A Novel Approach for Optimal Allocation of a Distributed Generator in a Radial Distribution Feeder for Tail End Node Voltage Improvement and Loss Minimization during Peak Load

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ABSTRACT

This paper proposes a novel approach for optimal allocation of a distributed generator in a radial distribution feeder for tail end node voltage improvement and loss minimization during peak load. A multi objective optimization method is proposed to determine optimal allocation of a distributed generation (DG) unit in a radial distribution feeder. The DG allocation problem has been formulated as multi objective function which includes two objectives: viz Power Loss Reduction and Tail End Node Voltage Improvement with associated weights. The proposed methodology uses Genetic Algorithm to optimize the multi objective function. This method is tested on standard IEEE 33 bus and 69 bus radial distribution systems using MATLAB 8.0. The results show that the proposed method yields considerable tail end node voltage improvement along with significant reduction in line losses during peak load.

Introduction

As a result of the application of deregulation in the electric power sector, a new identity appeared in the electric power system map known as "distributed generation" [1]. In general, Distributed Generation (DG) can be defined as electric power generation within distribution networks or on the customer side of the meter [2].

Most of the benefits of employing DG units in existing distribution networks have both economic and technical implications and they are interrelated [3]. The major technical benefits include:

➢ Reduction of line losses
➢ Voltage profile improvement
➢ Increased overall energy efficiency
➢ Enhanced system reliability and security
➢ Relieved T&D congestion

The major economical benefits include:

➢ Deferred investments for upgrades of facilities
➢ Reduced O&M costs of some DG technologies
➢ Reduced fuel costs due to increased overall efficiency
➢ Lower operating costs due to peak shaving and
➢ Increased security for critical loads

There is increased interest by electricity suppliers in DG because they see it as a tool that can help them to fill niches in a liberalized market. In such a market, customers will look for the electricity services best suited for them. Different customers attach different weights to features of electricity supply, and DG technologies can help electricity suppliers to supply to the electricity customers the type of electricity service they prefer. In short, DG allows players in the electricity sector to respond in a flexible way to changing market conditions [4].

Determining the suitable location and size of DG is important in order to extract maximum benefits from the integration of DG into the distribution system. In literature, there are a number of approaches developed for placement and sizing

of DG units in distribution system. Chiradeja and Ramkumar [3] presented a general approach and set of indices to assess and quantify the technical benefits of DG in terms of voltage profile improvement, line loss reduction and environmental impact reduction. Khan and Choudry [5] developed an algorithm based on analytical approach to improve the voltage profile and to reduce the power loss under randomly distributed load conditions with low power factor for single DG as well as multi DG systems. Hung et al. [6] used an improved analytical method for identification of the best location and optimal power factor for placing multiple DGs to achieve loss reduction in large scale primary distribution networks. Kamel and Karmanshahi [7] proposed an algorithm for optimal sizing and siting of DGs at any bus in the distribution system to minimize losses and found that the total losses in the distribution network would reduce by nearly 85%, if DGs were located at the optimal locations with optimal sizes.

The genetic algorithm (GA) is an optimization and search technique based on the principles of genetics and natural selection. Application of GA to determine optimal allocation of DG proved to be an efficient technique and many authors has succeeded in applying it [8]-[11].

Mithulananthan et. al [8] have tried it taking power loss minimization alone as objective. Some authors have tried multi objective optimization in which they have considered voltage profile improvement as additional objective along with power loss minimization [9],[10] & [11]. Even though the voltage profile improvement was taken as one of the objective for DG allocation in many multi-objective allocation optimization which has been reported in the literatures, the tail end nodes voltages are not improved much. But in practical distribution systems, tail end nodes are victims of voltage drop, especially during peak load. The voltage drop across the distribution feeder will results in poor voltage at the tail end nodes there by

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affecting performance of customer equipments. So it is necessary to give special attention to improve tail end node voltage profile.

