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Real Power Loss Minimization in Distribution System Network Using DG Placement

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***Abstract*—**This article presents a technique to emphasize the network complexity problem with the use of Distributed Generation (DG) with an objective of reducing real power loss and improving voltage profile in distribution system. A soft computing Genetic Algorithm (GA) is used to randomly and identify the optimal locations of candidate bus for installation of DG units in a radial distribution network. Sensitivity analysis is integrated to identify and pick up sensitive nodes for installation of DG units at optimal locations. Method of DG placement and base case of radial distribution network are considered to study the performance of the present method. The constraints of voltage and branch current carrying capacity are included in the evaluation of the objective function. The proposed technique has been applied on 33-bus and 69-bus radial distribution systems at three different load levels to demonstrate the performance and effectiveness of the proposed algorithm.

Index Terms—Distribution system, Distribution Generation, Genetic Algorithm (GA), Real Power Loss, Voltage Profile.

1. INTRODUCTION

In recent decades, the modern power distribution network is constantly being faced with an ever-growing load demand, this load is results into increased burden and minimize the voltage. This reduction in voltage due to ineffective quantity of real power. Even in certain condition, industries have critical load requirement, it may results to voltage collapse. So improve the voltage profile and to reduce the voltage collapse real compensation is required. The need of increasing the entire efficiency of power utilities and reduce the losses in radial distribution level. There are many technique should be carried out to minimize the losses like network reconfiguration, installation of DG units and DG installation with network reconfiguration etc. Distributed Generation [1] is a technology which reduces the amount of energy loss in transmitting electric power from one system to another. This also reduces the size and number of power lines that must be constructed. DGs are nearest to customers so that transmission and distribution cost are avoided or reduced and the latest technologies have been implemented. Rau and wan [2] presented the technique to identify optimal locations of distributed generator in a radial feeder to minimize the losses and line loading. Rau and wan proposed the method to establish the optimal distributed generation allocation on radial feeder based on a Genetic Algorithm, considering all the technical constraints, like feeder capacity limits, feeder voltage profile and three phase short circuit current in the radial distribution system.

Merlin and Back [3] proposed radial distribution network reconfiguration problem and they used a branch-and-bound-type technique. Shirmohammadi and Hong [4] suggested a meta heuristic algorithm, commonly electric radial distribution system are coordinated radially, for effective arrangement of their protection systems. Radial feeder contain a number of switches that are normally open and switches that are normally closed. Regarding to a fault, some type of open switches should be closed irrespective of all of isolated part of switches to shifted to another healthy feeder. Such type of switches should be restore in radial feeder after removal of the fault. Civanlar et al. [5] proposed about a meta heuristic algorithm, radial feeder reconfiguration technique can be used to real time control tool and as well as strategy tool. Reconfiguring the structure of radial feeders from time depends, by switching the position of open/closed states of the switches to transfer load from one radial feeder to another, may increasing the overall efficiency of the system. This method is not suitable multiple switching operation at a time and reconfiguration of network depends on initial switch status. D. Das et al. [6] suggested, a fuzzy multi objectives techniques are considered for load balancing among radial feeders and also to reduces the real power loss by varying the deviation of node voltage, branch current and subject to a radial feeders. There are four objectives are modeled with fuzzy set to evaluate their imprecise nature and his or her anticipated value of each objective.

Nara et al. [7] presented, a meta heuristic search optimization Genetic Algorithm (GA) to minimize the real power loss using only install DG units at optimal candidate bus location in radial distribution system. A genetic algorithm (GA) is based on search optimization technique as natural selection and natural genetics. It consider the features of natural genetics and natural evolution procedures with search optimization. A genetic algorithm (GA) simulating the fittest solution among string structures and randomized information exchange of optimal string (solution). Since GA created old ones among the fittest string solution in every iteration. Zhu [8] proposed method of loss minimization problem to study Distribution Network Reconfiguration (DNRC) based on a refined genetic algorithm (GA). In DNRC problem, in which the objective function is to minimizes the real power loss and improved the voltage profile in Radial Distribution System (RDS). The Radial Distribution Network Load Flow (RDNLF) presented the precise branch-current and branch-voltage technique to reduce the system power loss. The refined genetic algorithm (GA) is not suitable to improve the chromosome coding, fitness function and mutation problem.

Rao et al. [9] presented Harmony Search Algorithm (HSA), is based on musical process of searching for a perfect state of conceptualized harmony. It uses a random search optimization technique instead of a gradient search which eliminates the necessary information about harmony. Harmony Search algorithm (HSA) is proposed to minimize real power losses in radial distribution network to solve the network reconfiguration problem to get optimal switching arrangements randomly. Rosehart and Nowicki [10] proposed real and rereal load flow equations based on the use of the Lagrangian multipliers associated to indicate buses where small-scale distributed generation should be placed. So the location of Distributed Generator should be decided based on their operators, location incentive based on the Lagrangian multipliers can be used. The use of Optimal Power Flow (OPF) and voltage stability constrained to determine the location of Distributed Generator based on reducing system cost and enhancing stability.

