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DIFFERENTIAL EVOLUTION BASED OPTIMAL PLACEMENT AND SIZING OF TWO DISTRIBUTED GENERATORS IN A POWER DISTRIBUTION SYSTEM

M. Abbagana[1*], G. A. Bakare[2], I. Mustapha[1],,B.U.Musa[1]
[1]Department of Electrical and Electronics Engineering, University of Maiduguri, Nigeria
[2]Electrical Engineering Programme, Abubakar Tafawa Balewa University, Bauchi Nigeria.
E-mail: moduabbagana@yahoo.com, bakare_03@yahoo.com, mustib@unimaid.edu.ng, musa_bu@yahoo.com

ABSTRACT

Distributed and disperse generation of electricity have been used to address economical and environmental challenges associated with centralized generation of electricity. This paper aims to minimize the power losses and improve the voltage profile of power distribution system by determining the optimal location and size of two Distributed Generation (DG) units. Differential Evolution (DE) technique is used for optimizing the formulated problem. Performance of the technique is tested on IEEE 33 bus radial distribution system consisting of 32 sections and six different scenarios were created by varying the DE parameters. MATPOWER and MATLAB software were used for the simulation. The results show that proper placement and size of DG units can have a significant impact on system loss reduction and voltage profile improvement. On the other hand, improper choice of size would lead to higher losses.

Keywords: *Differential Evolution, Distributed Generation, Loses, Optimization, Voltage, Nodes*

INTRODUCTION

Distributed Generation (DG) of electricity are increasingly attracting researchers due to their high efficiency, low investment cost, modularity and ability to exploit renewable energy sources. On the other hand, centralized generation of electricity based on bulk power planning pose many economical and environmental challenges. Therefore, the best alternative to overcome these challenges is to introduce distributed and dispersed generation, which can be conveniently located closer to load centers. DG is defined as any source of electrical energy of limited size interconnected to the distribution system. DG technologies include photovoltaic systems, wind turbines, fuel cells, small micro-sized turbines, sterling-engine based generators and internal combustion engine-generators [1]. However, efficient placement and sizing of distribution generation (DG) in practical networks can result in minimizing operational costs, environmental protection, improved voltage regulation, power factor correction, and power loss reduction and better voltage profile [2]. Numerous studies [3]-[5] used different approaches to evaluate the benefits DGs in a distribution system in terms of loss reduction, better voltage profile and loading level reduction. In [6] evolutionary programming with the objective of maximizing the reduction on the load supply costs was used. Authors in [7] used Particles Swarm Optimization (PSO) for optimal placement of multi-DGs, in which real power loss was minimized. Similarly, author in [8] proposed a PSO technique with the same objective as above. Author in [9] proposed the combination of Genetic Algorithm (GA) and Optimal Power Flow (OPF) to efficiently site and size a predefined number of DGs. This differs with other proposed methods that only define the optimal locations and capacities of DG as a means of ensuring that the maximum amount of DG can be connected to existing and future networks. In [10] a Genetic Algorithm based approach was used for optimal allocation of distributed generations in power systems for voltage sensitive loads. Author in [11] used analytical approach for sizing of DG unit operated at optimal power factor to reduce losses in radial distribution. Authors in [12] presented an Ordinal Optimization (OO) method for specifying the locations and capacities of DG such that a trade-off between loss minimization and DG capacity maximization is achieved. This paper proposed a Differential Evolution technique for the optimum placement and sizing of two DGs in a distribution network. The technique is based on meta-heuristics optimization technique employing differential evolution. A real power loss and voltage profile analysis is evaluated for the system with and without DG.

Problem Formulation

Size and location of DG are crucial factors in the application of DG for its maximum benefits. Since the impacts of distributed generation on system performance depend on system operating conditions and the characteristics of the distributed generation, it is necessary to use some solutions in planning and operation to attain the best performance. The real power loss reduction in a distribution system is required for efficient power system operation. The loss in the system can be calculated using eqn. (1) [7] called the 'exact loss formula [13] given the system operating conditions. Mathematically, the objective function can be written as [14].

