Performance Improvement of Electric Power Distribution System Using DG

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ABSTRACT

Distributed generation (DG) is a rapidly growing technology, which helps in proper planning for expansion of the electrical networks in order to face the load growth and to supply the consumers properly. In this article, computationally efficient & numerically robust distribution flow equations for the power flow solution of distribution system with distributed generation is presented. The effects of distributed generation on the system voltage profile and losses have been analyzed by using different sizes and locations of DG. The results show that the voltage profile is improved and losses are reduced, when a DG of proper size is incorporated at proper location in the system. The methodology is applied to IEEE-13 node test feeder system.

Keywords: Distributed Generation, Distribution Load Flow, DG Size and Location, System Losses, Voltage Profile

INTRODUCTION

An electrical distribution system is a service of electrical circuits that delivers power in the proper proportion to homes, commercial businesses and industrial facilities. To manage a loss reduction program in a distribution system it is necessary to use effective and efficient computational tools that allow quantifying the loss in each different network element for system losses reduction. The power loss in a distribution network can be minimized by either using capacitor banks, reconfiguration or by installing DG units. These different approaches for loss minimization have been discussed in [1]. Network reconfiguration in distribution systems is realized by changing the status of sectionalizing switches, and is usually done for loss reduction or for load balancing in the system. In order to improve the efficiency as well as reliability indices of the electrical distribution networks reconfiguration process is applied [2].

Distributed reactive power sources such as capacitor banks of optimal sizes at optimal locations can be placed, for improved voltage profile and hence to reduce the power losses [3], [4]. The dynamic programming method has been used to determine the optimum number, location, and size of shunt capacitors in a radial distribution feeder with discrete lumped loads so as to maximize overall savings, including the cost of capacitors [5]. The method also determines when capacitors are not economically justified.

Moreover, the radial distribution systems are less reliable because of its passive nature. The benefits of using DG resources are quantified for the simple case of a radial distribution feeder with concentrated load and distributed generator [6]. A multiple objective formulation considering the best compromise between different components of energy cost for the siting and sizing of DG resources has been proposed [7].

In past some work has been carried out to determine the location and size of the DG. A fuzzy-GA method to reduce power loss [8], loss sensitivity calculation [9], power losses using voltage sensitive nodes for unbalanced radial distribution system [10] are few of such work.

A probabilistic-based model is presented for selecting the optimum mix of renewable DG units that minimize the system annual energy losses in the distribution system without violating the system constraints [11]. A parametric cost–benefit analysis concerning the use of distributed generation (DG) technologies for isolated systems is also carried out [12].

In the present work, computationally efficient & numerically robust distribution flow equations are used for the power flow solution of distribution system [3]. The effects of distributed generation on the system voltage profile and losses have been analyzed. The results show that the voltage profile is improved and losses are reduced, when DG is incorporated in the system. The methodology is applied to IEEE-13 bus radial distribution test system. Section II describes about the distribution load flow and the power loss equations considered. Simulation runs are carried out on IEEE-13 bus radial distribution test system in Section III. Finally Section IV concludes the article.

DISTRIBUTION LOAD FLOW

The classical methods are inefficient in the analysis of distribution systems due to the special features of such networks—i.e., radial structure, high R/X ratio, un-transposed lines, and unbalanced loads along with single-phase and two-phase laterals. These characteristic features make the distribution systems power flow computation different and somewhat difficult to analyze when compared to the transmission systems' load flow analysis. Power flow in a distribution system obeys physical laws (Kirchhoff laws and Ohms law) which became part of the constraints in the DG placement problem. In this work the distribution system power flow method [3] is used & presented here. A balanced 3-phase radial distribution system is considered which is modeled by a set of *n* buses or nodes interconnected by *n* branches Figure 1. To simplify the analysis, the system is assumed to be balanced three phase system.

