Optimal Placement of Distribution Generation in Radial Distribution System

K.Sandhya, Dr.A.Jaya Laxmi and Dr.M.P.Soni

***Abstract*: In this paper the methodology to find the optimal size and location of distribution generation in radial distribution system is presented. The load flow technique for radial distribution system is proposed. The backward-forward sweep method is used to carry load flow analysis. The proposed methodology is applied on IEEE 33-bus test system. The results include the comparison of voltage profile and power flows before and after placing the DG.**

***Keywords:* Distribution Generation, Distribution System, Load Flow and Voltage Profile.**

I. INTRODUCTION

With the restructuring of Power Systems and with shifting trends towards distributed and dispersed generation, the issue of Power Quality is going to take newer dimensions. The share of DGs in power system worldwide is increasing and their contribution in the future power system is expected to be even more. Energy policies worldwide are encouraging installation of DGs in both transmission and distribution networks along with large scale power generating plants.

The general belief is that the future of the power generation will be DGs. But the fact is that the distribution systems were not planned to support the installation of active power generating units in them. DGs come with opportunities as well as challenges. They, in one hand, are expected to be the solution of most of the power system problems while, on the other hand, they are adding new problems. Their grid connection, pricing, change in protection scheme are the name of the few. Still maximum benefit from this new power generation technology can reap if it is handled properly. Hence, utilities and distribution companies need tools to place small generating units in their distribution systems.

II. LOAD FLOW

In any radial distribution network, the electrical equivalent of a branch-i, which is connected between nodes 1 and 2 having resistance $r_{(i)}$ and inductive reactance $x_{(i)}$ is shown in Fig.1.

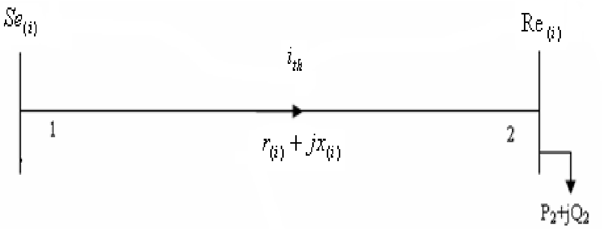

Fig.1. Electrical equivalent of a typical branch-i

From Fig.1 current flowing through the branch-i is given by

$$I(\text{Re}(i)) = \left(\frac{P(\text{Re}(i)) + j * Q(\text{Re}(i))}{V(\text{Re}(i))}\right)^* \quad \dots (2.1)$$

where,

Se(i) = Sending end node
Re(i) = Receiving end node
Let
I(i)=I(Re(i)) … (2.2)

V(Re(i)) = Voltage magnitude at branch i

V(Re(i))=V(Se(i))-I(i)×(R(i)+jX(i)) … (2.3)

where,
R = Resistance of branch i
X = Reactance of branch i

The active and reactive power losses in branch i are given by

$$\text{P (i)} = |I(i)|^2 \times R(i) \quad \dots (2.4)$$

$$\text{Q (i)} = |I(i)|^2 \times X(i) \quad \dots (2.5)$$

ln = number of branches
nd = number of nodes

Normally the substation voltage $V_{(i)}$ is known and is taken as $|V_{(1)}|$ =1.0 (p.u) Initially, P(i) and $Q(i)$ are set to zero for all i. Then the initial estimate of $P_{(2)}$ and $Q_{(2)}$ will be the sum of the loads of all the nodes beyond node 2 plus the local load of

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node 2. For all the branches i = 1,2,…….,nd-1 , compute $P_{(i+1)}$ and $Q_{(i+1)}$. Compute $|V_{(i=1)}|$, $P(i)$ and $Q(i)$ using Eqns. (2.3), (2.4) and (2.5). This will complete iteration. Update the loads $P_{(i+1)}$ and $Q_{(i+1)}$ (by including losses) and repeat the same procedure until all the voltage magnitudes are computed to a tolerance level of 0.0001 p.u. in successive iterations.