Minimize

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}\left(P_iP_j + Q_iQ\right) + \beta_{ij}(Q_iP_j - P_iQ_j)]. \qquad (1)$$

Where,

$$\left.\begin{aligned} \alpha_{ij} &= \frac{R_{ij}\mathrm{Cos}(\delta_i-\delta_j)}{V_iV_j} \\ \beta_{ij} &= \frac{R_{ij}\mathrm{Sin}(\delta_i-\delta_j)}{V_iV_j} \end{aligned}\right\} \qquad (2)$$

P_i and Q_i are net real and reactive power injection in bus 'i', respectively

R_{ij} is the resistance between buses 'i' and 'j'

V_i and δ_i are the voltage and angle at bus 'i' respectively. Subject to power balance constraints:

$$\sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L \qquad (3)$$

Voltage constraints: $|V_i|^{min} \leq V_i \leq |V_i|^{max}$ (4)

Currents Limits: $|I_{ij}| \leq |I_{ij}|^{max}$ (5)

Where,

P_L is the real power loss in the system

P_{DGi} is the real power generation of DG at bus i

P_{Di} is the power demand at bus i

I_{ij} is the current between buses i and j

Modelling of DG Units

A constraint for DG source, similar to central generation, is active power constraint. It can be formulated as:

$$P_G^{min} \leq P_G \leq P_G^{max} \qquad (6)$$

The reactive power output of DG units is also important and must be considered. Small and medium sized DG units mostly use asynchronous generators that are not capable of providing reactive power. Several options are available to solve this problem. On the other hand, DG units with a power electronic interface are sometimes capable of delivering a certain amount of reactive power [3]. These interfaces or power converters can generate and inject reactive power (Q) to the network, but ratings of elements increase. The reactive power generation of DG units which use synchronous generators, depends on reactive power control strategy. There are two control strategies for this group. Constant Q/ constant power factor mode, Voltage regulated mode. Considering this point, the bus connected to the DG can be modeled as PQ or PV bus, depending on control strategy.

DG Type 1

Certain type of DGs like photovoltaic will produce real power only. To find the optimal DG size at bus 'i', when it supplies only real power, the necessary condition for minimum loss is given by:

$$P_i = P_{DGi} - P_{Di} = -\frac{1}{A_{ij}} \sum_{\substack{j\neq 1 \\ j\neq i}}^{n} (A_{ij} P_j - B_{ij} Q_j) \qquad (7)$$

From equation (7), we obtain the following relationship:

$$P_{DGi} = P_{Di} - \frac{1}{A_{ij}} \sum_{\substack{j\neq 1 \\ j\neq i}}^{n} (A_{ij} P_j - B_{ij} Q_j) \qquad (8)$$

Equation (8) gives the optimal DG size for each bus so as to minimize the total real power loss. Any size of DG other than P_{DGi} placed at bus i, will lead to a higher loss. This loss however is function of loss coefficient A_{ij} and B_{ij}.When DG is installed in the system, the values of loss coefficients will change as it depends on the state variable voltage and angle.

DG Type 2

For synchronous condenser DG, it provides only reactive power to improve voltage profile. To determine the optimal DG placement, we again differentiate the loss equation on either side with respect to Q_i. The optimal DG size for every bus in the system is given by equation (9)

$$Q_{DGi} = Q_{Di} - \frac{1}{A_{ij}} \sum_{\substack{j\neq 1 \\ j\neq i}}^{n} (A_{ij} Q_j - B_{ij} P_j) \qquad (9)$$

DG Type 3

Here we consider that the DG will supply real power and in turn will absorb reactive power. In the case of the wind turbines, induction generator is used to produce real power and the reactive power will be consumed in the process [15]. The amount of reactive power they require is an ever increasing function of the active power output. The reactive power consumed by the DG wind generation in simple form can be given as in equation (10) [4].

$$Q_{DGi} = -\left(0.5+0.004P_{DG}^{2}\right)$$

(10)

The loss equation will be modified. After following the similar methodology of the two types, optimal DG size can be found by solving (11)

$$0.003A_{ij}P_{DGi}^{3} + P_{DGi}[1.004A_{ij}+0.08A_{ij}Q_{Di} - 0.08Y_{i}] + (X_{I} - A_{ij}P_{Di}) = 0 \tag{11}$$

Equation (8) gives the amount of real power that a DG should produce when located at bus 'i', so as to obtain the minimum system loss whereas the amount of reactive power that it consumes can be calculated from equation (11).