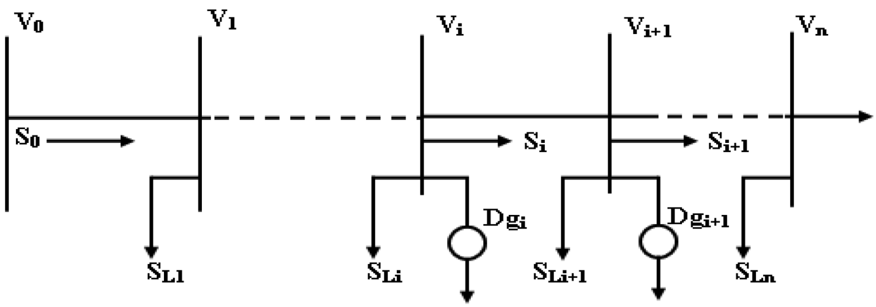

Figure 1. One line diagram of a radial feeder

Consider a distribution system that consists of a radial main feeder only, as shown in Figure 1 comprising *n* branches/nodes. V_o represents the substation bus voltage magnitude and is assumed to be constant. V_o is assumed as reference voltage and hence, lines are represented by a series impedance $Z_l = R_l + jX_l$, and loads are treated as constant power sinks $S_L = P_L + jQ_L$. Distributed generators are to be placed at the nodes where real and reactive power injections are required. With this representation, the network becomes a ladder network with nonlinear shunt loads. If the power supplied from the substation $S_0 = P_0 + jQ_0$ is known, then power and the voltage at the receiving end of the first branch can be calculated as follows.

$$S_1 = S_0 - S_{loss1} - S_{L1} = S_0 - z_1 \left| S_0 \right|^2 / V_0^{\ 2} - S_{L1} \quad (1)$$

$$V_1 \angle 0_1 = V_0 - z_1 I_0 = V_0 - z_1 S_0^* / V_0 \quad (2)$$

Repeating the same process yields the following recursive formula for each branch on feeder,

$$P_{i+1} = P_i - R_{i+1} * \frac{p_i^2+Q_i^2}{|V_i|^2} - P_{\text{Li}} + P_{Dg_{i+1}} \tag{3}$$

$$Q_{i+1} = Q_i - X_{i+1} * \frac{\left(p_i^2+Q_i^2\right)}{|V_i|^2} - Q_{\text{Li}} + Q_{Dg_i} \tag{4}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2\left(R_{i+1}P_i + X_iQ_i\right) + \frac{\left(R_{i+1}^2+X_{i+1}^2\right)\left(p_i^2+Q_i\right)}{|V_i|^2} \tag{5}$$

Where,

$P_{i,}$ Q_i: real & reactive power flows from node *i* to *i+1*,
V_i: bus voltage at node *i*,
$P_{Dgi,}$ Q_{Dgi}: real & reactive power injections from DG at node *i*.

The Dist Flow equations mentioned above can be generalized to include laterals. Figure 2 represents a distribution system comprising the main feeder as well as laterals. For notational simplicity, the lateral branching out of node k is referred to as the lateral k & the node k is referred to as the branching node.

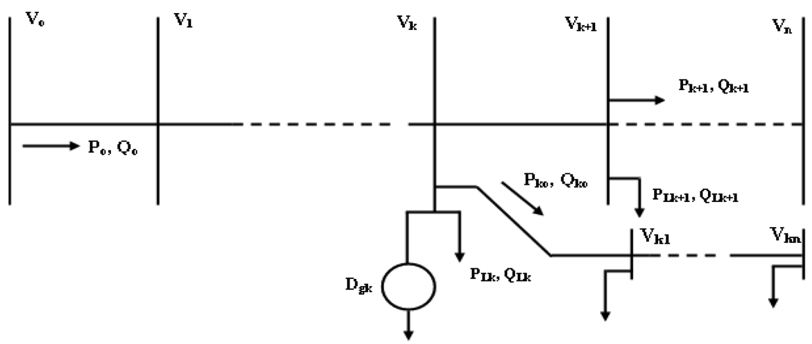

Figure 2. One line diagram of radial feeder with laterals

For lateral *k* with *nk* branches, the same process of formulation applied to the main feeder can be repeated for the lateral by using line flow equations (3), (4) and (5) and the new terminal conditions $V_{k0} = V_{k,}$ $P_{kn} = 0$, $Q_{kn} = 0$. As a result, we have the following $3(nk+1)$ equations, $i = 0, 1\ldots\ldots nk\text{-}1$.

$$x_{ki+1} = f_{ki+1}\left(x_{ki}, u_{ki}+1\right), i = 0,1\ldots\ \ldots nk{-}1 \tag{6}$$

$$\begin{aligned} x_{kn_1} &= P_{kn} = 0; \\ x_{kn_2} &= Q_{kn} = 0; \end{aligned} \tag{7}$$

$$x_{k0_3} = V_{k0}^2 = V_k^2 = x_{0k_3} \tag{8}$$

Hence, in general, for a distribution network of n branches & l laterals, there are $3(n+l+1)$ Dist flow equations. They are of the form,

$$G(x,u) = 0 \tag{9}$$

Where $x = \ x_i^T \ldots\ldots\ldots\ x_l^T\, x_0^T]^T$, $x_k = [\ x_{ko}^T \ldots\ldots\ldots\ x_{kn}^T]^T$

Dist flow equations can be used to determine the operating point "x" of the system if the DG sizes u are given. These equations can be utilized to develop a computationally efficient and numerically robust solution algorithm.