Celli et al. [11] proposed multi objective formulation technique for sitting and sizing of DG resources into existing distribution network adopted by Genetic Algorithm (GA). Wang and Nehrir [12] proposed an analytical method to determine the optimal location of distribution generation (DG) to place in radial as well as network system to minimize the system power loss and improve the voltage profile. In power system, the proper location of DGs can be strategically placed in power system for grid reinforcement, reducing power losses and on-peak operating costs, improving voltage profile and load factors. In this paper, GA [13] has been proposed to solve the radial distribution system network problem in the presence of distributed generation. The Genetic Algorithm is tested on 33- and 69-bus systems and results obtained are compared to base system.

This article consists of six sections are following as: Section II gives the problem formulation, Section III describes sensitivity analysis for DG sizing, Section IV discuss about of proposed optimization algorithm, Section V gives the results and discussion, and Section VI presented conclusions.

2. PROBLEM FORMULATION

2.1 Power Flow Equations

Power flows in a radial feeder are calculated by the following set of mathematical equations [13] derived from the single line diagram shown in Fig. 2.1

$$P_{i+1} = P_i - P_{Loss,i} - P_{Li+1}$$

$$= P_i - \frac{R_i}{|V_i|^2}\{P_i^2 + (Q_i + Y_i|V_i|^2)^2\} - P_{Li+1} \qquad (2.1)$$

$$Q_{i+1} = Q_i - Q_{Loss.i} - Q_{Li+1}$$

$$= Q_i - \frac{X_i}{|V_i|^2}\{P_i^2 + (Q_i + Y_{i1}|V_i|^2)^2\} - Y_{i1}|V_i|^2$$

$$- Y_{i2}|V_{i+1}|^2 - Q_{Li+1} \qquad (2.2)$$

$$|V_{i+1}|^2 = |V_i|^2 + \frac{R_i^2 + X_i^2}{|V_i|^2}(P_i^2 + Q_i^2) - 2(R_iP_i + X_iQ_i)$$

$$= |V_k|^2 + \frac{R_i^2 + X_i^2}{|V_i|^2}(P_i^2 + (Q_i + Y_i|V_i|^2)^2)$$

$$- 2\big(R_iP_i + X_i(Q_i + Y_i|V_i|^2)\big) \qquad (2.3)$$

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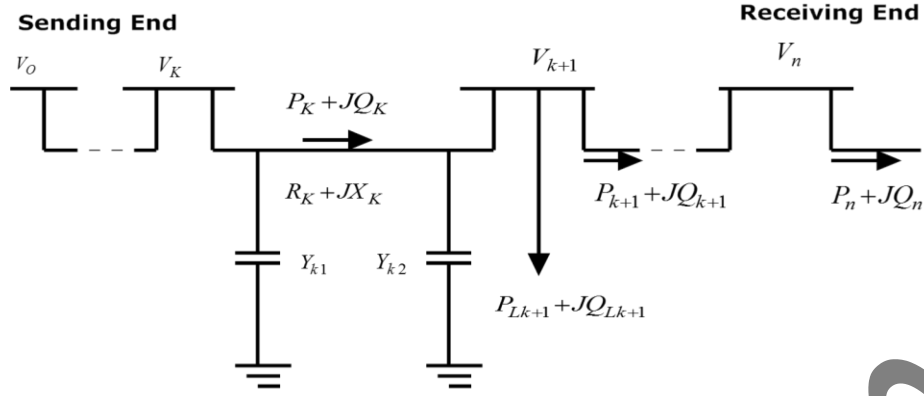

Fig. 2.1 Single diagram of radial distribution system

The real power loss of radial feeder connecting buses i and i+1 may be computed as

$$P_{Loss}(i, i+1) = R_i.\frac{(P_i^2 + Q_i^2)}{|V_i|^2} \quad (2.4)$$

The total real power loss of the radial feeder, $P_{T,Loss}$, may then be computed by the losses of all line section of the feeder, which is given as

$$P_{T,Loss} = \sum_{i=1}^{n} P_{Loss}(i, i+1) \quad (2.5)$$

2.2 Real Power Loss Reduction using Only DG Installation

The real power loss reduction when a DG install at optimal Location in distribution network in shown in Fig. 2.2. The installation of DG unit in radial distribution network has several advantages. It improves the integrity, reliability and efficiency of overall of system. It reduces line losses, improving the voltage profile and reliving the overloading of the network.