Once all the nodes and branches are identified, then voltage magnitudes of all the nodes are calculated by using the Eqn. (2.3). It is necessary to obtain the exact feeding through all the receiving end nodes and the voltage magnitudes of all the nodes as the voltage of the substation is known ($V_{(1)}$). Then compute the branch losses using Eqns. (2.4) and (2.5). The convergence criterion is that if the magnitude of voltage difference of successive iterations is less than the error (i.e., 0.0001) value, the solution is converged. The backward-forward sweep method is used to carry load flow analysis.

III. PLACEMENT OF DG

The objective of the placement technique is to minimize the real power loss. The DG supplies real power and absorbs reactive power so the bus where the DG is installed has to be treated as a load bus. Most of the wind turbines have the similar characteristic, so the location at which they are connected has been treated as load buses while performing load flow analysis.

The objective function can be written as:

Min P_L ... (3.1)

Such that $P_G = P_D + P_L$ ... (3.2)

where, P_L is the real power loss in the system, P_G and P_D are its power generation and demand, respectively.

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij}(P_iP_j + Q_iQ_j) + B_{ij}(Q_iP_j - P_iQ_j) \quad \text{... (3.3)}$$

where

$$\left.\begin{aligned} A_{ij} &= \frac{R_{ij}Cos\,(\delta_i - \delta_j)}{V_iV_j} \\ B_{ij} &= \frac{R_{ij}Sin\,(\delta_i - \delta_j)}{V_iV_j} \end{aligned}\right\} \quad \text{... (3.4)}$$

$P_{i\ and}\ Q_i$ are net real and reactive power injection in bus ‘i’, respectively.

R_{ij} is the line resistance between buses ‘i’ and ‘j’.

Vi and δ_i are the voltage and angle at bus ‘i’, respectively.

For wind turbines, induction generators are used to produce real power and reactive power will be consumed in the process. The amount of reactive power they consume is a function of the active power output. The reactive power consumed by a DG (wind turbine generator) in a simple form can be represented by Equ. (3.5).

$$Q_{DG} = -(0.5 + 0.04\,P_{DG}^2) \quad \text{... (3.5)}$$

Now the real loss equation can be written as

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\begin{bmatrix} A_{ij}[(P_{DGi} - P_{Di})P_j + (-1 - 0.04P_{DGi}^2 - Q_{Di})Q_j] \\ + B_{ij}[(-1 - 0.04P_{DGi}^2 - Q_{Di})P_j - (P_{DGi} - P_{Di})Q_j] \end{bmatrix} \quad \text{.. (3.6)}$$

The necessary condition for minimum loss is:

$$\frac{\partial P_L}{\partial P_{DGi}} = 2A_{ii}(P_i - 0.08P_{DGi}Q_j) + 2\sum_{\substack{j=1 \\ j\neq 1}}^{n} B_{ij}(-0.08P_{DGi}P_j - Q_j) = 0 \quad \text{... (3.7)}$$

$$\begin{bmatrix} A_{ii}[P_{DGi} - P_{Di} + 0.08P_{DGi}(0.05 + 0.04P_{DGi}^2 + Q_{Di})] + \\ \sum_{\substack{j=1 \\ j\neq i}}^{n}(A_{ij}P_j - B_{ij}Q_j) - 0.08P_{DGi}\sum_{\substack{j=1 \\ j\neq 1}}^{n}(A_{ii}Q_j + B_{ij}P_j) = 0 \end{bmatrix} \quad \text{... (3.8)}$$

Let,

$$\left.\begin{aligned} X_i &= \sum_{\substack{j=1 \\ j\neq i}}^{n}(A_{ij}P_j - B_{ij}Q_j) \\ Y_i &= \sum_{\substack{j=1 \\ j\neq 1}}^{n}(A_{ii}Q_j + B_{ij}P_j) \end{aligned}\right\} \quad \text{... (3.9)}$$