The real power loss in the network can be calculated as the sum of the i^2r loss on each branch, i.e.,

$$p(x) = \sum_{k=0}^{l} \sum_{i=0}^{kn^{-1}} r_{ki-1} \frac{p_{ki}^2+Q_{ki}^2}{V_{ki}^2} \tag{10}$$

Where, P_{ki} & Q_{ki} are real & reactive power injected at i^{th} bus connected to k^{th} lateral & $(ki{-}1)$ is the resistance of $(ki\text{-}1)$ branch.

TEST SYSTEM AND RESULTS

In this work IEEE 13-bus radial distribution test system is considered [14]. First the distribution load low of the test system is performed without placing DG units. The base case real & reactive power losses & voltage profile of the system is calculated. Then, based on the total load on the system, various sizes of DG are considered i.e. between 5 to 30% of the total load on the system. Distribution load flow is again performed with various DG sizes. The real & reactive power losses and system voltage profile are calculated including the DG units & are compared with the results of base case i.e. without DG.

The study is done for different sizes of DG. The size of DG is varied from 5% to 30% of the total load on the system, in step of 5%. The total load on the system is 3.8266 MVA & the voltage is 4.16 KV. So the DG sizes taken are 0.1933 MVA (for DG size of 5% of total system load), 0.38266 MVA (for DG size of 10% of total system load), 0.57399 MVA (for DG size of 15% of total system load), 0.76532 MVA (for DG size of 20% of total system load), 0.95665 MVA (for DG size of 25% of total system load) and 1.14798 MVA (for DG size of 30% of total system load).

The real power loss & reactive power loss without the placement of DG are 0.0298 MW & 0.0836 MVAR respectively. We have placed the DG of different sizes in a particular node & seen the variation of loss & system node voltages with different sizes of DG.

From the Table 1 & Figure 3, it is clear that the power losses are reduced as the DG size is increased when connected to node 2. The real & reactive power losses are 0.0242 MW & 0.0671 MVAR respectively, when a DG of 5% of total load is placed in node 2. These two losses are reduced to 0.0199 MW & 0.0541 MVAR, when DG size is increased to 10% of total load respectively. As we go on increasing the DG size to 15%, 20% & 25% of the total system load the real & reactive power losses are reduced to 0.0167 MW & 0.0446 MVAR, 0.0147 MW & 0.0446 MVAR, 0.0138 MW & 0.0359 MVAR respectively. Whereas the DG size is increased further i.e. to 30% of the total system load, the real & reactive power losses are increased to 0.0140 MW & 0.0365 MVAR. This increase in losses after a particular size of DG shows that DG size should be in proper proportion to the total load of the system. So, when placed at node 2, the size of DG corresponding to minimum losses is 25% of the total system load. Similarly, the real & reactive power losses are 0.0219 MW & 0.0559 MVAR respectively, when a DG of 5% of total load is placed in node 8, shown in Table 1. These two losses are reduced to 0.0173 MW & 0.0441 MVAR, when DG size is increased to 10% of total load respectively. With increasing DG size to 15% of the total system load the real & reactive power losses are reduced to 0.0156 MW & 0.0356 MVAR. But, as the DG size is increased further i.e. from 20% to 30% of the total system load, the real & reactive power losses are increased, instead of decreasing, from 0.0168 MW & 0.0343 MVAR to 0.0275 MW & 0.0518 MVAR. So, when placed at node 8, the size of DG corresponding to minimum real power loss is 15% of the total system load.

Table-1.
Variation of power loss with different DG sizes when placed in node 2 & 8

Size of DG (in %ge of total load)	Size of DG (in MVA)	Real Power Loss (in MW)		Reactive Power Loss (in MVAR)	
		At node2	At node8	At node2	At node8
5%	0.19330	0.0242	0.0219	0.0671	0.0599
10%	0.38266	0.0199	0.0173	0.0541	0.0441
15%	0.57399	0.0167	0.0156	0.0446	0.0356
20%	0.76532	0.0147	0.0168	0.0386	0.0343
25%	0.95665	0.0138	0.0208	0.0359	0.0398
30%	1.14798	0.0140	0.0275	0.0365	0.0518

