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GA based Optimal DG Placement for Power Loss Reduction and Voltage Stability Improvement

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***Abstract*--The voltage deviation from the nominal value is a major problem in the distribution system during operation of the system. Normally voltage profile of load buses decreases from source to loads at far end. With the deviation in load connected to the system, voltage profile of the load buses increases/decreases and may lead to the collapse of the system and subsequent loss of economy. Another problem in distribution system is line losses which reduces the efficiency of the system. Among the possible solutions for these problems, DG allocation is a promising one which feeds the system with additional benefits. However a non-optimal allocation of DG can adversely affect the performance of the system. This paper proposes GA based optimization algorithm to improve voltage profile of the system and simultaneously reduces the total real and reactive power losses.**

Index Terms- (DG) Distributed Generator, (GA) Genetic Algorithm, (RDS) Radial Distribution System.

I. INTRODUCTION

Line losses have a major impact on efficiency of power system as a considerable amount of power continuously getting lost due to line resistance [1]. Distribution systems in India are usually radial in nature due to their operational simplicity. The Radial Distribution Systems (RDS) are fed at only one point and the power flow in the RDS is unidirectional. Due to high ratio of R/X in distribution system compared to transmission system, distribution lines constitute large bus voltage deviation, high power losses and low system stability [2-5]. Hence, line loss reduction and voltage profile improvement are major challenges for the distribution utilities. Several attempts have been made by researchers to improve the voltage profile and efficiency of distribution system.

There are many schemes are proposed in the literature to achieve the mentioned objectives by embedding small resources of electricity with distribution network called Distributed Generator (DG).Modern advancement in renewable technology has pushed DG in as a probable solution for these issues [6-8]. DG is small size generators or any power source sited close to the load being served. It is also known as an onsite or decentralizes generation [9-10].With the rapid advancement in the new technological era, utilization of DG's in power system is continuously increasing. Use of renewable resource saves the conventional resources and provides clean and green energy [9], [11]. Ministry of new and renewable energy resources, India has targeted to increase the renewable generation by five times by the end of 2022[12].

Location and capacity of DG plays a very important role as if it is optimal, it can increase the benefits many fold. Installation of DG at non-optimal location may increase the line losses and can further reduce the voltage profile of the system. Therefore, to find the optimal location and size of DG in the system is a major challenge for any system planner [9], [10]. There are various methods and approaches proposed in the literature for optimal allocation of DG to the distribution system. In [13], Hereford Search Algorithm is proposed based on artificial intelligent technique for optimal location of the DG. In [14], authors proposed analytical approach using a quantitative index to optimize DG location which is calculated through continuous power flow technique. In [15], a multi-objective GA is proposed in combination with Multi-Attribute Decision Making Method to optimize the location and sizing of DG in distribution system.GA shows various advantages over other proposed techniques and is a powerful approach for the optimization problem. GA is a global search approach which analyzes the solution among a random set of possible solution and have an advantage that this do not require any prior information of gradient surface. Evolution concept of genetic algorithm inherits the fundamental concepts found in nature [16]-[17].

In this paper GA is used in the proposed algorithm to optimize DG site and size to provide active power support and improve the voltage profile of the system. The main objective of the present work is to find the location and capacity of DG to reduce the system line losses and improve the cumulative voltage deviation in distribution system through DG allocation. The proposed method is tested on standard IEEE 33 radial distribution system under varying operating conditions and the results obtained are promising is achieving the goals.

II. PROBLEM FORMULATION

Interconnection of DG improves the performance of the system by reducing the line losses and bus voltage deviation, only when allocated optimally. It also serves the system with various other advantages like voltage stability enhancement, improvement in system loadability etc., voltage stability can be defined as the ability of the system to retain the bus voltage constant even in varying load conditions. Advantages of DG's can be maximized by connecting DG at most suitable location among all candidate buses. Line losses and bus voltage profile are the most important parameter which affects the performance and stability of the system.

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The losses in the system are continuous through heat dissipation from the lines, which reduces the efficiency of the system. Line loss increases with the increase in load demand; power loss in supply line is evaluated by load flow analysis and can be represented as follows:

$$P_L = \sum_{i=1}^{n} {I_a}^2 R_i \quad (1)$$

$$Q_L = \sum_{i=1}^{n} {I_r}^2 X_i \quad (2)$$

Where P_L, Q_L are the total active and reactive power loss of the system respectively.