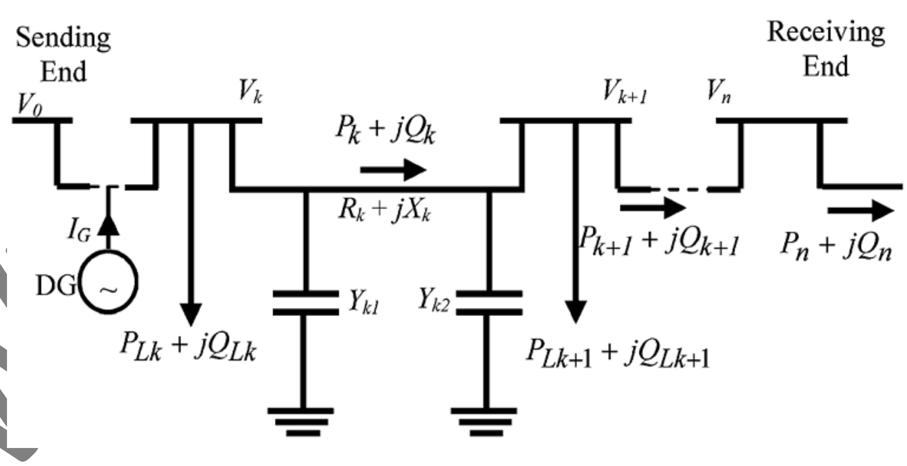

Fig. 2.2 DG installation at optimal candidate bus in distribution system

The power flow equation in radial distribution system shown in figure. 2.2, is given by

$$P_{DG,Loss} = \frac{R_i}{V_i^2}(P_i^2 + Q_i^2) + \frac{R_i}{V_i^2}(P_G^2 + Q_G^2 - 2P_iP_G - 2Q_iQ_G)\left(\frac{G}{L}\right). \quad (2.6)$$

The real power loss reduction, when before and after installation DG unit is given by

$$\Delta P_{Loss}^{DG} = \frac{R_i}{V_i^2}.(P_G^2 + Q_G^2 - 2P_iP_G - 2Q_iQ_G)\left(\frac{G}{L}\right) \quad (2.7)$$

2.3 Objective Function of the Problem solution

The objective function of the problem solution is formulated to maximize the real power loss reduction in radial distribution system, which is given by

Maximize

$$f = \max(\,\Delta P_{Loss}^{DG}) \tag{2.8}$$

Subjected to

$$\left.\begin{array}{c} V_{min} \le |V_i| \le V_{max} \\ and\ |I_{i,i+1}| \ \le |I_{i,i+1,max}| \\ \sum_{i=1}^{n} P_{Gi} \ \le \sum_{i=1}^{n}(P_i + \ P_{Loss,i}) \end{array}\right\} \tag{2.9}$$

$$\left.\begin{array}{l} \det(A) \ = \ 1 \text{ or } -1 \text{ (radial system)} \\ \det(A) \ = \ 0 \text{ (not radial)} \end{array}\right\} \tag{2.10}$$

3. SENSITIVITY ANALYSIS FOR DG INSTALLATION

A new method to determine candidate nodes for placement of Distributed Generator (DG) using Loss Sensitivity Factors. To identify the location for DG placement in distribution system Loss Sensitivity Factors can be used. The loss sensitivity factor is able to predict which bus will have the highest loss reduction when a DG is placed. The estimation of these candidate buses basically helps in reduction of the search space for the optimization problem. Consider a distribution line with an impedance R+jX and a load of Peff + jQeff connected between i and j buses as given below in Fig. 3.1.

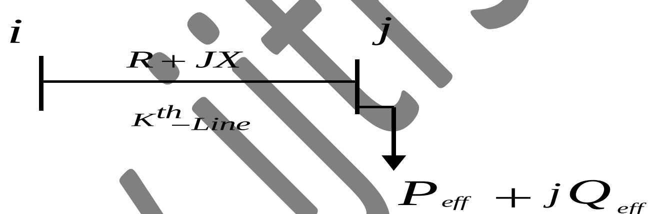

Fig. 3.1 A Distribution Line With An Impedance And a Load

Real power loss in the line of the Fig. 3.1 is given by $[I_k^2]*[R_k]$, which can also be expressed as,

$$P_{lineloss} = \frac{(P_{eff}^2 + Q_{eff}^2)R_i}{V_i^2} \tag{3.1}$$

The loss sensitivity factor (LSF) expressed by the equation

$$\frac{\partial P_{lineloss}}{\partial P_{eff}} = \frac{2*P_{eff}*R_i}{V_i^2} \tag{3.2}$$

Using equation (12), LSFs are used to decide the sequence in which buses are to be considered for optimal DG unit installation. The size of DG unit at candidate bus is calculated by Genetic Algorithm**.**

4. OVERVIEW OF GENETIC ALGORITHM

Genetic Algorithm (GA) is a Meta Heuristic search algorithm based on the mechanics of natural selection and natural genetics [7]. It combines the adaptive nature of the natural genetics or the evolution procedures of organs with functional optimizations. By simulating the survival of the fittest among string structures, the optimal string (solution) is searched by randomized information exchange. In every generation, a new set of artificial strings is created using bits and pieces of the fittest of the old ones. It efficiently exploits historical information to speculate on a new search point with expected improved performance. "Genetic Algorithms are effective parameter search techniques [8]. They are considered when conventional techniques have not achieved the desired speed, accuracy or efficiency. GAs are different from conventional optimization and search procedures in the following ways.

