} LQ(i) \quad (2.4)$$

$P(m2)$ = Sum of the real power loads of all the nodes beyond node $m2$ plus the Real power load of the node $m2$ itself plus the sum of the real power loss of all the branches beyond node $m2$.

$Q(m2)$ = Sum of the reactive power loads of all the nodes beyond node $m2$ plus the reactive power load of the node $m2$ itself plus the sum of the reactive power loss of all the branches beyond node $m2$.

$$A(jj) = P(m2) \cdot R(jj) + Q(m2) \cdot X(jj) - 0.5 \cdot |V(m1)|^2 \quad (2.5)$$

$$B(jj) = \sqrt{A^2(jj) - [Z^2(jj) \cdot (P^2(m2) + Q^2(m2))]} \quad (2.6)$$

From equations (2.5) and (2.6) receiving end voltage is given by:

$$V(m2) = \sqrt{B(jj) - A(jj)} \quad (2.7)$$

Real and reactive power losses in the branch jj are

$$LP(jj) = \frac{R(jj) \cdot (P^2(m2) + Q^2(m2))}{|V^2(m2)|} \quad (2.8)$$

$$LQ(jj) = \frac{X(jj) \cdot (P^2(m2) + Q^2(m2))}{|V^2(m2)|} \quad (2.9)$$

2.3. Load Flow Computation

Once $P(m2)$ and $Q(m2)$ are computed using the above logic (section 2.2), voltage magnitudes of all the nodes can be easily computed using the equation (2.7). Further real and reactive power losses are obtained using equations (2.8) and (2.9). The convergence criterion of the algorithm is that if, in successive iteration, the maximum difference in voltage magnitude (DVMAX) is less than 0.0001 p.u., the solution has been converged.

3. IDENTIFICATION OF OPTIMAL DG LOCATION-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 Loss Sensitivity factors 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. DGs can be placed on the nodes with the highest suitability. 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 voltages, real and reactive power losses. The real and reactive power loss in any branch (equations: 2.8 & 2.9) can be considered as the loss at the receiving end bus of the same line. The same equations can be re-write as the equations (3.1) & (3.2) to get the loss at the receiving end bus (m2) of the line jj [5].

$$P_{line\ loss}[m2] = \frac{R(jj) * (P^2(m2) + Q^2(m2))}{|V^2(m2)|} \quad (3.1)$$

$$Q_{line\ loss}[m2] = \frac{X(jj) * (P^2(m2) + Q^2(m2))}{|V^2(m2)|} \quad (3.2)$$

The Sensitivity factors, Real power loss ($P_{line\ loss}[m2]$) with respect to effective reactive power ($Q(m2)$) are given by equation (3.3).

$$\frac{\partial P_{line\ loss}[m2]}{\partial Q[m2]} = \frac{(2 * Q(m2) * R(jj))}{(V(q))^2} \quad (3.3)$$

The loss sensitivity factors are then, linearly normalized into a [0, 1] range with the largest sensitivity having a value of 1 and the smallest one having a value of 0. These loss sensitivity factors and the p.u. nodal voltages are used as the inputs to the Fuzzy Inference System (FIS), which determines the nodes more suitable for DG installation in the descending order of output. In this paper, two input and one-output variables are selected. Input variable-1 is Loss Sensitivity Factor (LSF) and Input variable-2 is the per unit nodal

voltage (V). Output variable is DG suitability index (DGSi).

Loss sensitivity factor 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 LSF. They are L, LM, M, HM and H. All the five membership functions are triangular as shown in Fig. 3. 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. 4. Five membership functions are selected for DGSi. They are L, LM, M, HM and H. These five membership functions are also triangular as shown in Fig. 5.

