Determining the Optimal Location and Sizing of Distributed Generation Unit using Plant Growth Simulation Algorithm in a Radial Distribution Network

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Abstract: - Distributed generation (DG), is the process of generating electricity from many small energy sources and connecting it directly to the distribution network. Determining the optimum location and sizing of distributed generation units is one of the major factors in the distributed network. For maximum power loss reduction, proper positioning and sizing of DG are ardently necessary. In this paper, a heuristic method which employs the plant growth simulation algorithm(PGSA) is proposed to determine the sizing of the distributed generating unit and loss sensitivity factor is used in selection of the optimal location of DG.PGSA is a random search algorithm which is inspired by the growth of the plant. By simulating the growth process of plant phototropism, a probability model is established. Reduction of line losses in the radial distribution network is the main objective of this paper. The proposed method is applied to IEEE 10 bus system and IEEE 33 bus systems. The solution obtained by the proposed method has outperformed in the quality.

Key-Words: - Distributed Generation, distributed network, heuristic method, plant growth simulation algorithm, sensitivity factor, line losses.

1 Introduction

A distributed generation unit generates electrical power from a close-by fuel depending on the type of availability like the solar concentration, wind speeds etc. to reduce the strain on the main supply line. This increases reliability and reduces cost of power generation and saves non-renewable power resources. This concept of power generation would lead to a greener way which is environment friendly and healthier lifestyles. Since, power flows only in a single direction, that is, from transmission line to the distribution system. Since the recent past, there have been an increasing number of generation units being connected to the distribution system that is, a generation unit at the customer side of the meter, such units are called DG. The positioning and the magnitude of the generated power supplied to the distribution system by the DG have an influence on the daily workings of the whole system. It can either make it more efficient or decrease the efficient operation of the system which could adversely affect the stability of the system.Large power supplied by a DG can even reverse the direction of flow of current. Therefore, finding a position for the DG which is economically viable, through a suitable size and minimization of losses is of utmost importance. The objective put in simpler terms is to reduce losses of the system and improves the voltage profile.

DG, for the moment loosely defined as small scale electricity generation, is a fairly new concept in the economic literature about electricity markets is given in [1]. The increasing DG raises concerns on the actual benefits of loss minimization are discussed in [2]. Usually distribution feeders have high R/X ratio due to this normal load flow like Newton Raphson, Fast decoupled method cannot be applied for the radial distribution system. An improved method to solve load flow problem in balanced radial distributed systems is introduced in [3]. In [4], a new and fast distribution power flow solution is presented which reduces the solution required iterations resulting in power flow solution performance improvement. To solve the load flow problem of radial distribution network a technique is proposed based on network graphical information is given in [5]. The positioning and the magnitude of the generated power supplied to the distribution system by the DG have an influence on the daily workings of the whole system. Locations and capacities of DG sources have major impact on the system losses in a distribution network. A novel combined genetic algorithm (GA) and Particle swarm optimisation (PSO) is discussed in [6]. In [7], combined power loss sensitivity method is proposed and novel method is modified for distributed generation location and calculating their sizes for minimum loss and improved voltage profiles.

A new methodology using PSO for the placement of DG in the radial distribution systems to reduce the power loss is proposed in [8], where single DG placement is used to find the DG location and its size which corresponding to the maximum loss reduction is specified. Many evolutionary techniques are used for the optimum placement like genetic algorithm, simulated annealing are discussed in [9-10]. A new islanding detection method for use of grid-interconnected distributed generators is given in [11]. An interactive fuzzy satisfying method based on hybrid modified frog leaping algorithm is used to solve the DG problem is discussed in [12]. DG influences power system stability and losses. Dynamic programming search method is presented for locating and sizing of DG to enhance voltage stability and reduces the network losses simultaneously have been proposed in [13].
In this paper, the power loss has been calculated using the radial load flow method, the loss sensitivity factor is considered for the placement of DG and PGSA is used for the sizing of DG. No of approaches has been discussed for optimising [14-23].

The remainder of the paper is organised as follows. The problem formulation is described in section 2. The distributed generation is briefly discussed in section 3. Sections 4 and 5 include introduction to the Plant growth simulation algorithm and its implementation. Numerical results are presented in section 6. Section 7 gives the conclusions.