Load and Feeder Model

The distribution feeder model adopted is shown in Fig.1, as suggested in [9], which allows the installation of loads and generation in all buses. Each branch has the following properties: origin bus, destiny bus, impedance per unit length, apparent power installed, and load power factor. The model chosen is the constant power one. There can be a load $(P_L + jQ_L)$ and a power generation $(P_G + jQ_G)$ in any bus. The substation is the feeder swing bus, while all the others, including those where generators are found, are PQ buses, with active and reactive powers specified and voltage to be determined. The reactive power generated by the unit installed at the i^{th} bus must be such that:

$$Q_G^{\min} \le Q_G \le Q_G^{\max} \tag{12}$$

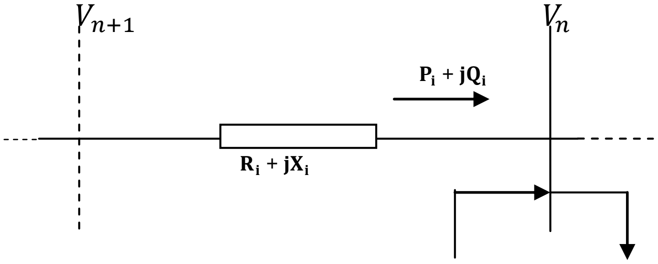

Fig 1: Feeder model

Realization of DG Based DG Placement and Sizing

The optimal placement and sizing of distributed generators in a power distribution system can be achieved using the following procedure:

Step I: At the initialization stage, relevant DE parameters such as maximum generation, $\text{gen}^{\max}$number of control, D, population size, np, scaling factor for mutation, F, and cross over rate, CR, are defined. Also, power distribution system data required for computation process are actualized from the database.

Step II: Run the base case Newton Raphson load flow using MATPOWER package version 3.0 to determine the initial bus voltage, and active power losses respectively.

Step III: Each control device of the possible location and the active power are treated as parameters for optimization. Then randomly generate initial population comprising the parameters within the parameter space. The objective function for each vector of the population is computed using equation (13);

$$f_{obj}^{n} = 1 + P_{loss} + \sum\left|(V_i - V^{lim})^2\right| \qquad (13)$$

$$\text{Where } V^{lim} = \begin{cases} V_i^{max} \text{ if } V_i > V_i^{max} \\ V_i^{min} \text{ if } V_i < V_i^{min} \end{cases}$$

Step IV: Update the generation count.

Step V: Perform mutation, cross over, selection and evaluation of the objective function as described in III.

Step VI: If the generation count is less than the preset maximum number of generations, go to step IV otherwise.

Step VII: With the optimal size and location of DGs, run the final load flow to obtain the final voltage profile and the corresponding system active power loss

Simulation Results and Discussions

In order to see the best locations of DGs in the distribution system with the view of minimizing the total real power losses, the differential evolution algorithm was used. Also, an IEEE 33 bus radial distribution system consisting of 32 sections shown in Fig. 2 is used in order to demonstrate the effectiveness and feasibility of the techniques.

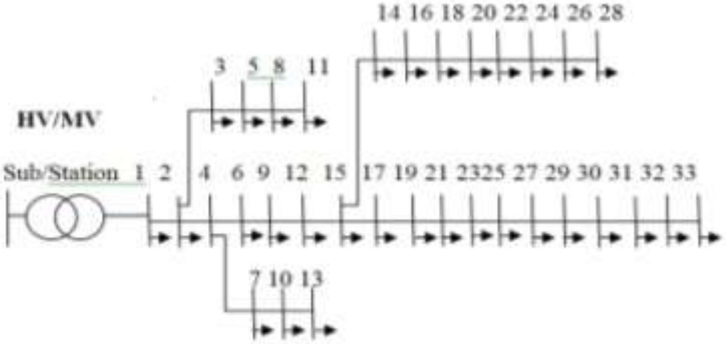

Fig 2: Single line diagram of the 33-Bus Radial Distribution System

The DE parameters were varied according to the scenarios in Table 1 to see which scenario is the best. The algorithm reached a stable (optimum) solution with 30 iterations as depicted in Figures 3 – 14 below, and the corresponding detailed outputs are given in Table 2 and 3.

Table 1: Different DE parameters settings.

Scenario	Best locations	DG sizes (MW)	Initial power loss (kW)	Final power loss (kW)	%Power loss reduction
1	NODE 20 and 25	1.5232 and 0.7944	221.4346	95.1110	57.0478
2	NODE 25 and 22	1.0099 and 1.2972	221.4346	93.1010	57.9555
3	NODE 16 and 30	1.9012 and 0.6485	221.4346	96.2738	56.5227

4	NODE 20 and 23	1.3108 and 1.0792	221.4346	93.8411	57.6213
5	NODE 27 and 22	0.9237 and 1.0516	221.4346	91.9408	58.4795
6	NODE 21 and 22	0.9309 and 1.1407	221.4346	92.1237	58.3969