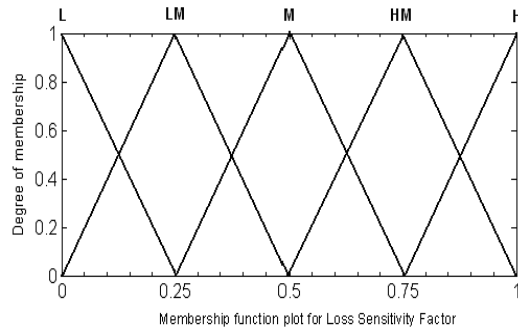


Fig. 3. Membership function plot for Loss Sensitivity Factor (LSF)

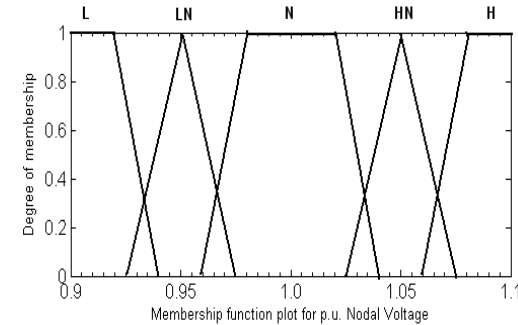


Figure 4. Membership function plot for p.u. Nodal Voltage.

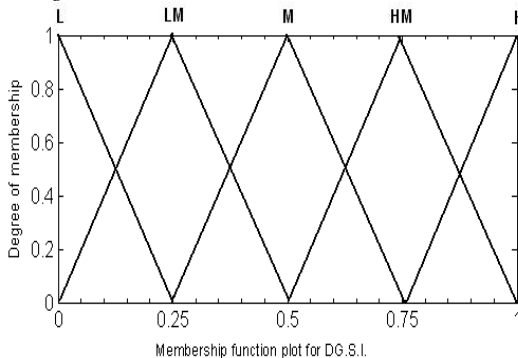


Figure 5. Membership function plot for DG.S.I.



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 Loss Sensitivity Factor (LSF) and the output is the suitability of DG placement. The rules are summarized in the fuzzy decision matrix in Table 1. The consequents of the rules are in the shaded part of the matrix.

Table 1. Decision matrix for determining the optimal DG locations

AND		Voltage				
		L	LN	N	HN	H
L S F	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

4. IDENTIFICATION OF OPTIMAL DG SIZE USING REAL CODED GENETIC ALGORITHM.

In this study, Real Coded Genetic Algorithm is used. Compared with binary GA, it offers higher accuracy of the control variables. RCGA is similar to normal GA except decoding the control variable information is eliminated; hence it will reduce the computation time. In RCGA the control variable information is encoded in the form of real value, hence it will avoid the usage of decoding process.

4.1. Phases of RCGA

In this study, Real Coded Genetic Algorithm (RCGA) is used. Compared with binary GA, it offers higher accuracy of the control variables. RCGA is similar to normal GA except decoding the control variable information is eliminated; hence it

will reduce the computation time. In RCGA the control variable information is encoded in the form of real value, hence it will avoid the usage of decoding process. The applications of crossover and mutation operator are different in Real-coded Genetic Algorithm. The construction of RCGA to solve the problem and is given as follows:

4.1.1. Presentation of control variables

To apply RCGA to solve a specific problem, one has to define the solution representation and the coding of control variables. The optimization problem here is to use the Distributed Generation Units in minimizing the Distribution system losses. In this study, Real Coded Genetic Algorithm is used. Comparing with binary GA, it offers higher accuracy of the control variables.

4.1.2. Fitness Function (FF)

GA is usually designed to maximize or minimize the FF, which is a measure of the quality of each candidate solution. After control variables are coded, the objective function (fitness) will be evaluated. These values are the measures of quality, which is used to compare different solutions. The better solution joins the new population and the worse one is discarded. The fitness value of an individual will determine its chance to propagate its features to future generations. Here Total Power Loss in the Distributed Generation is used in formulation of the fitness function (FF). Therefore RCGA fitness function (FF) is formed as follows:

$$FF = Max \left(\frac{10}{1 + TLP} \right) \tag{4.1}$$

Where TLP is total power loss in the Distribution system. It can be found from the Load Flow Solution.

4.1.3. Crossover

Crossover is one of the main distinguishing features of GAs that make them different from other algorithms. Its main aim is to recombine blocks on different individual to make a new one.

Crossover is performed using the two crossover operators. These two crossover operators are the convex crossover and the heuristic crossover. A random number *r* is generated between zero and one. If the random number *r* is less than 0.5 then convex crossover operator is used to produce the offspring, otherwise heuristic crossover operator is used to produce the offspring.