2 Problem Formulation

The main objective of the proposed algorithm is to determine the optimal placement and sizing of DG unit

2.1 Finding Optimal Location of DG

Loss sensitivity factor method is used for finding the optimal location for placement of DG.

2.1.1 Loss Sensitivity Factor Method

For finding optimal location of DG, we have used Loss Sensitivity Factor Method. Sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps to reduce the number of solution space. Loss sensitivity factor method has been widely used to solve the capacitor allocation problem. Its application in DG allocation is new in the field. The real power loss in a system is given by (1). This is popularly referred to as ‘‘exact loss’’ formula:

$$P_{L=\sum_{i=1}^{N}\sum_{j=1}^{N}}\ [\propto_{ij}(P_iP_j + Q_iQ_j) + \propto_{ij}(Q_iP_j - P_iQ_j)] \quad (1)$$

where,

$$\propto_{ij} = \frac{r_{ij}}{v_i v_j}\cos(\delta_i - \delta_j) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{v_i v_j}\sin(\delta_i - \delta_j) \quad (3)$$

and

$$r_{ij} + x_{ij} = z_{ij} \quad (4)$$

are ij^{th} the element of $[z_{bus}]$ matrix with

$$[z_{bus}] = [y_{bus}]^{-1} \quad (5)$$

The sensitivity factor for real power loss with respect to the power injected is given
by:

$$\propto_i = \frac{\partial P_L}{\partial P_i} = 2\sum_{i=1}^{N}(\propto_{ij} P_j - \beta_{ij}Q_j) \quad (6)$$

2.2 Objective function

The main objective is to minimize the real power loss in the radial distribution network by optimally locating and sizing of DG. By proper locating and sizing of DG the losses will be reduced

$$Min.f = \sum_{i=1}^{n} P_{Loss\ i} \quad (7)$$

Power balance Constraint:

$$\sum_{i=2}^{n} P_{DG,i} \le \sum_{i=2}^{n} P_i + \sum_{i=1}^{b} P_{loss,i,i+1} \quad (8)$$

Voltage Constraint:

$$|V_1 - V_i| \le \Delta V_{max} \quad \forall\ i = 1,2..n \quad (9)$$

2.3 Computational procedure

Step 1: Run the base case load flow.
Step 2: Find the sensitivity factor using Eq. (6) and

rank the sensitivity in descending order to form priority list.
Step 3: Select the bus with the highest priority and place DG at that bus.
Step 4: Change the size of DG in ‘‘small’’ step and calculate loss for each by running load flow.
Step 5: Store the size of DG that gives the minimum loss.
Step 6: Compare the loss with the previous solution. If loss is less than previous solution, store this new solution and discard previous solution.
Step 7: Repeat Step 4 to Step 6 for all buses in the priority list.

3 Distributed Generation

Distributed generation, is the process of generating electricity from many small energy sources and connecting it directly to the distribution network or on the customer's side of the meter. It can also be called as on-site generation, dispersed generation, decentralized generation, decentralized energy or distributed energy.

From the definition, the DG includes those generating units that cannot supply reactive power and are located close to the customer or the end user. However, there is no specific defined capacity for the DG. Limitation on the capacity of the DG taken into account in this paper is dependent on the total load on the system.

DG kinds are based on the classification of the power resource available in the vicinity of the location such as biomass, biogas, solar and wind. They can be micro-turbines, solar cells, fuel cells and Combined Heat and Power (CHP). Each of them is defined by a particular characteristic like producing only real or reactive power. In Thailand, thermal power generation with utilization of biomass is what is widely utilized to generate using a DG. Therefore, this paper considers the generation unit that can generate both real and reactive power.
Benefits of Distributed Generation are Loss reduction,Improved utility system reliability, Voltage support and improved power quality.
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4 Plant Growth Simulation Algorithm

The plant growth simulation algorithm is based on the plant growth process, where a plant grows a trunk from its root, some branches will grow from the nodes on the trunk and then some new branches will grow from the nodes on the branches. Such process is repeated, until a plant is formed. Based on an analogy with the plant growth process, an algorithm can be specified where the system to be optimized first “grows” beginning at the root of a plant and then “grows” branches continually until the optimal solution is found.