In distribution system bus voltage continuously reduces away from source end. With the increment in load of the system, this problem becomes more predominant. This causes reduction in the voltage stability margin and the system become more vulnerable to the disturbance. Hence voltage profile improvement is major aspect of this analysis. Bus voltages of the system can also be obtained from load flow analysis of the system. To keep the optimization problem minimizing, voltage profile of the system is replaced by cumulative voltage deviation (CVD), which can be represented by following formula:

$$CVD = \sum_{i=1}^{n} (1 - V_i) \quad (3)$$

Where (I = 1, 2, 3……n) bus of the system

DG's can provide potential solution for the above problems. DG's are classified by the kind of support which they provide to the system. Either active, reactive or both kind of power support may be expected from DG's. DG injects the power at the load end, by virtue of that it reduces the demand of the power at respective bus location. This reduction in demand reduces the overall line losses of the system. This injection of power also improves the balance of active to reactive power which improves the voltage profile.

The main objective of the proposed work is to maximize the benefits of the DGs by optimizing the size and location simultaneously. For solving any problem for optimization objective function or fitness function is to be formulated for determining the feasibility of the solution. In the proposed work, an objective function for real and reactive power loss minimization and to improve the overall voltage profile of the system is formulated. Mathematically it can be given as:

$$F\,(P_L, Q_L, CVD) = max\{W_P * P_L + W_Q * Q_L + W_V * (CVD)\} \quad (4)$$

Where W_P, W_Q and W_V are the weights assigned to the variables depending upon the objectives. The weights to the objective variables are assigned as follows:

$$W_{1,2,3} \epsilon [0,1] \quad (5)$$

$$W_P + W_Q + W_V = 1 \quad (6)$$

The combinations of W's which are giving the best solution are considered for the present work. The weights assigned to real and reactive power loss is considered equal always in different combinations so that the both the losses are optimize equally.

For the minimization of the problem fitness function is as follows:

$$FF = min\left\{\frac{1}{1 + F\,(P_L, Q_L, CVD)}\right\} \quad (7)$$

A. *Constraints*

Normally in optimization problem solution is achieved by considering certain constraints. In the present work, the above objective function is optimized by considering the following constraints:

1. Power balance constraint

$$P_G^{Net} \geq P_D^{Load} + P_L^{lines} \quad (8)$$

$$Q_G^{Net} \geq Q_D^{Load} + Q_L^{lines} \quad (9)$$

Here P_G And Q_G are the net active and reactive power generated in the system, P_D and Q_D are the active and reactive power demand of the load connected to the system and P_L and Q_L are the active and reactive line losses of the distribution system. For the stable operation of the system net power generated should be equal or greater than the sum of net power demand and power loss of the system.

2. Voltage constraint

$$V_{bus}^{min} \leq V_{bus} \leq V_{bus}^{max} \quad (10)$$

Stability of the system is highly affected by bus voltage hence bus voltage should lie in between maximum and minimum limits defied as V_{bus}^{max} and V_{bus}^{min} respectively.

3. DG size constraint

To obtain maximum benefits, DG size is considered in between 10% to 40% of the source capacity. DG's capacity lesser than the minimum limit provides negligible benefits and capacity over maximum limits reduces the system stability.

$$P_{10\%} \leq DG_R \leq P_{40\%} \quad (11)$$

III. Genetic Algorithm

In the proposed work the optimal location and capacity of DGs is obtained using Genetic Algorithm (GA). GA uses the concept of genetic evolution to achieve convergence and it can be utilized for both constrained and unconstrained optimization problem. GA has advantage over other conventional and modern optimization approaches is that it does not require any prior information of objective function. Also it does not deal directly with the parameters of optimization problem.GA propagates in a search space containing random sets of 'N' possible solutions, collectively called population. Each candidate solution contains a random

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set of 'n' possible location for DG connection and their corresponding random DG ratings, individually called genes. GA selects the candidates for operation by their biological selection of most fit candidate by the help of fitness function.GA converge the solution in iterative way by using genetic operators 'Reproduction' 'Crossover' and 'Mutation' inspired by natural evolution process. GA modifies the population of candidate solutions for every iteration as per the genetic operators; this modified population is called generation [19].

A. Population

To initialize the algorithm GA requires an initial set of probable solutions called initial population. This is completely a random group of candidate solution generated by random number generator and for these candidates no prior knowledge exists.

These candidate solution consist subset consisting properties of candidate related to the DG location and sizes, known as genes. These candidates can be constructed in following ways

- In binary representation of chromosomes (candidates) value of each gene is given in their binary equivalent. The major issue is to choose the count of bits in which genes are formulated.
- In real coding of chromosome, property of each gene is coded in their relevant decimal values.