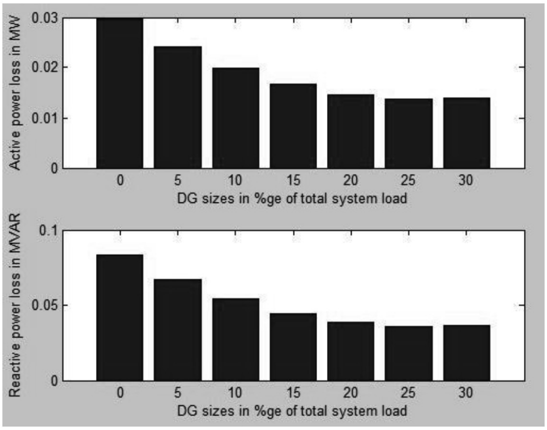

Figure 3.
Variation of power loss with variation in DG sizes when placed in node 2

Similarly the variation of power loss values with different DG sizes placed at node 10 & 11 is given in Figure 5 & 6. From the plots for the two nodes shown in Table 2, it's quite clear that the power loss does not always decrease with increase in DG size.

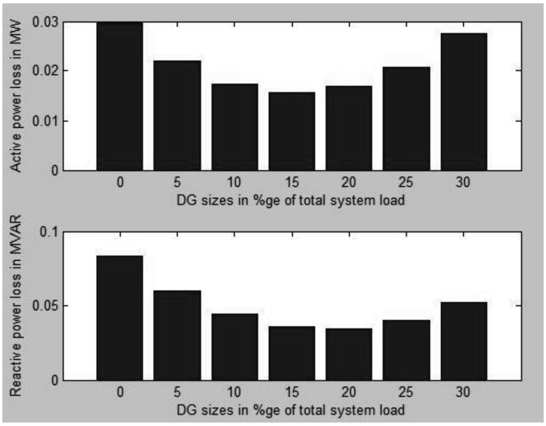

Figure-4.
Variation of power loss with variation in DG sizes when placed in node 8

Table 2.
Variation of power loss with different DG sizes when placed in node 10 & 11

Size of DG (in %ge of total load)	Size of DG (in MVA)	Real Power Loss (in MW)		Reactive Power Loss (in MVAR)	
		At node10	At node11	At node10	At node11
5%	0.19330	0.0228	0.0220	0.0653	0.0602
10%	0.38266	0.0182	0.0173	0.0519	0.0448
15%	0.57399	0.0158	0.0153	0.0435	0.0372
20%	0.76532	0.0157	0.0161	0.0398	0.0370
25%	0.95665	0.0176	0.0194	0.0406	0.0438
30%	1.14798	0.0217	0.0252	0.0459	0.0575

From the values of real & reactive power losses for different DG sizes at various nodes, we can see that the power losses do not always decrease with the increase in the DG penetration level or DG size. A proper size of DG is always required for efficient operation of the system. Table 3 shows the sizes of DGs corresponding to minimum loss in the system for a particular node.

The variation in node voltages from base case voltage profile at nodes 2, 8, 10 & 11 with different DG sizes is mentioned in Table 4 to 9.

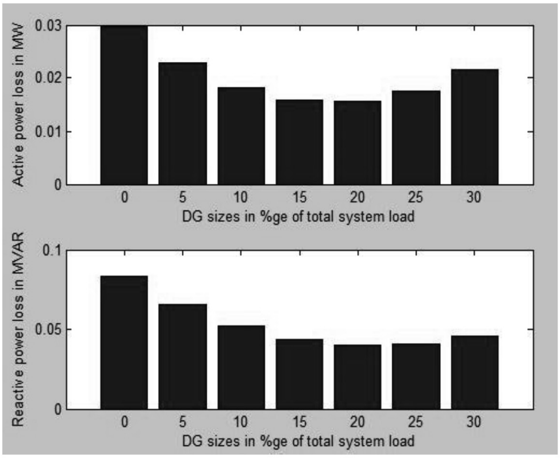

Figure 5.
Variation of power loss with variation in DG sizes when placed in node 10

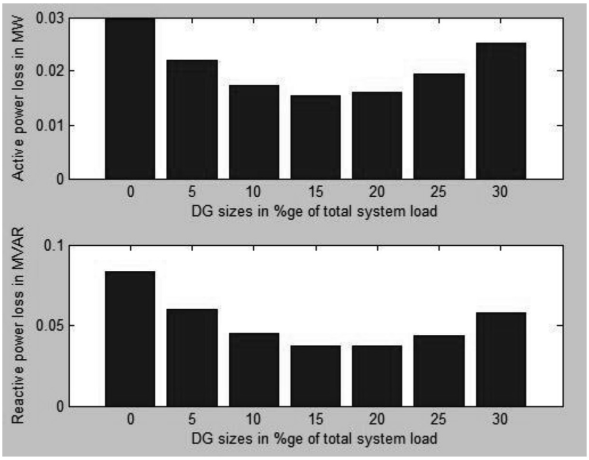

Figure 6.
Variation of power loss with variation in DG sizes when placed in node 11

In Figure 7 the variation in voltage profile with different DG sizes when placed at node 2 is shown. From the figure it is quite clear that there is improvement in node voltages with the increasing DG size. Similarly, the improvement in node voltages with various DG sizes when placed at nodes 8, 10 & 11 is shown in Figure 8, 9 & 10 respectively.