- GAs work with coding of parameters rather than the parameter themselves.

- GAs search from a population of points rather than a single point.
- GAs use only objective functions rather than additional information such as their derivatives.
- GAs use probabilistic transition rules, and not deterministic rules.

A Genetic Algorithm is an iterative procedure which begins with a randomly generated set of solutions referred as initial population. For each solution is set, objective function and fitness are calculated. On the basis of these fitness functions, pool of selected population is formed by selection operators, the solution in the pool has better average fitness than that of initial population. The crossover and mutation operator are used to generate new solutions with the help of solution in the pool. The process is repeated iteratively while maintain fixed number of solutions in the pool of selected population, as the iteration progress, the solution improves and optimal solution is obtained. With the above description, a simple Genetic Algorithm is given as follow:

Step 1: Randomly generate initial population strings.
Step 2: Calculate the fitness value for each string in the population.
Step 3: Create the pool after selection.
Step 4: Create off springs through crossover and mutation operation.
Step 5: Evaluate the off springs and calculate the fitness value for each solution.
Step 6: If the search goal is achieved, or an allowable generation is attained, return the best chromosome as the solution; otherwise go to step 3. The standard procedure of GA is depicted in Flowchart as shown in Fig. 4.1

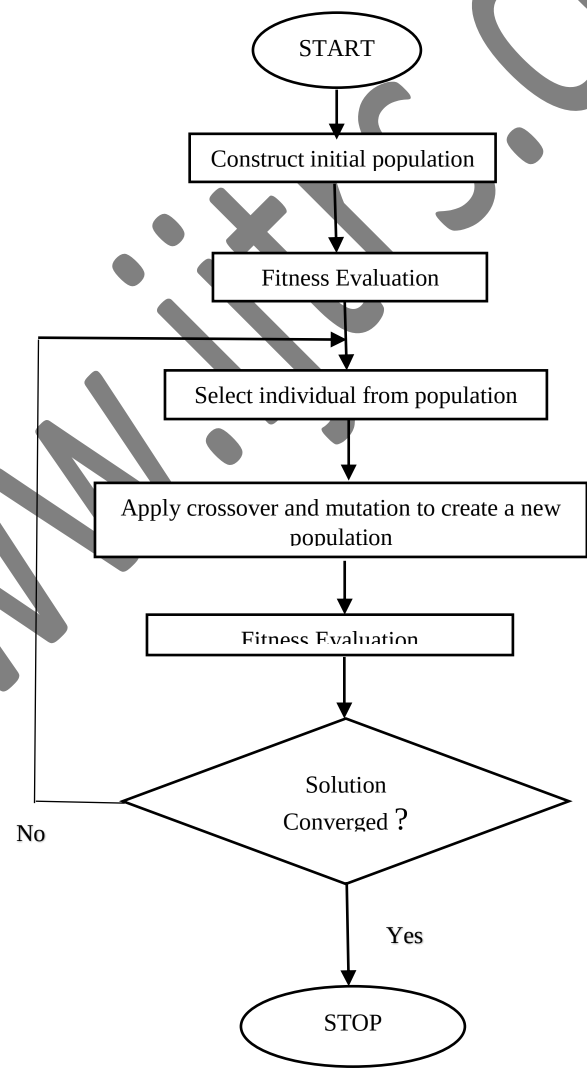

Fig. 4.1 Genetic Algorithm Flowchart

5. APPLICATION OF GA FOR POWER LOSS MINIMIZATION

Application of GA for loss minimization problem with DG installation is illustrated with the help of standard 33-bus radial distribution system. In 33-bus system, there are five open tie switches with branch numbers 33, 34, 35, 36, and 37, respectively, which forms five loops to (if formed) as shown in Fig. 5.1 [21], Further, assume that candidate buses for optimal installation of DG units are 8, 20, and 24 as shown in Fig. 5.1, The ratings of units will vary in discrete steps at specified location during optimization process. In order to represent an optimal network topology, only positions of open switches in the distribution network need to be known.