Table 2: Best placement, Size and power losses

Scenario	**Number of population members (np)**	**Iteration maximum (itermax)**	**DE-Step size (F)**	**Cross over probability constant (CR)**
1	20	30	0.4	0.5
2	30	40	0.5	0.6
3	40	50	0.6	0.7
4	50	60	0.7	0.8
5	60	70	0.8	0.9
6	70	80	0.9	1.0

Table 3:ssve and number of nodes violating limits

Scenario	**Initial**	**Initial**	**Final**	**Final**
	Ssve (p.u)	**No of nodes Violating limits**	**Ssve (p.u)**	**No of nodes Violating limits**
1	0.1369	18	0.0218	0
2	0.1369	18	0.0258	0
3	0.1369	18	0.0176	0
4	0.1369	18	0.0176	0
5	0.1369	18	0.0188	0
6	0.1369	18	0.0208	0

According to the outputs of the six scenarios, which are presented in table 2 and 3, the initial power loss of the test system which is 221.4346 kW reduced to 95.1110, 93.1010, 96.2738, 93.8411, 91.9408 and 92.1237 kW which is 57.0478, 57.9555, 56.5227, 57.6213, 58.4795 and 58.3969 percent of the initial loss respectively for the six scenarios. The nodes that violate the voltage limit dropped from 18 to 0 signifying the voltage profile has fall within the maximum and minimum limits. The sum of square of voltage error also reduced to 0.0218, 0258, 0.0176, 0.0176, 0.0188 and 0.0208 from 0.1369 p.u. The corresponding best DG sizes are 0.9237 and 1.0516 MW to be located at node 27 and 22. Compared with the remaining five scenarios, scenario 5 is the best in terms of the power loss. The number of nodes violating voltage error is the same for all the six scenarios. The convergence characteristics and the voltage profile before and after allocation of DG for the above scenarios are shown in the figures 3 – 14.