Table 3. DG sizes corresponding to minimum loss for a particular node

Node No.	DG sizes (in %ge of total system load)	DG sizes (in MVA)	Real power loss (in MW)	Reactive power loss (in MVAR)
2	25	0.95665	0.0138	0.0359
3	20	0.76532	0.0128	0.0329
4	15	0.57399	0.0162	0.0432
5	20	0.76532	0.0173	0.0436
6	20	0.76532	0.0173	0.0436
7	20	0.76532	0.0128	0.0329
8	15	0.57399	0.0156	0.0356
9	20	0.76532	0.0144	0.0382
10	20	0.76532	0.0157	0.0398
11	15	0.57399	0.0153	0.0372
12	15	0.57399	0.0153	0.0372
13	15	0.57399	0.0153	0.0372

Table 4. Node voltages with 5% DG size

Node No.	Node voltages in KV (without DG)	Voltages in pu when DG is placed at			
		Node 2	Node 8	Node 10	Node 11
1	4.1600	4.1600	4.1600	4.1600	4.1600
2	3.9558	3.9882	3.9896	3.9895	3.9895
3	3.7902	3.9068	3.9209	3.9208	3.9208
4	3.7902	3.9068	3.9209	3.9208	3.9208
5	3.9461	3.9808	3.9822	3.9822	3.9822
6	3.9461	3.9808	3.9822	3.9822	3.9822
7	3.7902	3.9068	3.9209	3.9208	3.9208
8	3.7709	3.9038	3.9244	3.9177	3.9177
9	3.9558	3.9623	3.9637	3.9637	3.9637
10	3.9558	3.9538	3.9552	3.9552	3.9552
11	3.7902	3.9068	3.9209	3.9250	3.9250
12	3.7902	3.9068	3.9209	3.9250	3.9250
13	3.7861	3.9068	3.9209	3.9250	3.9250

CONCLUSIONS

In this article the distribution flow analysis has been proposed for radial distribution networks. The proposed method has been tested in IEEE-13 bus radial distribution test system. The standard data taken is given in the Appendix.

Table 5. Node voltages with 10% DG size

Node No.	Node voltages in KV (without DG)	Voltages in pu when DG is placed at			
		Node 2	Node 8	Node 10	Node 11
1	4.1600	4.1600	4.1600	4.1600	4.1600
2	3.9558	4.0012	4.0031	4.0030	4.0030
3	3.7902	3.9201	3.9468	3.9465	3.9465
4	3.7902	3.9201	3.9468	3.9465	3.9465
5	3.9461	3.9939	3.9958	3.9957	3.9957
6	3.9461	3.9939	3.9958	3.9957	3.9957
7	3.7902	3.9201	3.9468	3.9465	3.9465
8	3.7709	3.9171	3.9568	3.9435	3.9435
9	3.9558	3.9755	3.9774	3.9773	3.9773
10	3.9558	3.9670	3.9689	3.9688	3.9688
11	3.7902	3.9201	3.9468	3.9549	3.9549
12	3.7902	3.9201	3.9468	3.9549	3.9549
13	3.7861	3.9201	3.9468	3.9549	3.9549

Table 6. Node voltages with 15% DG size

Node No.	Node voltages in KV (without DG)	Voltages in pu when DG is placed at			
		Node 2	Node 8	Node 10	Node 11
1	4.1600	4.1600	4.1600	4.1600	4.1600
2	3.9558	4.0139	4.0155	4.0152	4.0152
3	3.7902	3.9322	3.9711	3.9706	3.9706
4	3.7902	3.9322	3.9711	3.9706	3.9706
5	3.9461	4.0065	4.0082	4.0079	4.0079
6	3.9461	4.0065	4.0082	4.0079	4.0079
7	3.7902	3.9322	3.9711	3.9706	3.9706
8	3.7709	3.9292	3.9878	3.9676	3.9676
9	3.9558	3.9881	3.9897	3.9895	3.9895
10	3.9558	3.9796	3.9812	3.9810	3.9810
11	3.7902	3.9322	3.9711	3.9835	3.9835
12	3.7902	3.9322	3.9711	3.9835	3.9835
13	3.7861	3.9322	3.9711	3.9835	3.9835