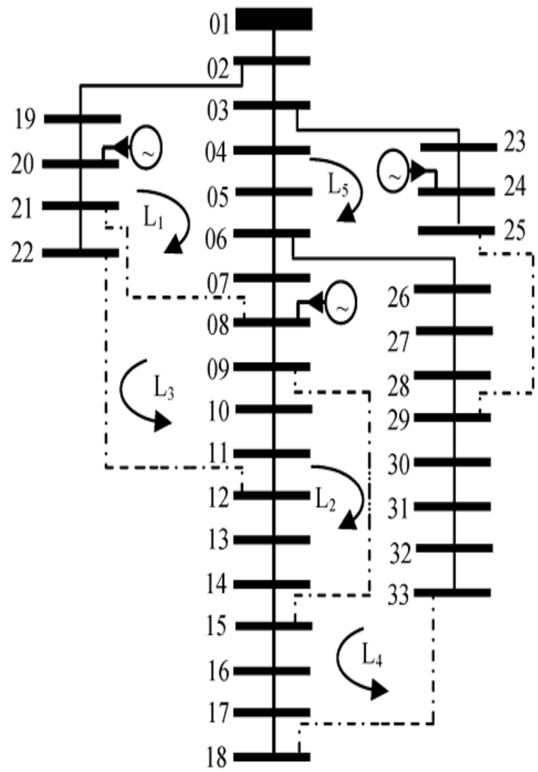

Fig. 5.1 33-bus radial distribution system

6. TEST RESULTS

In this article results have been presented after the implementation of the algorithm. The algorithm has been tested on 33-bus and 69 bus Radial Distribution system (RDS) correspondingly. In order to demonstrate the effectiveness of the proposed method (installation of DG units) using GA, it is applied to 33-bus and 69-bus radial distribution system. In the simulation of the network, three methods are considered to analyze the results.

Method I: The system is without reconfiguration and distributed generators (Base Case);

Method II: DG units reconfiguration are installed at candidate buses in the system (without Genetic Algorithm);

Method III: DG units without reconfiguration are installed at candidate buses in the system (with Genetic Algorithm)

A. 33-Bus System

The 33-bus radial distribution system as shown in Fig. 5.1 has following characteristics: Number of buses=33, number of lines=32, Slack Bus No=1;Base Voltage=12.66KV, Base MVA=160.2756 MVA;
The line and load data of network are taken from [9], and the total real and real power loads on the system are 3715 KW and 2300 KVAR. The parameter of GA algorithm used in the simulation of network are Population Size=50, Crossover Rate=0.8, Mutation rate=0.05, and number of iterations $N_{max} = 100$, Selection=0.5, Number of bits=6. The base case load flow solutions of 33-bus RDS with DG installations summarizes in Table 6.1

Table 6.1 Results of 33-Bus System

Methods		Load Level		
		Light (0.5)	**Nominal (1.0)**	**Heavy (1.6)**
Base Case (Method I)	Switches Opened	33, 34, 35, 36, 37	33, 34, 35, 36, 37	33, 34, 35, 36, 37
	Power Loss (kw)	47.06	202.67	575.27
	Minimum Voltage (p.u)	0.9583	0.9131	0.8529
Only DG Installation (Method II) (without GA)	Size of DG in MW (Bus Number)	0.1303(18) 0.1777(17) 0.5029(33)	0.1070(18) 0.5724(17) 1.0462(33)	0.1939(18) 0.9108(17) 1.6115(33)
	Power Loss (kw)	23.29	96.76	260.97
	% Loss Reduction	50.5	52.26	54.63
	Minimum Voltage (p.u)	0.9831	0.9670	0.9437
Only DG Installation (Method III) (with GA)	Size of DG in MW (Bus Number)	0.8705(24) 0.9409(30) 0.8536(13)	0.8457(24) 0.9427(31) 0.9831(14)	0.5831(31) 1.2000 (7) 0.6585(14)
	Power Loss (kw)	17.57	75.07	206.69
	% Loss Reduction	62.66	62.95	64.07
	Minimum Voltage (p.u)	0.9843	0.9717	0.9537

The percentage loss reduction In this article, a 33-bus radial distribution system data are using method I, method II and method III to computing real power loss, loss reduction and voltage profile in the Table 6.1. In method I, the system is without network reconfiguration and distributed generators, and method II DG units without reconfiguration are installed at candidate bus without genetic algorithm and method III same as method II expect that using genetic algorithm to reducing power loss and improving the voltage profile.

The size and location of distributed generators are randomly defined using 33-bus radial distribution system data in Table 6.1. Using sensitivity analysis (12) sensitivity factors are computed to install the DG units at candidate bus locations for method II and method III. After computing sensitivity factors at all buses, they are sorted and ranked. Only top three locations are selected to install DG units in the system. The limits of DG unit sizes chosen for installation at candidate bus locations are 0 to 2 MW. The candidate locations for method II and method III are given in Table 6.1. To assess the performance, the network is simulated at three load levels: 0.5 (light), 1.0 (nominal), and 1.6 (heavy) and simulation results are presented in Table 6.1. It is observed from Table 6.1, at light load, base case power loss (in kW) in the system is 47.06 which is reduced to 23.29 and 17.57 using method for method II and method III are 50.5 and 62.66 respectively.