The method proposed in this paper attempts to solve critical tail end node voltage problem by framing optimal allocation of DG problem as a multi objective problem using Genetic Algorithms (GA). Two indices viz **Power Loss Reduction Index (PLRI) and Tail End Node Voltage Deviation Index (TENVDI)** are combined together to obtain objective function to be minimized to get optimal allocation of DG such that minimum power loss and maximum tail end voltage improvement is achieved. The proposed methodology is implemented using MATLAB 8.0

The organization of this paper is as follows; section II addresses the problem formulation, section III introduces the Genetic Algorithm used in the methodology, & Section IV gives the solution method, Results & discussion are given in section V and finally section VI concludes the paper.

Multi-Objective Problem Formulation

An Optimum allocation of DG units are decided in such a way that the combined objective function of *power loss reduction index and tail end node voltage deviation index* is minimum. So it is needed to define objective function in terms of DG size, location & system bus voltage.

The total power loss of distribution network is given by,

$$P_{loss} = \sum_{i=1}^{Nb} I_i^2 * R_i \qquad (1)$$

Where,

i – branch number.

Nb – total no. of branches.

I_i – branch current.

R_i – branch resistance.

P_{loss} – real power loss.

The Power Loss Reduction Index (PLRI) is given by,

$$PLRI = \frac{Ploss_{(DG)}}{Ploss_{(BASE)}} \qquad (2)$$

Where,

$P_{loss(DG)}$ – power loss with DG.

$P_{loss(BASE)}$ – power loss without DG.

The Tail End Node Voltage Deviation Index (TENVDI) is given by,

$$TENVDI = \sqrt{\frac{\sum_{i=1}^{Nte} (1 - V_i)^2}{N_n}} \qquad (3)$$

Where,

i - bus number.

Nte – no. of tail end nodes.

N_n – total no. of nodes.

V_i – i^{th} node voltage.

The TENVDI in Pu is given by,

$$TENVDI_{PU} = \frac{TENVDI_{(DG)}}{TENVDI_{(BASE)}} \qquad (4)$$

Where,

$TENVDI_{(DG)}$ – Tail End Node Voltage Deviation Index with DG.

$Tenvdi_{(base)}$ – Tail End Node Voltage Deviation without DG.

The Multi Objective Function is formulated as,

$$F = W_1 * PLRI + W_2 * TENVDI_{PU} \qquad (5)$$

Such that,

$$W_1 + W_2 = 1 \qquad (6)$$

Subject to Constraints:

Line loadability limit:

$$P_{line\,(i,j)} < P_{line\,(i,j)max}$$

Bus Voltage limit:

$$V_{min} < V_i < V_{max}$$

The objective function 'F' is a combination of power loss reduction index (PLRI) & tail end node voltage deviation index (TENVDI in Pu) associated with weights. W_1 & W_2 are weighing factors in which *W_1 is weightage given to power loss reduction* and *W_2 is weightage given to tail end node voltage improvement*. In order to achieve optimal allocation of DG, the objective function 'F' is to be minimized so that minimum power loss & maximum tail end voltage improvement is obtained.

Genetic Algorithm

The Genetic algorithm (GA), proposed by Holland in 1975, is inspired by the natural selection and the law of regeneration and it is one of the most popular evolutionary-based algorithms. The planning programs that finally achieve the convergence criterion are translated into a bundle of chromosomes by encoding and control the search direction by the merits of fitness function [13].

Genetic Algorithm (GA) is direct, parallel, stochastic method for global search and optimization, which imitates the evolution of the living beings, described by Charles Darwin. GA is a part of the group of Evolutionary Algorithms (EA). The evolutionary algorithms use the three main principles of the natural evolution: reproduction, natural selection and diversity of the species, maintained by the differences of each generation with the previous. The GA holds a population of individuals (chromosomes), which evolve my means of selection and other operators like crossover and mutation. Every individual in the population gets an evaluation of its adaptation (fitness) to the environment. In the terms of optimization this means, that the function that is optimized is evaluated for every individual. The selection chooses the best gene combinations (individuals), which through crossover and mutation should drive to better solutions in the next population. One of the most often used schemes of GA is shown in Fig. 1 [14].