Table 7. Node voltages with 20% DG size

Node No.	Node voltages in KV (without DG)	Voltages in pu when DG is placed at			
		Node 2	Node 8	Node 10	Node 11
1	4.1600	4.1600	4.1600	4.1600	4.1600
2	3.9558	4.0261	4.0267	4.0263	4.0263
3	3.7902	3.9440	3.9945	3.9937	3.9937
4	3.7902	3.9440	3.9945	3.9937	3.9937
5	3.9461	4.0188	4.0194	4.0190	4.0190
6	3.9461	4.0188	4.0194	4.0190	4.0190
7	3.7902	3.9440	3.9945	3.9937	3.9937
8	3.7709	3.9410	4.0179	3.9907	3.9907
9	3.9558	4.0003	4.0009	4.0005	4.0005
10	3.9558	3.9917	3.9924	3.9919	3.9919
11	3.7902	3.9440	3.9945	4.0111	4.0111
12	3.7902	3.9440	3.9945	4.0111	4.0111
13	3.7861	3.9440	3.9945	4.0111	4.0111

Table 8. Node voltages with 25% DG size

Node No.	Node voltages in KV (without DG)	Voltages in pu when DG is placed at			
		Node 2	Node 8	Node 10	Node 11
1	4.1600	4.1600	4.1600	4.1600	4.1600
2	3.9558	4.0380	4.0369	4.0363	4.0363
3	3.7902	3.9553	4.0169	4.0157	4.0157
4	3.7902	3.9553	4.0169	4.0157	4.0157
5	3.9461	4.0306	4.0295	4.0289	4.0289
6	3.9461	4.0306	4.0295	4.0289	4.0289
7	3.7902	3.9553	4.0169	4.0157	4.0157
8	3.7709	3.9523	4.0470	4.0128	4.0128
9	3.9558	4.0121	4.0110	4.0104	4.0104
10	3.9558	4.0035	4.0024	4.0018	4.0018
11	3.7902	3.9553	4.0169	4.0379	4.0379
12	3.7902	3.9553	4.0169	4.0379	4.0379
13	3.7861	3.9553	4.0169	4.0379	4.0379

Table 9. Node voltages with 30% DG size

Node No.	Node voltages in KV (without DG)	Voltages in pu when DG is placed at			
		Node 2	Node 8	Node 10	Node 11
1	4.1600	4.1600	4.1600	4.1600	4.1600
2	3.9558	4.0495	4.0460	4.0452	4.0452
3	3.7902	3.9663	4.0384	4.0368	4.0368
4	3.7902	3.9663	4.0384	4.0368	4.0368
5	3.9461	4.0421	4.0386	4.0377	4.0377
6	3.9461	4.0421	4.0386	4.0377	4.0377
7	3.7902	3.9663	4.0384	4.0368	4.0368
8	3.7709	3.9663	4.0753	4.0339	4.0339
9	3.9558	4.0235	4.0200	4.0192	4.0192
10	3.9558	4.0150	4.0115	4.0106	4.0106
11	3.7902	3.9663	4.0384	4.0639	4.0639
12	3.7902	3.9663	4.0384	4.0639	4.0639
13	3.7861	3.9663	4.0384	4.0639	4.0639

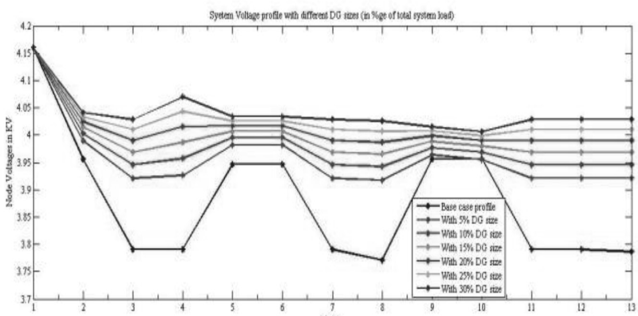

Figure 7. Variation of node voltages with variation in DG sizes when placed in node 2

The used method has advantages over the general load flow methods, in terms of its robustness and its simple calculation. The forward-backward sweep method is used here for the power flow calculation. DG is considered to be connected at all the buses except the slack bus. The effects of distributed generation on the system voltage profile and losses have been analyzed. The system is simulated for different sizes of distributed generation and a comparative study of the system with DG &