4.1 Probability model of plant growth

By simulating the growth process of plant phototropism, a probability model is established. In the model, a function $g(Y)$ is introduced for describing the environment of the node Y on a plant. The smaller the value of $g(Y)$ is, the better the environment of the node Y is for growing a new branch. The main outline of the model is as follows: A plant grows a trunk M from its root B_0 Assuming there are k nodes $B_{M1}, B_{M2}, \dots, B_{Mk}$that have better environment than the root B_0 on the trunk M, which means the function g(Y) of the nodes $B_{M1}, B_{M2}, \dots, B_{Mk}$ and B_0 satisfy $g(B_{mi}) < g(B_0)$,(i =1,2,…,k) , then the morphactin concentrations $C_{M1}, C_{M2}, \dots, C_{Mk}$ of the nodes $B_{M1}, B_{M2}, \dots, B_{Mk}$ can be calculated using (9):

$$\begin{cases} C_{Mi} = \frac{g(B_0) - g(B_{Mi})}{\Delta_1} \\ \Delta_1 = \sum_{i=1}^{k} (g(B_0) - g(B_{Mi})) \end{cases} \quad (10)$$

Where $(i = 1,2, \dots, k)$

The significance of eq. (10) is that the morphactin concentration of any node depends on the relative magnitude of the gap of the environmental functions between the root and the corresponding node in overall nodes, which really describes the relationship between the morphactin concentration and the environment.

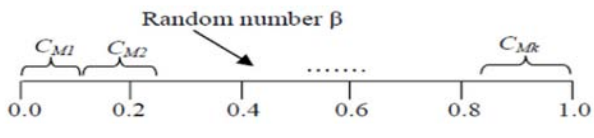

Fig.1 Morphactin Concentration State Space

From eq.(9), we can derivate $\sum_{i=1}^{k} C_{Mi} = 1$ which means that the morphactin concentrations $C_{M1}, C_{M2}, \dots, C_{Mk}$ of the nodes $B_{M1}, B_{M2}, \dots, B_{Mk}$ form a state space shown in Fig.1. Selecting a random number β in the interval [0, 1], β is like a ball thrown to the interval [0, 1] and will drop into one of $C_{M1}, C_{M2}, \dots, C_{Mk}$ in Fig.1, then the corresponding node that is called the preferential growth node will take priority of growing a new branch in the next step. For example, if random number β drops into C_{M2} which means $\sum_{i=1}^{1} C_{Mi} < \beta \leq \sum_{i=1}^{2} C_{Mi}$ then the node B_{M2} will grow a new branch m. Assuming there are q nodes $B_{m1}, B_{m2}, \ldots, B_{mq}$ which have better environment than the root B0, on the branch m, and their corresponding morphactin concentrations are $C_{m1}, C_{m2}, \ldots, C_{mq}$. Now, not only the morphactin concentrations of the nodes on branch m need to be calculated, but also the morphactin concentrations of the nodes except B_{M2} the morphactin concentration of the node B_{M2} becomes zero after growing the branch m on it) on trunk M need to be recalculated after growing the branch m. The calculation can be done using (11), which is gained from (10) by adding the related terms of the nodes on branch m and abandoning the related terms of the node B_{M2} .

$$\begin{cases} C_{Mi} = \frac{g(B_0) - g(B_{Mi})}{\Delta_1 + \Delta_2} \\ C_{mj} = \frac{g(B_0) - g(B_{mj})}{\Delta_1 + \Delta_2} \\ \Delta_1 = \sum_{i=1 i\neq 2}^{k} \left(g(B_0) - g(B_{Mi}) \right) \\ \Delta_2 = \sum_{j=1}^{q} \left(g(B_0) - g(B_{Mi}) \right) \end{cases} \quad (11)$$

Now, the morphactin concentrations of the nodes (except B_{M2}) on trunk M and branch m will form a new state space. A new preferential growth node, on which a new branch will grow in the next step, can be gained in a similar way as B_{M2} . Such process is repeated until there is no new branch to grow, and then a plant is formed. From the viewpoint of optimal mathematics, the nodes in a plant can express the possible solutions, $g(Y)$ can express the objective function; the length of the trunk and the branch can express the search domain of possible solutions; the root of a plant can express the initial solution; the preferential growth node corresponds to the basic point of the next searching iteration. In this way, the growth process of plant phototropism can be applied to solve the problem of integer programming.