Equ. (3.8), thus, can be written as

$$0.0032A_{ii}P_{DGi}^3 + P_{DGi}[1.004A_{ii} + 0.08A_{ii}Q_{Di} - 0.08Y_i] + (X_i - A_{ii}P_{Di}) = 0 \quad \text{... (3.10)}$$

If the above equation is solved for P_{DGi}, it will be known that the amount of real power that the wind turbine has to produce at various locations so as to minimize the real loss. This will solve the sizing problem and placement problem is solved by comparing the losses by putting DG of corresponding optimal sizes at various locations. The bus at which the total loss is minimum and corresponding size will be the optimal location and size, respectively.

IV. RESULTS

The computer programs have been developed in MATLAB software to examine the efficiency of the proposed approach. The proposed work is tested on 33-bus radial distribution system with a load of 3.72 MW and 2.3 MVAR. The proposed method is illustrated with 33 bus test system. Bus No. 1 is the source node connected to the transmission system while Branch 1 refers to the branch connecting Bus No. 1 to Bus No. 2. Based on the proposed methodology, the optimal DG sizes for all the buses are found in terms of their optimal real power production and corresponding reactive power consumption. The proposed algorithm is tested for solving IEEE-33 node systems whose single line diagram is shown in Fig. 2. The line, load data is shown in Table 1.

The voltages obtained before placing DG and after placing DG are tabulated in Table 2. From the results it can be observed that the voltages obtained from after placing DG is greater than before placing DG and the active power losses reduced from 202.50KW to 132.29 KW which results in

34.6716 % real power loss reduction and the reactive power losses reduced from 135.13 to 88.40 KVAR which results in 34.5815 % reactive power loss reduction and minimum voltage is increased to 0.94947 from 0.91306 (p.u).

Table.1.The line and load data for 33-node radial distribution system

Branch Number	**Sending end Node**	**Receiving end Node**	**Resistance R (Ω)**	**Reactance X(Ω)**	**Active power (kW)**	**Reactive power (KVAr)**
1	1	2	0.0922	0.0470	100.00	60.00
2	2	3	0.4930	0.2511	90.00	40.00
3	3	4	0.3660	0.1864	120.00	80.00
4	4	5	0.3811	0.1941	60.00	30.00
5	5	6	0.8190	0.7070	60.00	20.00
6	6	7	0.1872	0.6188	200.00	100.00
7	7	8	0.7114	0.2351	200.00	100.00
8	8	9	1.0300	0.7400	60.00	20.00
9	9	10	1.0440	0.7400	60.00	20.00
10	10	11	0.1966	0.0650	45.00	30.00
11	11	12	0.3744	0.1238	60.00	35.00
12	12	13	1.4680	1.1550	60.00	35.00
13	13	14	0.5416	0.7129	120.00	80.00
14	14	15	0.5910	0.5260	60.00	10.00
15	15	16	0.7463	0.5450	60.00	20.00
16	16	17	1.2890	1.7210	60.00	20.00
17	17	18	0.7320	0.5740	90.00	40.00
18	2	19	0.1640	0.1565	90.00	40.00
19	19	20	1.5042	1.3554	90.00	40.00
20	20	21	0.4095	0.4784	90.00	40.00
21	21	22	0.7089	0.9373	90.00	40.00
22	3	23	0.4512	0.3083	90.00	50.00
23	23	24	0.8980	0.7091	420.00	200.00
24	24	25	0.8960	0.7011	420.00	200.00
25	6	26	0.2030	0.1034	60.00	25.00
26	26	27	0.2842	0.1447	60.00	25.00
27	27	28	1.0590	0.9337	60.00	20.00
28	28	29	0.8042	0.7006	120.00	70.00
29	29	30	0.5075	0.2585	200.00	600.00
30	30	31	0.9744	0.9630	150.00	70.00
31	31	32	0.3105	0.3619	210.00	100.00
32	32	33	0.3410	0.5302	60.00	40.00