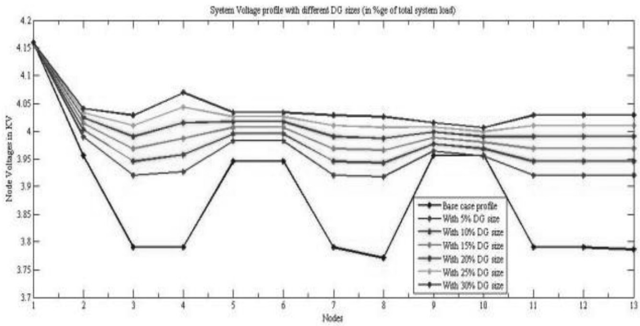

Figure 8. Variation of node voltages with variation in DG sizes when placed in node 8

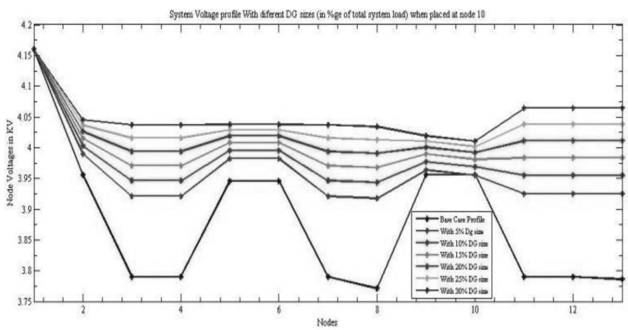

Figure 9. Variation of node voltages with variation in DG sizes when placed in node 10

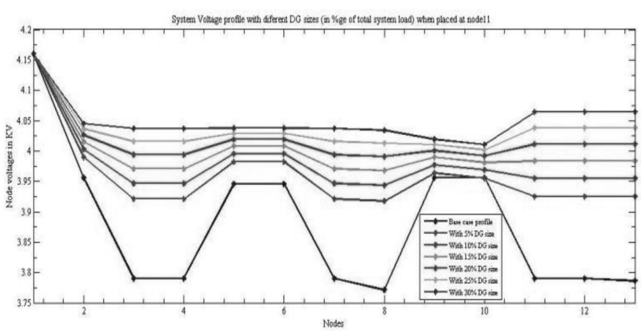

Figure 10. Variation of node voltages with variation in DG sizes when placed in node 11

without DG is carried out. The results reveal that, with the incorporation of DG, the system voltage profile improves to a greater extent and also the system loss is minimized extensively. The results show that the voltage profile is improved and losses are reduced, when DG is incorporated in the system.

From Table 6 & 8, we see that, the voltage at node 11 is improved from 5% to 6.5% from its base case value, when the size of DG placed at node 11 is increased from 15% to 25% of total system load. However, from the table of power losses we see that with the increase in DG size the power losses do not decrease always. When DG size of 15% of total system load is placed at node 11, total power loss is improved by 48% from its base case value, as shown in Table 2. But the increase of DG size from 15% to 25%, the power loss has been worsened by 34% from its base case value. This increase in losses after a particular size of DG shows that DG size should be in proper proportion to the total load of the system.

APPENDIX

The IEEE 13 node test feeder system is shown in Figure A-1. The feeder voltage here is 4.16 kV. The load data & line segment data are given in Table A.1 & A.2. The node 650 is considered as the slack bus or the substation bus. The nodes 632, 671, 680, 633, 634, 692, 675, 645, 646, 684, 611, 652 are considered serially as nodes 2 to 13 respectively.

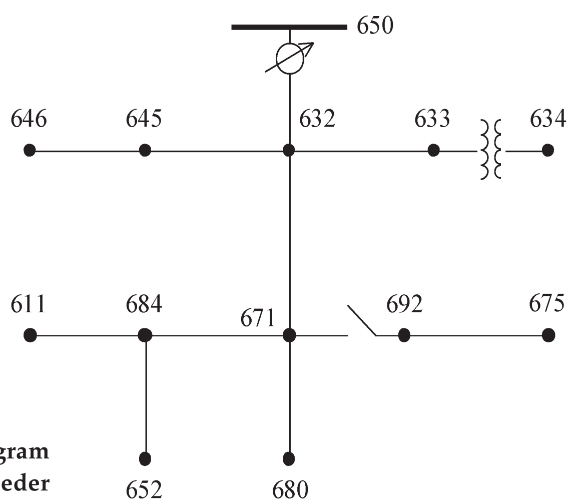

Figure A-1. One line diagram of IEEE 13 node test feeder

Table A.1.1. Load Data (Spot Load)