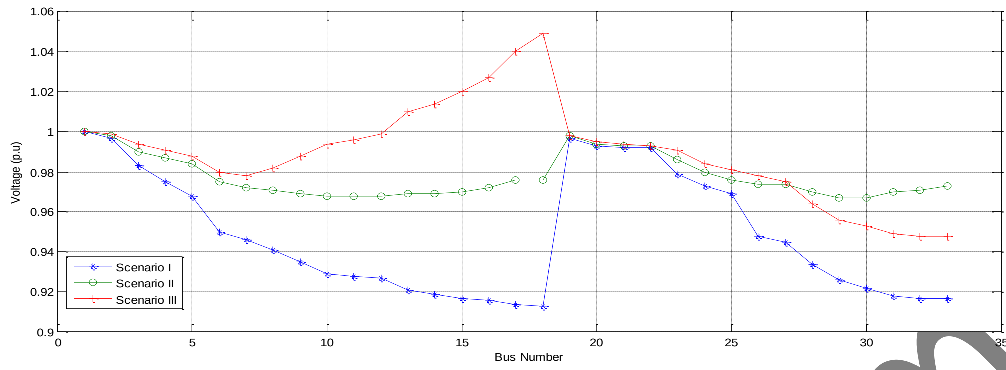

Fig. 6.1 (a) Voltage Profile of 33-bus Radial Distribution System at Light Load (0.5)

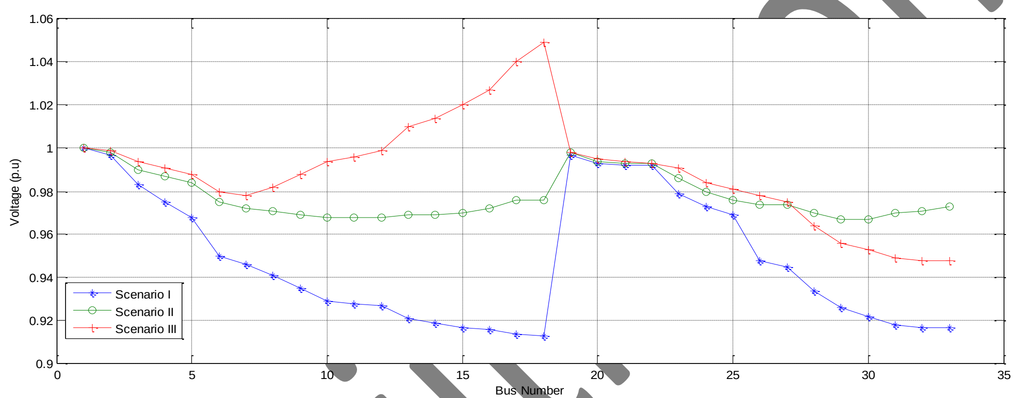

Fig. 6.1 (b) Voltage Profile of 33-bus Radial Distribution System at Normal Load (1.0)

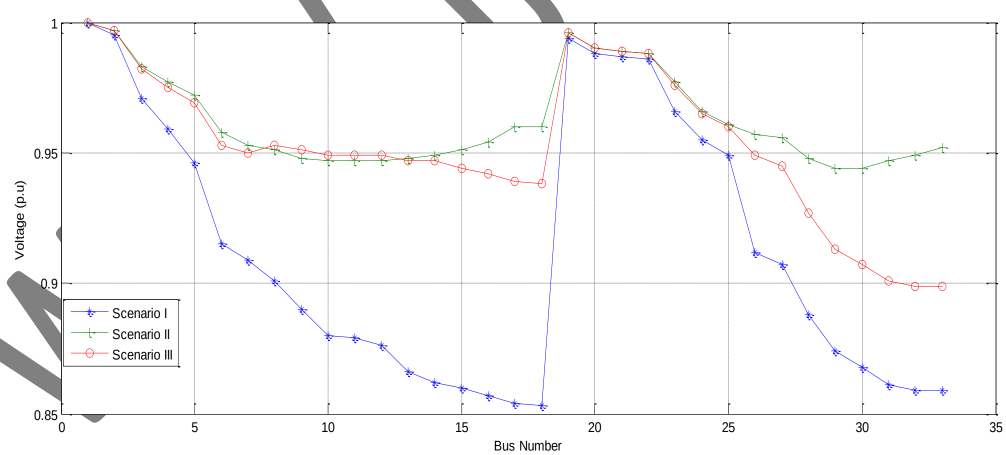

Fig. 6.1 (c) Voltage Profile of 33-bus Radial Distribution System at Heavy Load (1.6)

The power loss (in KW) for method II and method III at nominal and heavy load conditions is 96.76, 75.04 and 260.97, 206.69 respectively Similarly the percentage loss reduction for methods II and method III at nominal and heavy load conditions is 52.26, 62.95 and 54.63, 64.07 respectively. This shows that for all the three load levels, power loss reduction using method III (proposed method) is highest, which elicits the superiority of the proposed method over the others. However, as load increases from light to heavy, improvement in percentage loss reduction in all methods is almost the same. From Table 6.1 and Fig. 6.1, it is seen that improvement in power loss reduction and voltage profile for method III are higher when compared to method II, so we can say that method III is more effective as compared to all three methods. Method III describes as DG installation with using Genetic Algorithm.