The steps involved in this GA scheme for optimization are explained below [14] & [15]:

a)Generate initial population – the first generation is randomly generated, by selecting the genes of the chromosomes among the allowed alphabet for the gene. Because of the easier computational procedure it is accepted that all populations have the same number (*N*) of individuals.

b)Calculation of the fitness values of the function that we want to minimize or maximize.

c)Check for termination of the algorithm – it is possible to stop the genetic optimization by

Value of the function – the value of the function of the best individual is within defined range around a set value. It is not recommended to use this criterion alone, because of the stochastic element in the search procedure, the optimization might not finish within sensible time;

Maximal number of iterations – this is the most widely used stopping criteria. It guarantees that the algorithms will give some results within some time, whenever it has reached the extremum or not;

Stall generation – if within initially set number of iterations (generations) there is no improvement of the value of the fitness function of the best individual the algorithms stops.
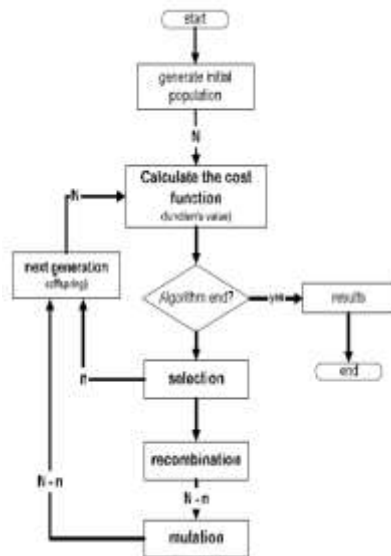
Figure 1. Genetic Algorithm Scheme

d)Selection – between all individuals in the current population are chose those, who will continue and by means of crossover and mutation will produce offspring population. At this stage elitism could be used – the best *n* individuals are directly transferred to the next generation. The elitism guarantees, that the value of the optimization function cannot get worst (once the extremum is reached it would be kept).

e)Crossover – the individuals chosen by selection recombine with each other and new individuals will be created. The aim is to get offspring individuals that inherit the best possible combination of the characteristics (genes) of their parents.

f)Mutation – by means of random change of some of the genes, it is guaranteed that even if none of the individuals contain the necessary gene value for the extremum, it is still possible to reach the extremum.

g) New generation – the elite individuals chosen from the selection are combined with those who passed the crossover and mutation, and form the next generation.

Proposed Methodology

The proposed technique based on multi objective GA for optimal allocation of a DG unit in radial distribution feeder is as follows:

Step 1: Input load data & line data of distribution network.

Step 2: Using forward-backward method of load flow analysis [16], calculate distribution system power loss.

Step 3: Generate initial population of chromosomes with random size and position and set iteration count to zero. Each chromosome is associated with a bus position & real power rating of DG.

Step 4: Fix the maximum limits on DG size and its position. Limit on position of DG depends on no. of buses in test system under consideration.

Step 5: For each chromosome check the bus voltage with specified limits and in any case if it is exceeding limit then the chromosome is infeasible and discarded.

Step 6: For each chromosome, calculate fitness function value which is value of objective function F in present case.

Step 7: Arrange the objective function values from minimum to maximum and discard the unfit values and retain most fit values.

Step 8: Perform Mutation and Mating operations on retained chromosomes to generate new set of chromosomes.

Step 9: Calculate fitness values of new set of chromosomes generated.

Step 10: Increase iteration count by 1 & repeat step 5 to 9 until iteration count reaches maximum iteration.

The solution obtained after completion of step 10 is *optimal solution to the problem*. The value of the chromosome at the end includes *optimal size & location of the DG* for the given distribution system.

Results and Discussion

IEEE-33 bus radial distribution system:

The proposed methodology is tested on IEEE-33bus radial distribution system having following characteristics:

Number of buses=33; Number of lines=32; Slack Bus no=1; Base Voltage=12.66KV; Base MVA=100 MVA;

The test system is simulated in MATLAB 2008 & the proposed methodology has been tested, whose results are as shown below. The loads are assumed to be peak load.:
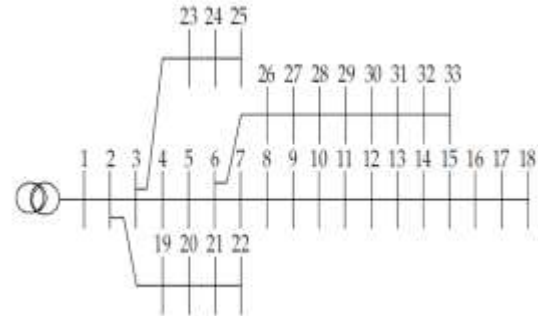