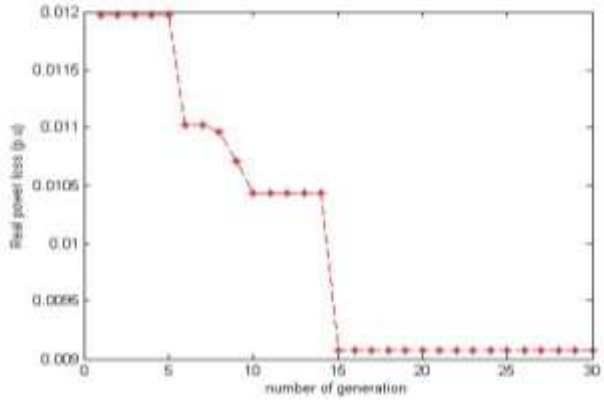

Fig 3: Convergence characteristics for scenario 1 of the 33 bus test system

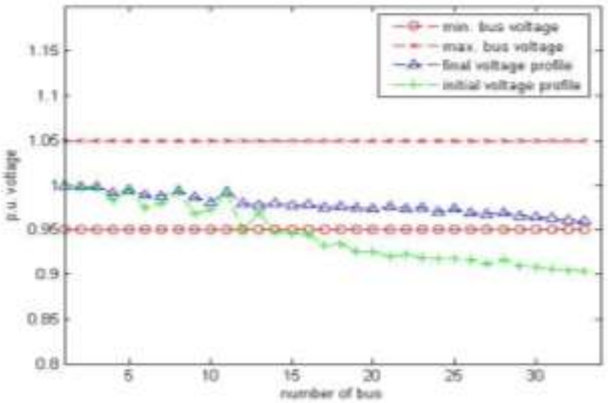

Fig 4: Voltage profile for scenario 1 of the 33 bus test system

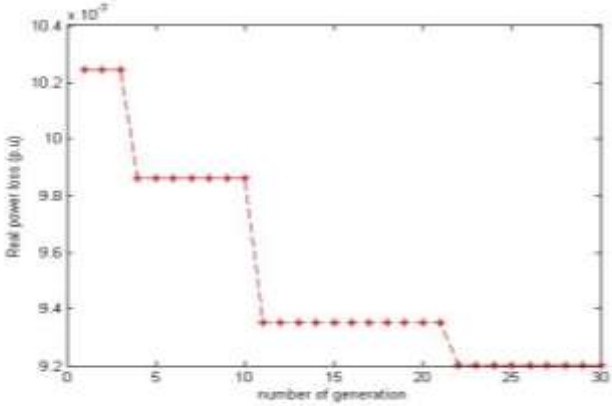

Fig 5: Convergence characteristics for scenario 2 of the 33 bus test system

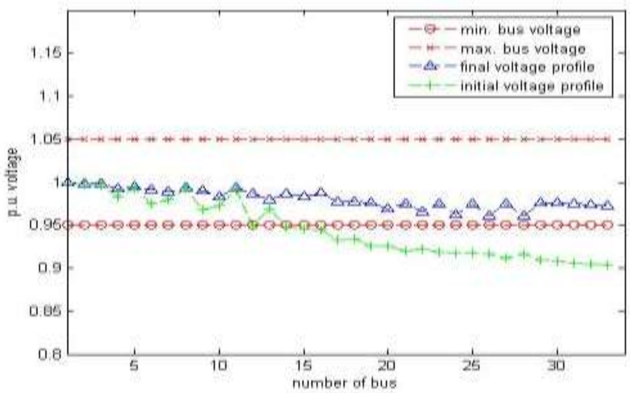

Fig 6: Voltage profile for scenario 2 of the 33 bus test system

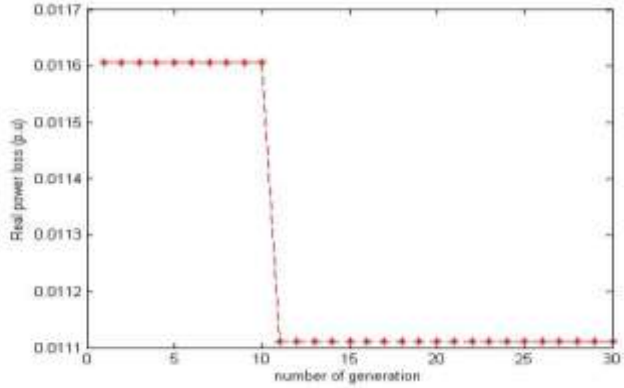

Fig 7: Convergence characteristics for scenario 3 of the 33 bus test system

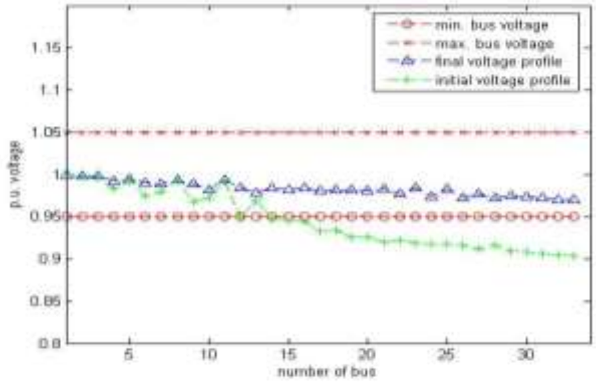

Fig 8: Voltage profile for scenario 3 of the 33 bus 3 of test system

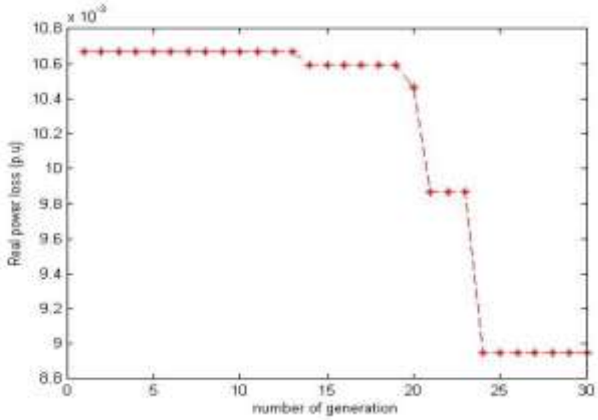

Fig 9: Convergence characteristics for scenario 4 of the 33 bus test system

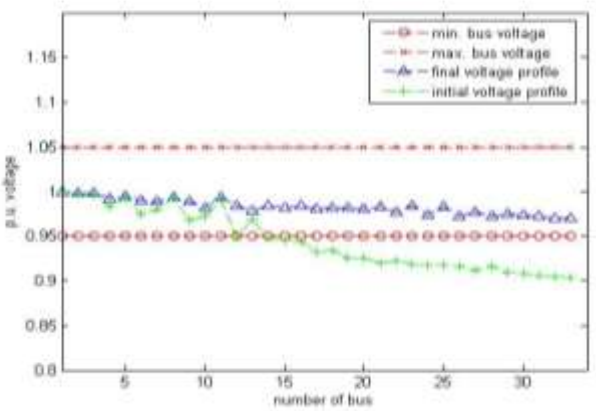

Fig 10: Voltage profile for scenario 4 of the 33 4 bus test system

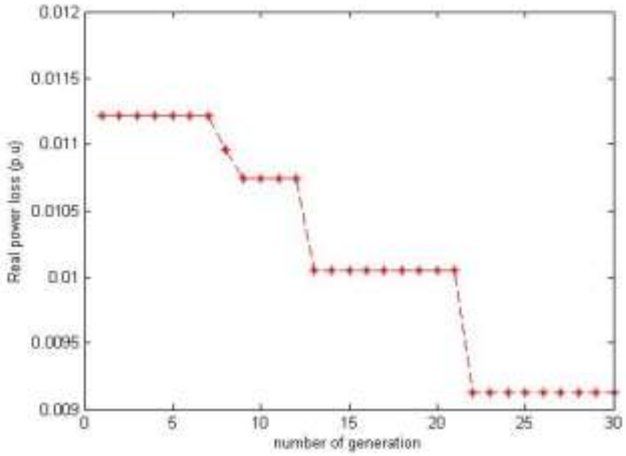