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B. 69-Bus System

The 69-bus radial distribution system, as shown in Fig.6.2 [20], has following characteristics:
Number of buses=69, Number of lines=68, Slack Bus No=1
Base Voltage=12.66 KV, Base MVA= 160.2756 MVA
The base case load flow solutions of 69-bus RDS with DG installations summarizes in Table 6.4.

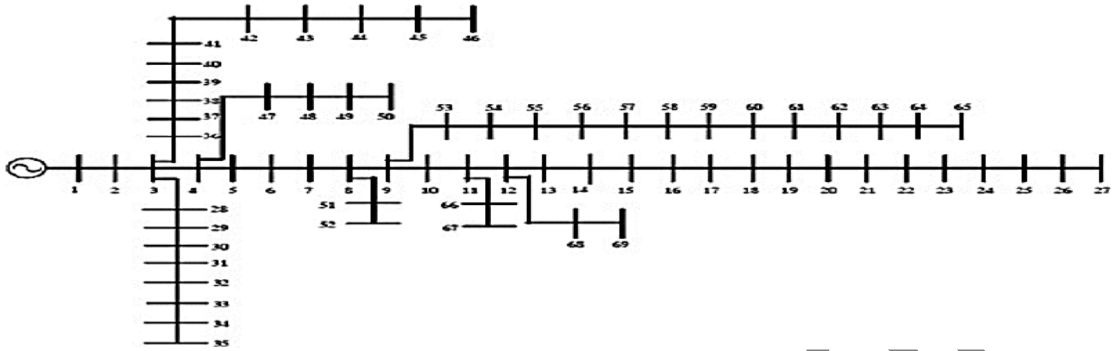

Fig. 6.2 69-Bus Radial Distribution System

Total system loads for base configuration are 3802.19 KW and 2694.06 KVAR. Similar to test systems 6.1, this test system is also simulated for two method at three load levels and results are presented in the Table 6.3. The limits of DG unit size chosen for installation at candidate bus locations are same as test case 1.The base case power loss (in KW) at light, nominal, and heavy load conditions is 51.61, 225, and 652.53, respectively.

Table 6.2 Results of 69-Bus System

It is observed from Table 6.3, at light load, base case power loss (in kW) in the system is 51.61 which is reduced to 21.92 and 18.63 using method II and method III respectively. The percentage loss reduction for method II and

Methods		**Load Level**		
		Light (0.5)	**Nominal (1.0)**	**Heavy (1.6)**
Base Case (Method I)	Switches Opened	69, 70, 71, 72, 73	69, 70, 71, 72, 73	69, 70, 71, 72, 73
	Power Loss	51.61	225.00	652.53
	Minimum Voltage (p.u)	0.9567	0.9092	0.8445
Only DG Installation (Method II) (without GA)	Size of DG in MW (Bus Number)	0.2579(65) 0.1280(64) 0.5857(63)	0.1018(65) 0.3690(64) 1.3024(63)	0.1589(65) 0.8308(64) 1.9710(63)
	Power Loss	21.92	86.77	230.61
	% Loss Reduction	57.53	61.43	64.66
	Minimum Voltage (p.u)	0.9846	0.9677	0.9478
Only DG Installation (Method III) (with GA)	Size of DG in MW (Bus Number)	0.2339(14) 0.8781(63) 0.8174 (2)	0.3996(15) 0.1119(67) 1.5979(61)	1.0046(19) 1.5557(61) 1.3249(64)
	Power Loss	18.63	72.78	193.29
	% Loss Reduction	63.90	67.65	70.37
	Minimum Voltage (p.u)	0.9905	0.9725	0.9715

method III are 57.53 and 63.90 respectively. The power loss (in KW) for method II and method III at nominal and heavy load conditions is 86.77, 72.78 and 230.61, 193.29 respectively. Similarly the percentage loss reduction for method II and method III at nominal and heavy load conditions is 61.43, 67.65 and 64.66, 70.37 respectively. This shows that for all the three load levels, power loss reduction using method III (proposed method) is highest, which elicits the superiority of the proposed method over the others. However, as load increases from light to heavy, improvement in percentage loss reduction in all methods is almost the same. From Table 6.3 and Fig. 6.3, it is seen that improvement in power loss reduction and voltage profile for method III are higher when compared to method II. This implies that only DG Installation using genetic algorithm does yield desired results of maximizing power loss reduction and improved voltage profile.