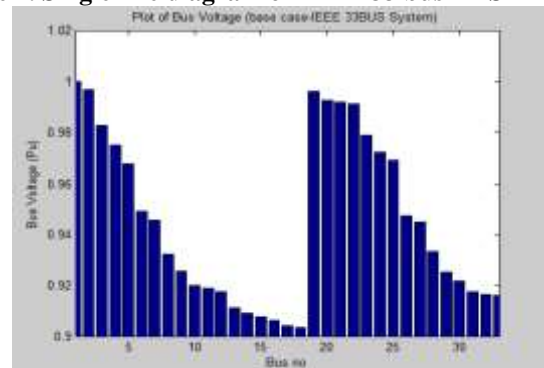**Figure 2. Single line diagram of IEEE-33 bus RDS**
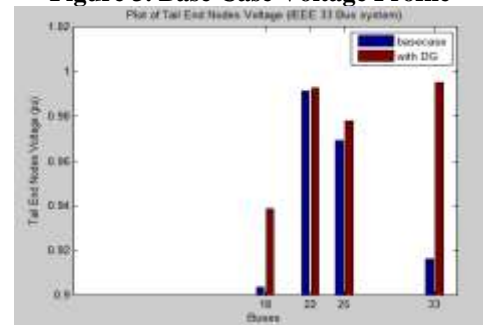

Figure 3. Base Case Voltage Profile

Figure 4. Comparison of Tail End Node Voltages with and without DG

Table 1. Tail End Node Voltage Improvement with DG

Tail End Nodes	Base CaseVoltage (pu)	Voltage with DG (pu)	% Improvement
18	0.9038	0.9389	3.88
22	0.9916	0.9929	0.13
25	0.9693	0.9781	0.907
33	0.9164	0.9951	8.58

Table 2. Real Power Loss Reduction with DG

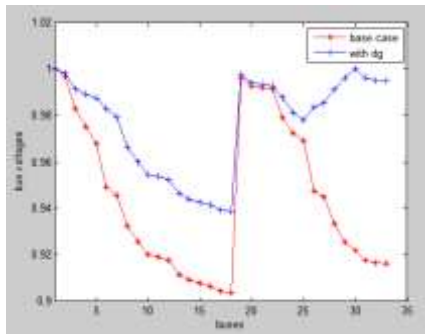| Base Case Real Power Losss (kw)	Real Power Loss with DG (kw)	% Reduction
210.97	78.413	62.83

Figure 5. Comparison of Voltage Profile with DG

As per the proposed methodology with 90% weightage given to power loss reduction and 10% weightage to tail end node voltage improvement in multi objective function, the optimal location of DG is found to be bus number 30 with optimal size of 1.7622 MW and 0.8535 MVAR. The result tabulated in Table 2 clearly shows that there is 62.83% reduction in real power loss of system and more importantly there is considerable improvement in tail end node voltage given in Table 1. Hence the proposed method gives better tail end node voltage along with loss minimization as shown in Fig 4. The voltage profile of the distribution system with DG and without DG is shown in Fig

Ieee-69 bus radial distribution system:

The proposed methodology is tested on IEEE-69 bus radial distribution system having following characteristics:
Number of buses=69; Number of lines=68;Slack Bus no=1; Base Voltage=12.66KV; Base MVA=100 MVA;
The test system is simulated in MATLAB 2008 & the proposed methodology has been tested, whose results are as shown below. The loads are assumed to be peak load
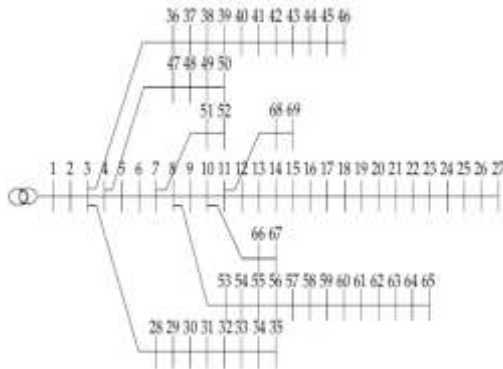