4.1.3.1. Convex crossover:

Convex crossover is used in this paper as the following formulation.

$$\begin{aligned}
 x' &= \lambda_1 x + \lambda_2 y \\
 y' &= \lambda_1 y + \lambda_2 x \\
 \lambda_1 + \lambda_2 &= 1, \\
 \lambda_1, \lambda_2 &> 0
 \end{aligned}
 \tag{4.2}$$

Where x, y are the two parents, x', y' are their two offspring. λ_1 and λ_2 are obtained by a uniform random number generation between 0 and 1.

4.1.3.2. Heuristic crossover

A heuristic crossover operator is used based on the evolutionary direction provided by each parent, the fitness ratio of best chromosome and each parent, and the distance between the best chromosome and each parent [6].

$$h(i,j)_{new} = K_1 * h(i,j)_{old} + K_2 * K_3 * (Parent(1,j) - Parent(i,j))
 \tag{4.3}$$

$$Offspring(i,j) = Parent(i,j) + h(i,j)_{new}
 \tag{4.4}$$

Each gene of offspring is produced from each gene of parent using the equation (4.4).

4.1.4. Mutation

Mutation is used to introduce some sort of artificial diversification in the population to avoid premature convergence to local optimum. An arithmetic mutation operator that has proved successful in a number of studies is dynamic or non-uniform mutation, which is used in this study. This is designed for fine-tuning aimed at achieving a high degree of precision. For a given parent x, if the gene x_k is selected for mutation, then the resulting gene is selected with equal probability from the two choices.

$$\begin{aligned}
 x'_k &= x_k + r(b_k - x_k)(1 - \frac{t}{T})^b \\
 \text{or} \\
 x'_k &= x_k - r(x_k - a_k)(1 - \frac{t}{T})^b
 \end{aligned}
 \tag{4.5}$$

Where r is a uniform random number chosen between the range (0 1), t is the current generation number, T is the maximum number of generations and b is a parameter determining the degree of non-

uniformity. The amount of mutation decreases as the number of generations increases.

5. RESULTS

The proposed algorithm is applied to 15-bus [7], 33-bus [8], 69-bus [9] and 85-bus [7] test systems and the results are presented in Tables 2,3,4, and 5 respectively.

Table 2. DG Unit sizes at the preferred bus locations for 15-bus system

Bus No.	DG Unit size in kVA
6	546
3	769
11	364
Minimum bus voltage in p.u. (before)	0.9451
Minimum bus voltage in p.u. (after)	0.9923
Total power loss in kW (before)	61.7339
Total power loss in kW (after)	4.6685
Reduction in power loss (%)	92.44%

Table 3. DG Unit sizes at the preferred bus locations for 33-bus system

Bus No.	DG Unit size in kVA
6	1843
28	92
29	139
30	1815
Minimum bus voltage in p.u. (before)	0.8793
Minimum bus voltage in p.u. (after)	0.9664
Total power loss in kW (before)	368.9625
Total power loss in kW (after)	35.4085
Reduction in power loss (%)	90.40%



Table 4. DG Unit sizes at the preferred bus locations for 69-bus system

Bus No.	DG Unit size in kVA
57	345
58	92
61	1952
Minimum bus voltage in p.u. (before)	0.9093
Minimum bus voltage in p.u. (after)	0.9735
Total power loss in kW (before)	224.9608
Total power loss in kW (after)	21.8942
Reduction in power loss (%)	90.27%

Table 5. DG Unit sizes at the preferred bus locations for 85-bus system

Bus No.	DG Unit size in kVA
8	887
58	1003
27	1245
Minimum bus voltage in p.u. (before)	0.8722
Minimum bus voltage in p.u. (after)	0.9752
Total power loss in kW (before)	315.3708
Total power loss in kW (after)	34.4799
Reduction in power loss (%)	89.07%

6. CONCLUSIONS

In this paper, a two-stage methodology of finding the optimal locations and sizes of Distributed Generation units for minimization of losses of radial distribution systems is presented. Fuzzy approach is proposed to find the optimal DG locations and RCGA method is proposed to find the optimal DG sizes. Based on the simulation results, the following conclusions are drawn:

By installing DG units at all the potential locations, the total power loss of the system has been reduced significantly and bus voltages are improved substantially. The proposed fuzzy approach is capable of determining the optimal DG locations based on the LSF values and the per unit node voltages. The proposed RCGA method

iteratively searches the optimal DG sizes effectively for the minimum power loss.

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