Fig 11: Convergence characteristics for scenario 5 of the 33 bus test system

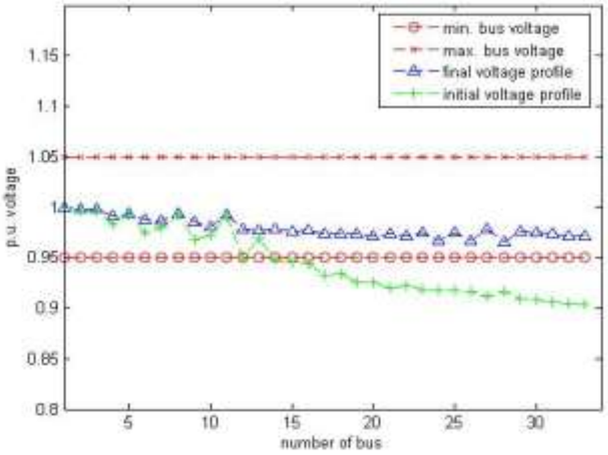

Fig 12: Voltage profile for scenario 5 of the 33bus test system

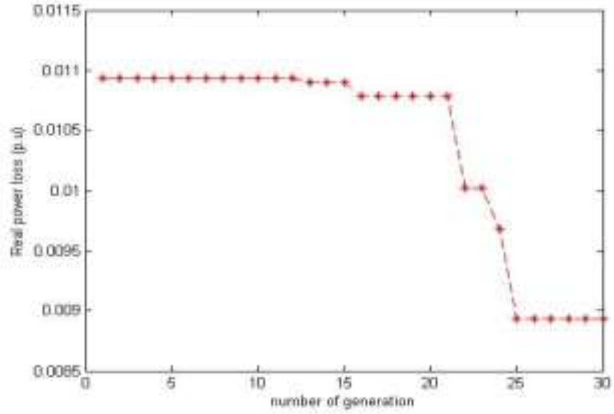

Fig 13: Convergence characteristics for scenario 6 the 33bus of the 33bus test system

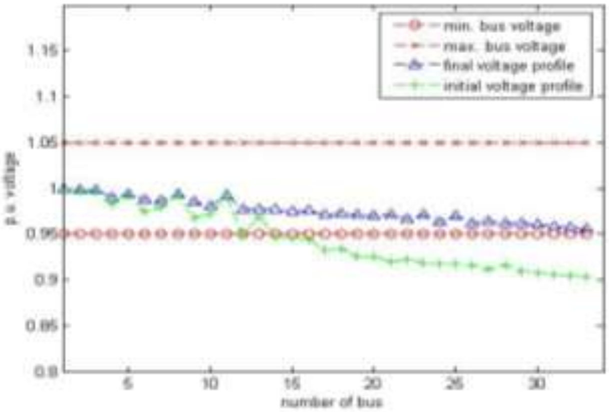

Fig 14: Voltage profile for scenario 6 of test system

CONCLUSIONS

Differential Evolution technique is used for the optimum placement and sizing of two DG in a distribution network. The feasibility and effectiveness of this technique has been demonstrated on IEEE 33 bus radial distribution system consisting of 32 sections. Simulation results revealed that the proper placement and size of DG units can have a significant impact on system loss reduction and voltage profile improvement. It also revealed how improper choice of size would lead to higher losses.

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