In this paper real number coding is used for the representation of chromosomes. With respect to the number of DG's connected, twice no of genes are inherited in each chromosome. Half of the genes carried the location properties and rest carried the respective sizes of DG.

B. Genetic operators

After evaluating the fitness of each candidate using fitness function, GA converge the solution by their genetic operators which are Reproduction (Selection), Crossover & Mutation. This complete evolution process is nature inspired, although it's not necessary to use all the operators. Use of operators can be modified as per requirement of the problem.

- *Reproduction*

The reproduction operator reduces the search space for achieving convergence by selecting the parents in descending fitness order. This operator transfer the pair of parent chromosome for the next step of evolution by giving higher priority to higher fit candidate and removes those candidates which do not satisfies the minimum fitness criteria. In this way selection ensures the propagation of best genetic material to the next upcoming generation.

- *Crossover*

The crossover is one of the most important genetic operator as it produces the new generation by performing the crossover of genetic material between two selected parents. Crossover can be performed to generate one child chromosome inherited best from both the parents. However two child chromosomes can be generated after random transfer of genetic material between parent chromosomes. Generally transfer of genes is performed by one point crossover, two point crossovers or multipoint crossover.

- *Mutation*

This operator introduces diversity in population. This operator works at gene level for each candidate. It randomly selects a gene from chromosome and modifies it by a specific rate. This produces the diversity in new population from older one. This helps to avoid premature convergence and leads towards better solutions.

C. Algorithm control parameters

Control parameters are applied at every step of algorithm to control the execution of the algorithm. This is necessary to control because uncontrolled evolution may lead the algorithm towards non-optimal results or may keep algorithm un-converged.

The common parameters for the genetic algorithm are Initial population size, selection rate, crossover rate and mutation rate. Other parameters can be added as per requirement of the problem. Population size defines the area of search space. Large population size has the advantage of better results but may increases the time of execution.

Selection rate is defined by the fitness below which candidate marked as unfit for optimization. This helps in selection of candidate with better fitness. A higher fitness level reduces the execution time of algorithm as it selects the candidates with high value of fitness. But this may lead to premature convergence as it may drop a candidate with potential fitness which will reduce the probability to achieve global solution.

Crossover and Mutation are the most important steps of evolution. Crossover rate control the frequency of crossover operation whereas mutation rate controls the percentage of diversity introduced by operator in child chromosome. Higher mutation rate may distinct the child from rest of population.

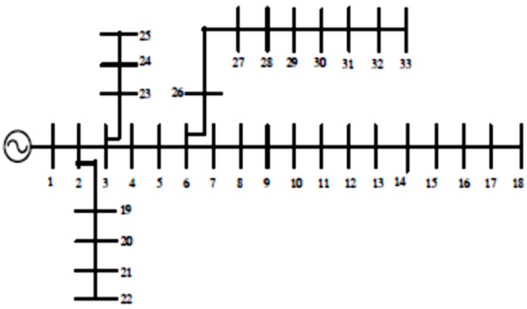

Fig.1.IEEE 33 Bus radial distribution systems

IV. SOLUTION METHODOLOGY

GA evaluates the fitness of each candidate by fitness function. To initiate the algorithm, population of candidate solution is obtained using load flow of considered test system and is randomly generated. The total 500 candidate solutions are generated randomly to optimize 3 DG's in IEEE 33 bus radial distribution system. Fitness of these candidates is obtained by fitness function.

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Fitness functions variables which are active power loss, reactive power loss and cumulative voltage deviation (CVD)are obtained by load flow analysis for every candidate solution. Reproduction operator is then chooses the fit candidates and forward them for further evolution process. Average fitness is observed for the reproduction operator by manual observation. Candidates below this fitness level are eliminated from the population.

Random N point crossover is performed to generate offspring. Genes of candidate chromosomes are interchanged by this operator and new population formed. This operation is controlled by crossover rate (0.05). Now the offspring is forwarded to mutation operator. Mutation operator randomly selects a gene and alters it by multiplying a random number. This operation is controlled by mutation rate (0.05).This operation maintains the diversity in population and prevent the premature convergence which may occur due to elimination of possible candidate at earlier stages. Fitness of this population is again evaluated and the operation is again followed in iterative way until convergence achieved. The flow chart of the proposed method is shown in Fig. 2.