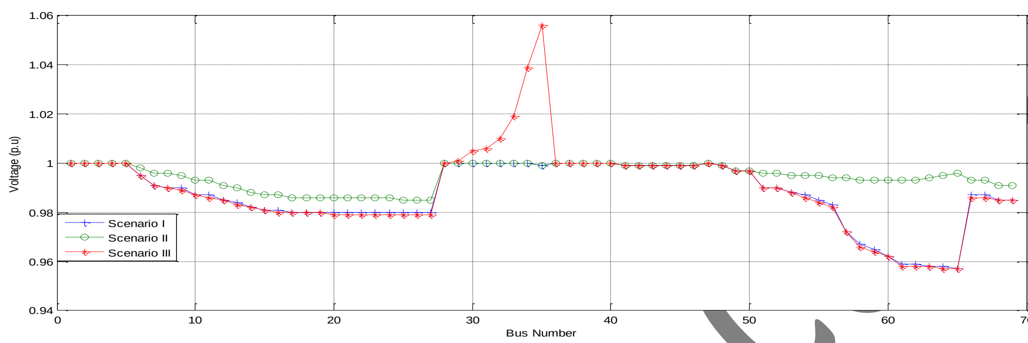

Fig. 6.3 (a) Voltage Profile of 69-bus Radial Distribution System at Light Load (0.5)

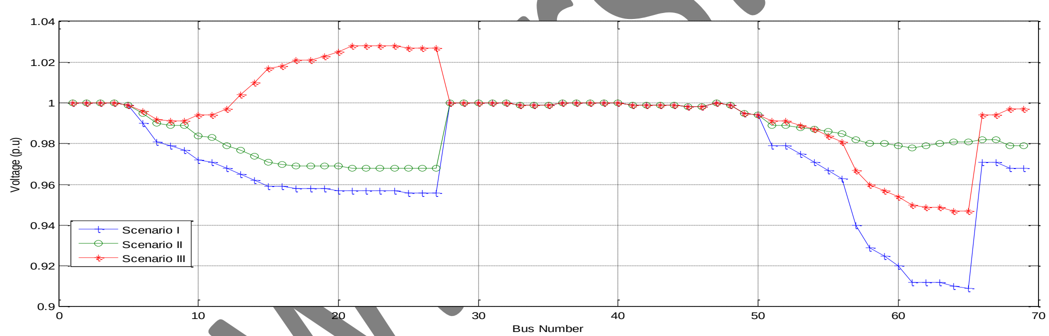

Fig. 6.3 (b) Voltage Profile of 69-bus Radial Distribution System at Nominal Load (1.0)

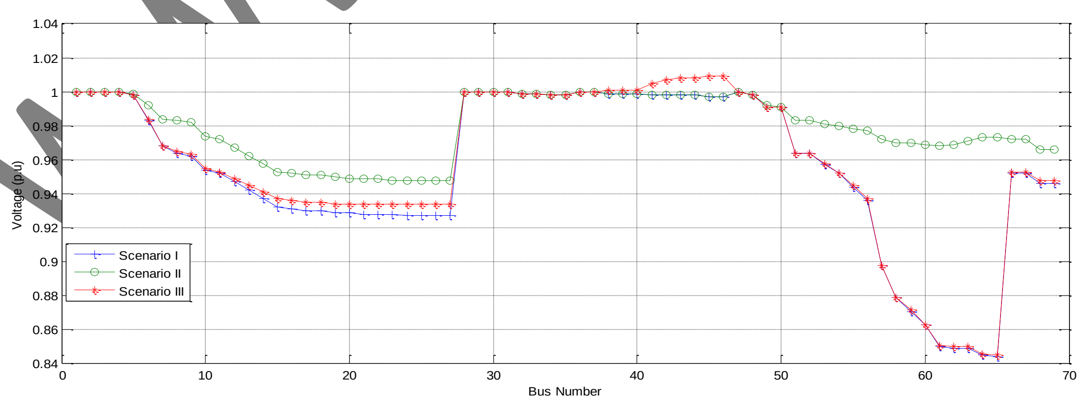

Fig. 6.3 (c) Voltage Profile of 69-bus Radial Distribution System at Heavy Load (1.6)

CONCLUSION

In this article, a technique has been proposed to only installation of DG units with Genetic Algorithm randomly at optimal candidate bus locations in distribution system. The only DG installations technique with GA used to minimizing the real power loss and improving the voltage profile. By the loss sensitivity factor, to choose the optimal candidate bus location to install DG units in the system. The size of DG unit at candidate bus is calculated using GA. The proposed methods are tested on 33-bus and 69-bus system at three different load levels viz., light, nominal, and heavy. The results show that only DG installation method with GA is more effective in reducing power loss and improving the voltage profile compared to base system. The results show that the percentage power loss reduction is improving as the number of DG installation locations are increasing from one to four, but rate of improvement is decreasing when locations are increased from one to four at all load levels. However, the ratio of percentage loss reduction to DG size is highest when number of DG installation locations is three. The computational result show that performance of the method III are better than method I and method II.

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