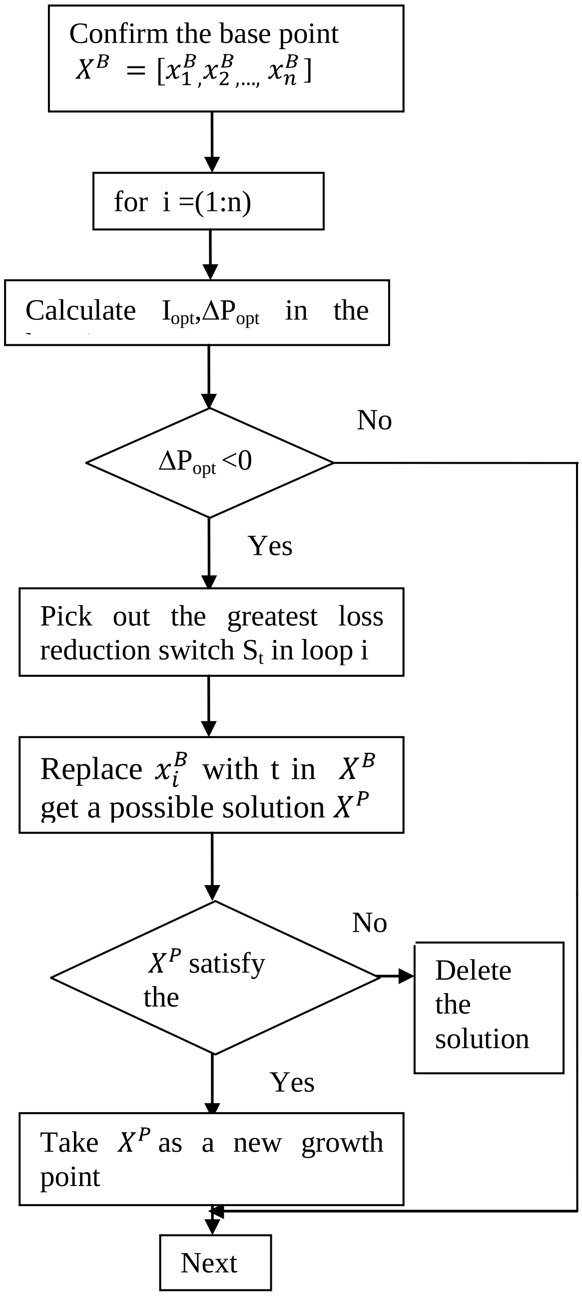

Fig. 2 Flowchart for searching new growth points

5 Finding Optimal Size of DG using Plant Growth Optimization Algorithm

Step 1: Calculate Real Power losses in the system using the radial distribution load flow for the values of DG.

Step 2: According to the priority list formed using sensitivity factor, place DG .

Step 3: DG size is selected using PGSA.
Step 4: Compare the Real Power losses for every size of DG.

Step 4: Save the DG size corresponding to minimum real power loss.

Step 5: Continue Steps 2 to 5 for 50 iterations with 5 different sizes of DG in every iterations.

Step 6: Choose the best size among 50 values with minimum Real Power loss and stop the iteration.

6 Simulation results

The proposed algorithm is tested on IEEE 10-bus system and IEEE 33-bus system.

6.1 Standard 10-Bus feeder

Table 1 IEEE 10-bus data

Line No.	From Bus,i	To Bus, i+1	$R_{i,i+1}$ (Ω)	$X_{i,i+1}$ (Ω)	P_L (kW)	Q_L (kV AR)
1	0	1	0.1233	0.4127	1840	460
2	1	2	0.0140	0.6057	980	340
3	2	3	0.7463	1.2050	1790	446
4	3	4	0.6984	0.6084	1598	1840
5	4	5	1.9831	1.7276	1610	600
6	5	6	0.9053	0.7886	780	110
7	6	7	2.0552	1.1640	1150	60
8	7	8	4.7953	2.7160	980	130
9	8	9	5.3434	3.0264	1640	200

Table 2 Result of IEEE 10-bus system

Initial Loss before placing DG	786.3717kW
No of iterations	50
No of nodes per iteration	5
DG size	4.8899MW
Run time	11.23sec
DG Location	Bus 9
Percentage Loss reduction	78.32
Minimized Loss after placing DG	170.4689kW

From table 2, the losses before the placement of DG were found to be 786.37 KW. After placing DG of 4.8899 MW at 9^{th} bus, the losses were 170.4689 KW. Number of nodes per iteration was 5 and total number of iterations was 50. Runtime was of 11.3 sec on Windows 7, 1.8 GHz processor with 2 GB RAM. Voltage profile was found to be drastically improved throughout the system.