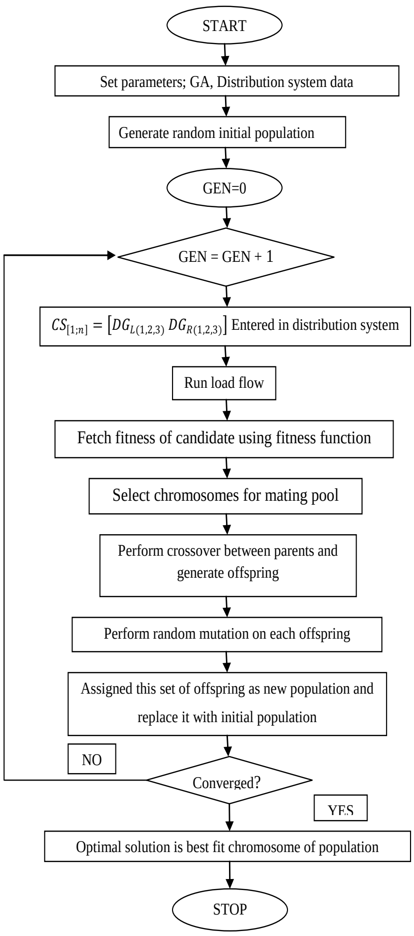

Fig. 2 Flow chart of proposed Algorithm

V. Simulation Result

Location and sizing of DG for the objectives considered are obtained. For each topology and locations results for distribution system performance is analyzed by load flow of the system. The GA gives the optimal bus locations (3, 17, and 28) with optimal rating of (0.8256 p.u., 0.2134 p.u. and 0.4571 p.u.) respectively for IEEE 33-bus radial distribution system. Initially system performance analysis is performed for base loading condition. It is observed that with the increment in load of the system, performance of the system reduces in the form of increment in system losses and reduction in voltage profile. The load is increased in steps of 5% and for each load profile the system analysis is performed to evaluate the effects of DG placement by the proposed method.

Table-I presents reduction in cumulative voltage deviation of the system. The analysis is done for the 100, 105, 110, 115, and 120 percent of loading condition. Reduction in voltage deviation with increase in load conditions is indexed in table shown below. Fig.3 shows the comparative bus voltage profiles for all the buses with and without DG system for various loading condition. This graph shows the significance of DG interconnection for improvement in bus voltage profile of the system.

TABLE I: Performance Evaluvation of DGfor CVDProfile of The System

Loading condition	System status	Optimal Bus Location	Respective DG ratings (PU)	CVD (PU)	CVDR (%)
100%	Without DG	-	-	1.0137	48.60
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.5210	
105%	Without DG	-	-	1.0499	47.09
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.5555	
110%	Without DG	-	-	1.0862	45.67
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.5901	
115%	Without DG	-	-	1.1226	44.34
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.6248	
120%	Without DG	-	-	1.1592	43.09
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.6596	

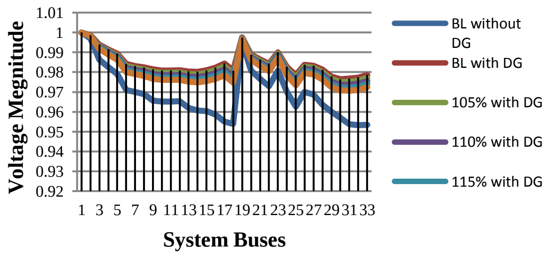

Fig.3. Bus voltage profile of the system under different loading conditions

Reduction in cumulative voltage deviation of the system by connecting DG at optimal locations is shown in Fig. 4. This figure shows benefits of DG even in increase load conditions. Table-II shows the reduction in active power losses of the system operating with DG's. Over 50% reduction in loss profile is achieved by the proposed algorithm. It is evident that

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reduction in loss profile of the system is consistent with different loading conditions. Under base load condition, system shows active losses 0.123 p.u. (without DG's), 0.057 p.u. (with DG's). Reduction in losses of the system achieved is 53.66%. Fig. 5 graphically represents the results of table II. The figure shows the bar graph of loss profile improvement for all the cases.