Node	Phase 1 MW	Phase 1 MVAR	Phase 2 MW	Phase 2 MVAR	Phase 3 MW	Phase 3 MVAR
3	385	220	385	220	385	220
6	160	110	120	90	120	90
7	0	0	0	0	170	151
8	485	190	68	60	290	212
9	0	0	170	125	0	0
10	0	0	230	132	0	0
13	128	86	0	0	0	0
12	0	0	0	0	170	80

Table A.1.2. Load Data (Distributed Load)

Node A	Node B	Phase 1 MW	Phase 1 MVAR	Phase 2 MW	Phase 2 MVAR	Phase 3 MW	Phase 3 MVAR
2	3	385	17	10	66	117	68

Table A.2. Line Segment data

Branch	Sending end	Receiving End	Conductor type (Configuration)	Length (ft.)
1	1	2	603	500
2	2	3	602	500
3	2	9	XFM-1	0
4	2	5	603	300
5	3	4	601	2000
6	3	7	607	800
7	3	11	601	2000
8	5	6	604	300
9	7	8	601	1000
10	9	10	Switch	0
11	11	12	605	300
12	11	13	606	500

Table A.3. Impedance of various configurations

Configuration 601:

Z (R + jX) in ohms per mile

0.3465 + j0.0179	0.1560 + j0.5017	0.1580 + j0.4236
0.1560 + j0.5017	0.3375 + j1.0478	0.1535 +j0.3849
0.1580 + j0.4236	0.1535 +j0.3849	0.3414 +j1.0348

B in micro Siemens per mile

6.2998	-1.9958	-1.2595
-1.9958	5.9597	-0.7417
-1.2595	-0.7417	5.6386

Configuration 602:

Z (R + jX) in ohms per mile

0.7526 + j1.1814	0.1580 + j0.4326	0.1560 + j0.5017
0.1580 + j0.4326	0.7475 + j1.1983	0.1535 +j0.3849
0.1560 + j0.5017	0.1535 +j0.3849	0.7436 +j1.2112

B in micro Siemens per mile

5.6990	-1.0817	-1.6905
-1.0817	5.1795	-0.6588
-1.6905	-0.6588	5.4246

Configuration 603:

Z (R + jX) in ohms per mile

0.0000 + j0.0000	0.0000 + j0.0000	0.0000 + j0.0000
0.0000 + j0.0000	1.3294 + j1.3471	0.2066 +j0.4591
0.0000 + j0.0000	0.2066 +j0.4591	1.3288 +j1.3569

B in micro Siemens per mile

0.0000	0.0000	0.0000
0.0000	4.7097	-0.8999
0.0000	-0.8999	4.6658

Configuration 604:

Z (R + jX) in ohms per mile

1.3238 + j1.3569	0.0000 + j0.0000	0.2066 + j0.4591
0.0000 + j0.0000	0.0000 + j0.0000	0.0000 + j0.0000
0.2066 + j0.4591	0.0000 + j0.0000	1.3294 + j1.3471

B in micro Siemens per mile

4.6658	0.0000	-0.8999
0.0000	0.0000	-0.8999
-0.8999	-0.8999	4.7097

Configuration 605:

Z (R + jX) in ohms per mile

0.0000 + j0.0000	0.0000 + j0.0000	0.0000 + j0.0000
0.0000 + j0.0000	0.0000 + j0.0000	0.0000 + j0.0000
0.0000 + j0.0000	0.0000 + j0.0000	1.3292 + j1.3475

B in micro Siemens per mile

0.0000	0.0000	0.0000
0.0000	0.0000	0.0000
0.0000	0.0000	4.5193

Configuration 606:

Z (R + jX) in ohms per mile

0.7982 + j0.4463	0.3192 + j0.0328	0.2849 - j0.0143
0.3192 + j0.0328	0.07891 + j0.4041	0.3192 + j0.0328
0.2849 - j0.0143	0.3192 + j0.0328	0.7982 + j0.4463

B in micro Siemens per mile

96.8897	0.0000	0.0000
0.0000	96.8897	0.0000
0.0000	0.0000	96.8897

Configuration 607:

Z (R + jX) in ohms per mile

0.7982 + j0.4463	0.3192 + j0.0328	0.2849 - j0.0143
0.3192 + j0.0328	0.07891 + j0.4041	0.3192 + j0.0328
0.2849 - j0.0143	0.3192 + j0.0328	0.7982 + j0.4463

B in micro Siemens per mile

96.8897	0.0000	0.0000
0.0000	96.8897	0.0000
0.0000	0.0000	96.8897

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