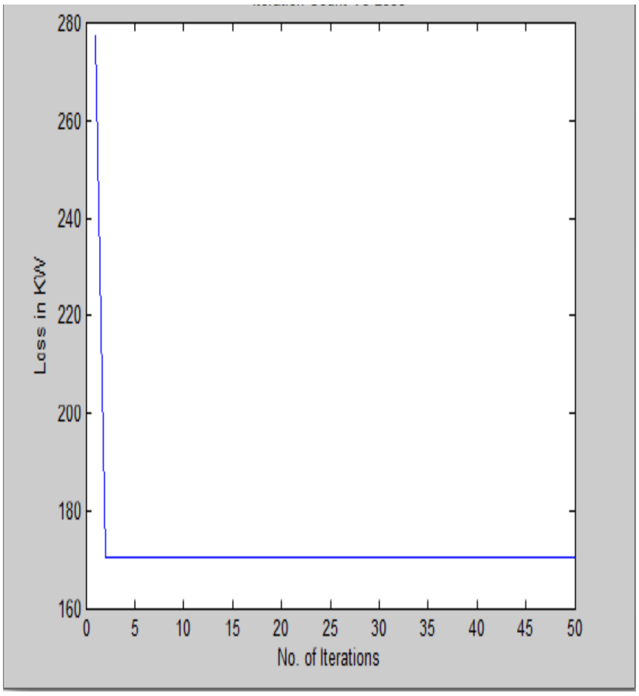

Fig. 3 Convergence Curve for 10-Bus system

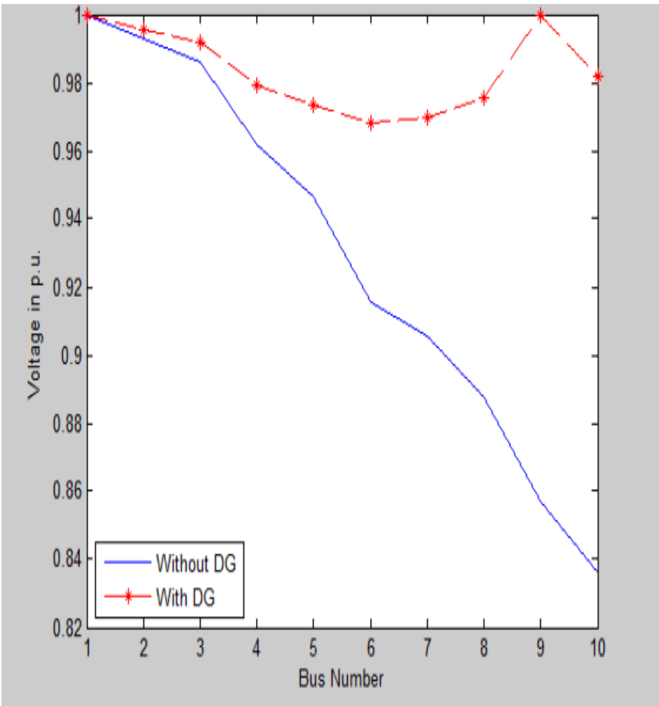

Fig. 4 Voltage Profile with and without DG for 10-Bus system.

6.2 For standard 33-Bus feeder

Table 3 IEEE 33-bus data

Line No	Sending End	Receiving end	R (Ω)	X(Ω)
1	1	2	0.0922	0.047
2	2	3	0.493	0.2511
3	3	4	0.366	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.819	0.707
6	6	7	0.1872	0.6188
7	7	8	1.7114	1.2351
8	8	9	1.03	0.74
9	9	10	1.04	0.74
10	10	11	0.1966	0.065
11	11	12	0.3744	0.1238
12	12	13	1.468	1.155
13	13	14	0.5416	0.7129
14	14	15	0.591	0.526
15	15	16	0.7463	0.545
16	16	17	1.289	1.721
17	17	18	0.732	0.574
18	2	19	0.164	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.898	0.7091
24	24	25	0.896	0.7011
25	6	26	0.203	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.059	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.963
31	31	32	0.3105	0.3619
32	32	33	0.341	0.5302

From table 4, the losses before the placement of DG were found to be 211.20 KW. After placing DG of 2.53 MW at 6th bus, the losses were 75.3 KW. Number of nodes per iteration was 5 and total number of iterations was 50. Runtime was of 32.34 sec on Windows 7, 1.8 GHz processor with 2 GB RAM.Voltage profile was found to be drastically improved throughout the system.