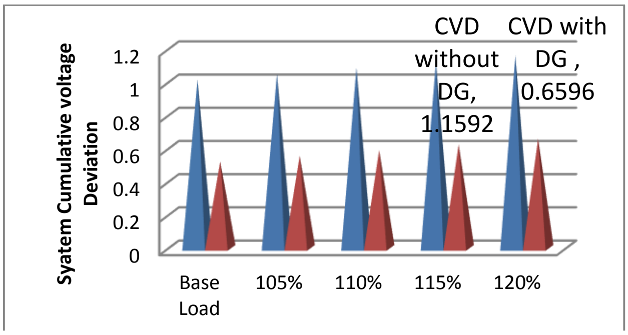

Fig.4. Cumulative voltage profile of the system: Comparative analysis between without DG and with DG

TABLE II
PERFORMANCE EVELUVATION OF DGOVER ATIVE LOSS PROFILE OF THE SYSTEM

Loading condition	System status	Optimal Bus Location	Respective DG ratings (PU)	Active Power Loss (P_L)	P_L Profile Improve ment (%)
100%	Without DG	-	-	0.123	53.66
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.057	
105%	Without DG	-	-	0.132	54.54
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.060	
110%	Without DG	-	-	0.142	55.63
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.063	
115%	Without DG	-	-	0.152	55.92
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.067	
120%	Without DG	-	-	0.163	56.44
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.071	

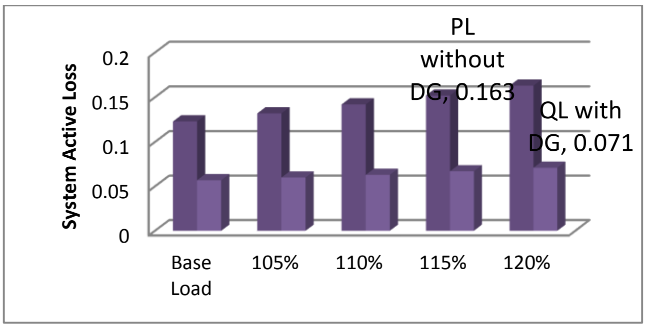

Fig.5. Active loss profile of the system: Comparative analysis between without DG and with DG condition of the system

In Fig. 5 it can be observed that the losses are less when the DG's are connected in the system as compared to the system without DG's. Improvement in reactive loss profile of the system is shown in table III. The proposed method is also applied for different loading conditions and the results shows the effectiveness of the optimal placement of the DG's. Reactive losses of system are graphically shown in fig.5 and improvement in reactive power loss profile is evident for all the cases.

TABLE III
PERFORMANCE EVELUVATION OF DGOVER REACTIVE LOSS PROFILE OF THE SYSTEM

Loading conditio n	System status	Optimal Bus Location	Respective DG ratings (PU)	Reactive Power Loss (Q_L)	Q_L Profile Improve ment (%)
100%	Without DG	-	-	0.088	51.13
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.043	
105%	Without DG	-	-	0.094	52.12
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.045	
110%	Without DG	-	-	0.101	52.47
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.048	
115%	Without DG	-	-	0.109	53.21
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.051	
120%	Without DG	-	-	0.116	53.54
	With DG	3,17,28	0.8256, 0.2134, 0.4571	0.054	

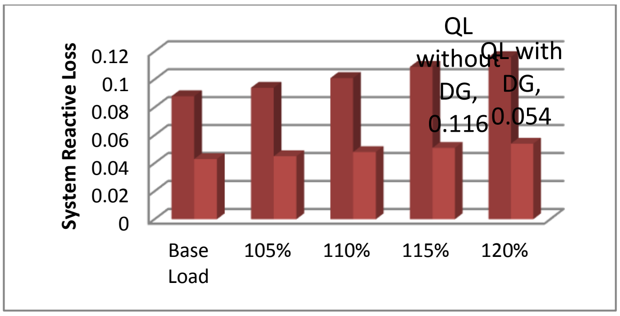

Fig.6. Reactive loss profile of the system: Comparative analysis between without DG and with DG condition of the system

Line losses and cumulative voltage deviation in the system are reduced effectively by optimizing the DG's location and ratings. Results and graphs mentioned above are presenting the effectiveness of the methodology.

VI. CONCLUSION

This paper presents a heuristic approach (Genetic Algorithm) to carry out optimal placement of DG in distribution network. The analysis of the proposed method is tested on the IEEE 33-bus radial distribution network, and the results show the significance of the proposed method in improving the voltage profile and loss reduction of the system. DG location and size in distribution system was bounded by some inequality constraints and this algorithm successfully attends the convergence with satisfying all the constraints.GA is advantageous as it have less computation time and possess high level of convergence. Analysis of the results performed by load flow analysis depicts the effectiveness of the approach. Voltage profile and Power losses of the system have

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improved considerably by placing and sizing the DG's by the proposed GA based optimization method. The proposed method is also tested under varying operating conditions by increasing the real and reactive loads of the system in steps. The results obtained shows that even under stressed operating conditions the proposed method is able to improve the voltage profile and power loss of the system. Search space of this technique is random and works on principal of genetic evolution which provides solution near to global optima.

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