Base MVA = 100 **Base KV = 12.66**

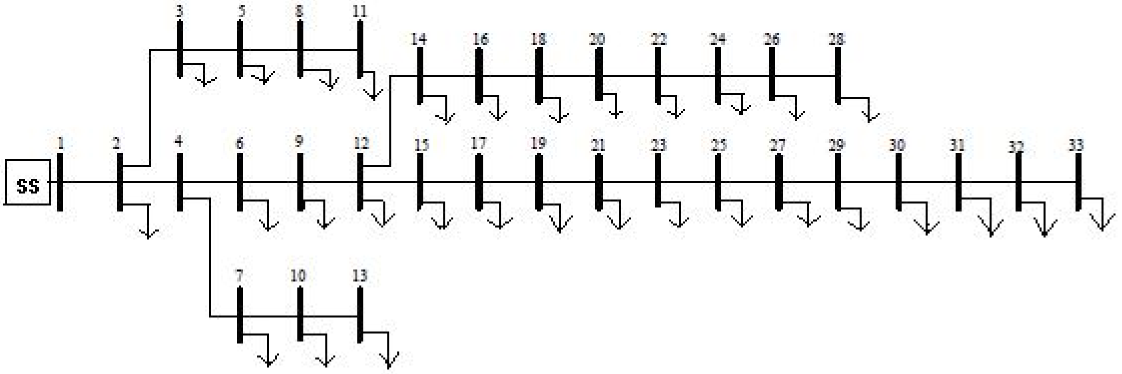

Fig. 2. Single line diagram of 33-Bus radial distribution system.

Table 2. Voltages obtained for 33-Bus system

Node No.	**Voltage (p.u)**		**Node No.**	**Voltage (p.u)**	
	Before placing DG	**After placing DG**		**Before placing DG**	**After placing DG**
1	1.00000	1.00000	17	0.91367	0.95005
2	0.99702	0.99769	**18**	**0.91306**	**0.94947**
3	0.98295	0.98716	19	0.99650	0.99716
4	0.97547	0.98230	20	0.99292	0.99358
5	0.96807	0.97764	21	0.99221	0.99288
6	0.94967	0.96503	22	0.99158	0.99224
7	0.94618	0.96258	23	0.97938	0.98361
8	0.94134	0.96281	24	0.97271	0.97696
9	0.93507	0.96364	25	0.96938	0.97365
10	0.92925	0.96504	26	0.94774	0.96313
11	0.92839	0.96421	27	0.94517	0.96061
12	0.92689	0.96277	28	0.93373	0.94937
13	0.92074	0.95685	29	0.92552	0.94129
14	0.91848	0.95467	30	0.92196	0.93779
15	0.91706	0.95331	31	0.91780	0.93370
16	0.91570	0.95200	32	0.91688	0.93280
			33	0.91660	0.93782

Table 3. Comparison of Active and Reactive power losses in 33-Busradial distribution system

DG placement	**Active power losses (KW)**	**Reactive power losses (KVAR)**

Before placing DG	202.70	135.23
After placing DG	25.29	3.34

Table 4. Bus ranking based up on the loss reduction capability for 33-Bus radial distribution system

Bus NO.	DG Size (MW)	DG Size (MVAR)	Real power losses (KW)	Reactive power losses (KVAR)	Real power loss reduction (%)	Reactive power loss reduction (%)	$P_i = P_g - P_d$ (MW)
10	**1.1079**	**0.0991**	**132.29**	**88.40**	**34.6716**	**34.5815**	**1.0479**
9	0.7461	0.0723	147.59	98.21	27.1160	27.3218	0.6861
16	0.6726	0.0680	147.71	98.21	27.0567	27.3218	0.6126
17	0.6502	0.0669	151.03	101.77	25.4172	24.6873	0.5902
15	0.5370	0.0615	153.62	101.80	24.1382	24.6651	0.4770
11	0.5390	0.0616	156.59	104.04	22.6716	23.0074	0.4940
30	0.5123	0.0605	159.61	107.14	21.1802	20.7133	0.3123
12	0.3007	0.0536	174.58	116.30	13.7876	13.9347	0.2407
8	0.2766	0.0531	181.86	121.09	10.1925	10.3899	0.0766