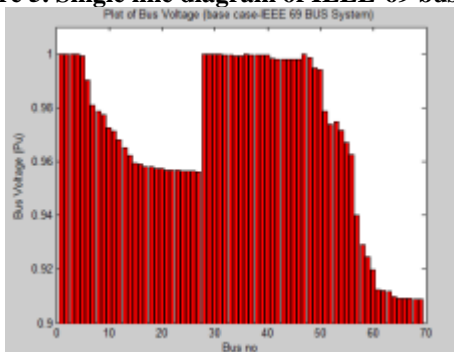**Figure 5. Single line diagram of IEEE-69 bus RDS**

Figure 6. Base Case Voltage Profile

As per the proposed methodology with 70% weightage given to power loss reduction and 30% weightage to tail end node voltage improvement in multi objective function, the optimal location of DG is found to be bus number 58 with optimal size of 1.9073 MW and 0.9237 MVAR.
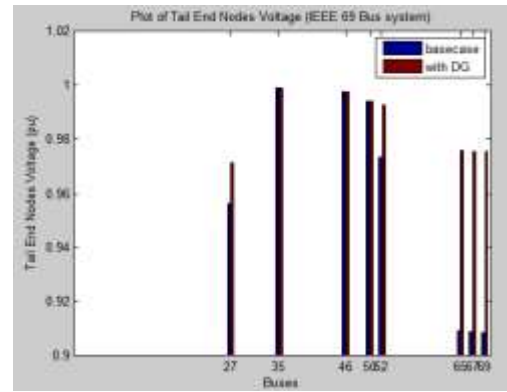

Figure 7. Comparison of Tail End Node Voltages with and without DG

Table 3. Tail End Nodes Voltage Improvement with DG

Tail End Nodes	Base CaseVoltage (pu)	Voltage with DG (pu)	% Improvement
27	0.9563	0.9716	1.59
35	0.9992	0.9992	0
46	0.9978	0.9978	0
50	0.9942	0.9942	0
52	0.9737	0.9927	1.95
65	0.9092	0.9758	7.62
67	0.9091	0.9758	9.98
69	0.9088	0.9755	7.33

Table 4. Real Power Loss Reduction with DG

Base Case Real Power Losss (kw)	Real Power Loss with DG (kw)	% Reduction
236.46	57.59	75.65

The result tabulated in Table 4 clearly shows that there is 75.65 % reduction in real power loss of system and more importantly there is considerable improvement in tail end node voltage given in Table 3.
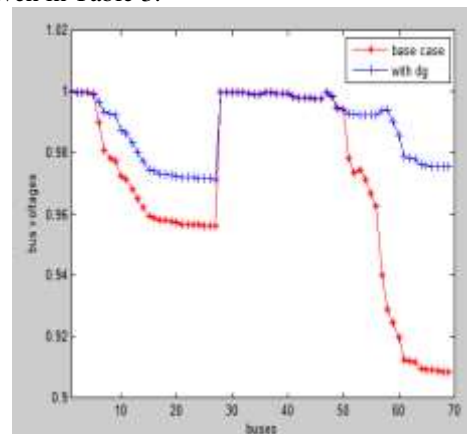

Figure 8. Comparison of Voltage Profile with DG

The voltage profile of the distribution system with DG and without DG is shown in Fig 9.

Conclusion

G interconnection to distribution system provides many techno economic benefits which depend on its allocation in the distribution system. So siting & sizing of DG is a key issue in planning of Distributed Generation. This paper presents a method based on Genetic algorithm for optimal allocation of a DG unit considering multi-objective optimization function which is combination of power loss reduction & tail end node voltage improvement. It is apparent from the simulation results of GA optimization method that there is considerable reduction in power loss & more importantly there is exceptional improvement in tail end node voltage which is a practical problem of many rural distribution system and also critical from the operation point of customer equipments connected to it which face problem of voltage drop very often.

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