Table 4 Result of IEEE 33-bus system

Initial Loss before placing DG	211.27 kW
No of iterations	50
No of nodes per iteration	5
DG size	2.53MW
Run time	32.34sec
DG Location	Bus 6
Percentage Loss reduction	64.36
Minimized Loss after placing DG	75.3 kW

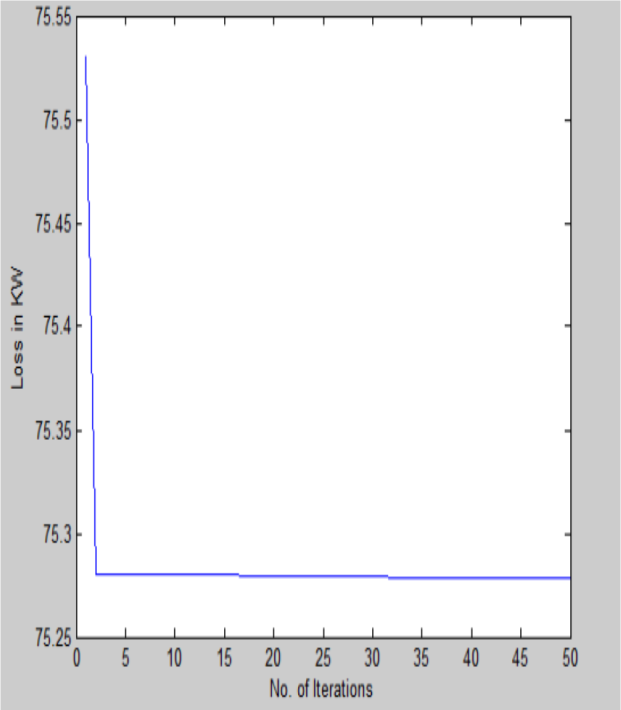

Fig. 5 Convergence Curve for 33-Bus system

PGSA was applied to IEEE 10-bus standard system and IEEE33-bus standard system. In the 10-Bus system, final losses after placement of 4.8899 MW DG were found to be 170.4689 KW which were 786.37 KW with a loss reduction of 78.32%. In the 33-Bus system, final losses after placement of DG of size 2.53 MW were found to be 75.3 KW which were 211.20 KW with a loss reduction of 64.35%.

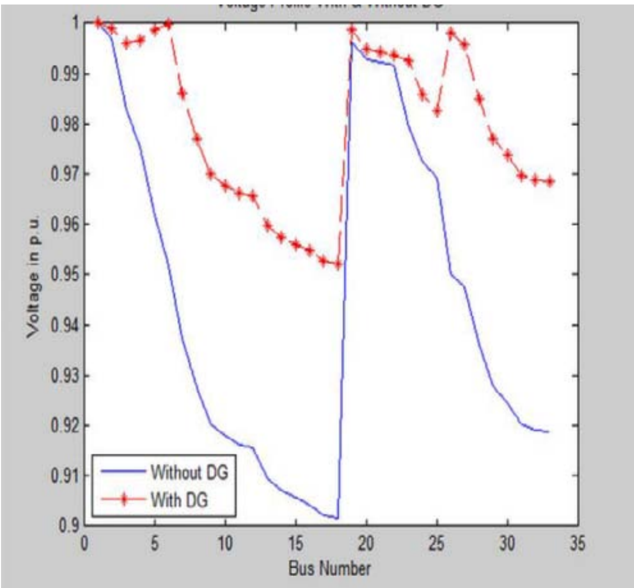

Fig. 6 Voltage Profile with and without DG for 33-Bus system

7. Conclusion

The loss sensitivity factors were used to determine the candidate locations of the buses where DG has been placed. Loss sensitivity factor application in DG allocation was efficient in finding DG location successfully. The total loss in the system is decreasing by finding optimal location and size of distributed generation unit in a radial distribution system. The voltage profile of the system is improved. Using the plant growth simulation algorithm, the optimal solution is realized and better results are obtained. This method is found easy to implement and easily applicable to practical purposes. Hence, the proposed algorithm was found to be efficient and can guarantee global optimal solutions.

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