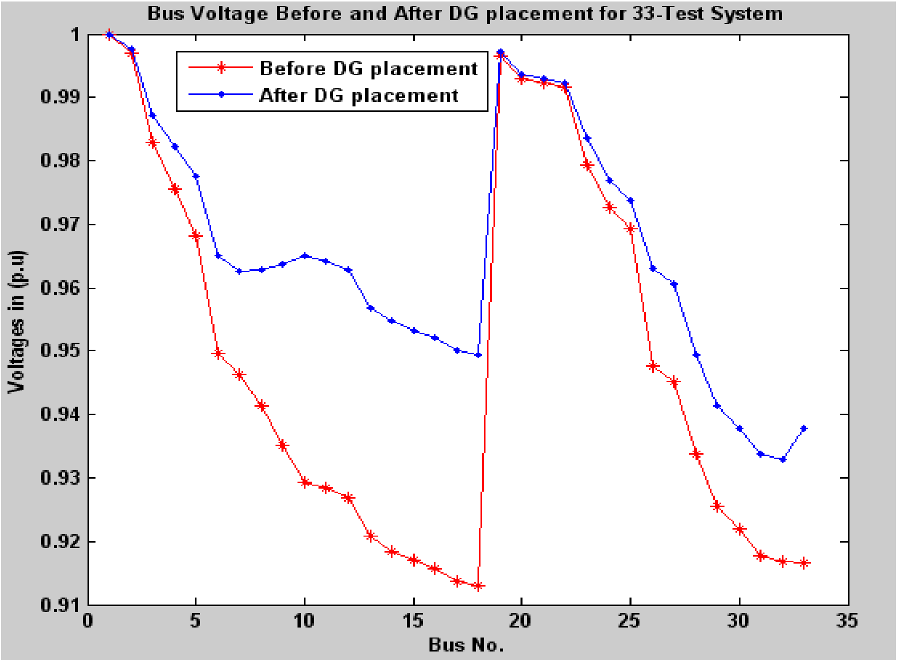

Fig.3 Bus Voltages Before and After Optimal DG Installation in the 33-Bus System

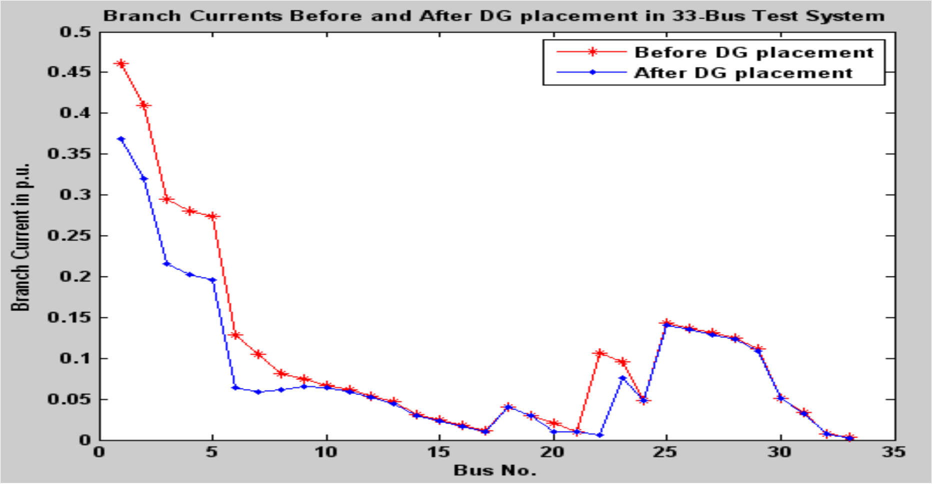

Fig. 4. Branch Currents Before and After Optimal DG Installation in the 33-Bus System

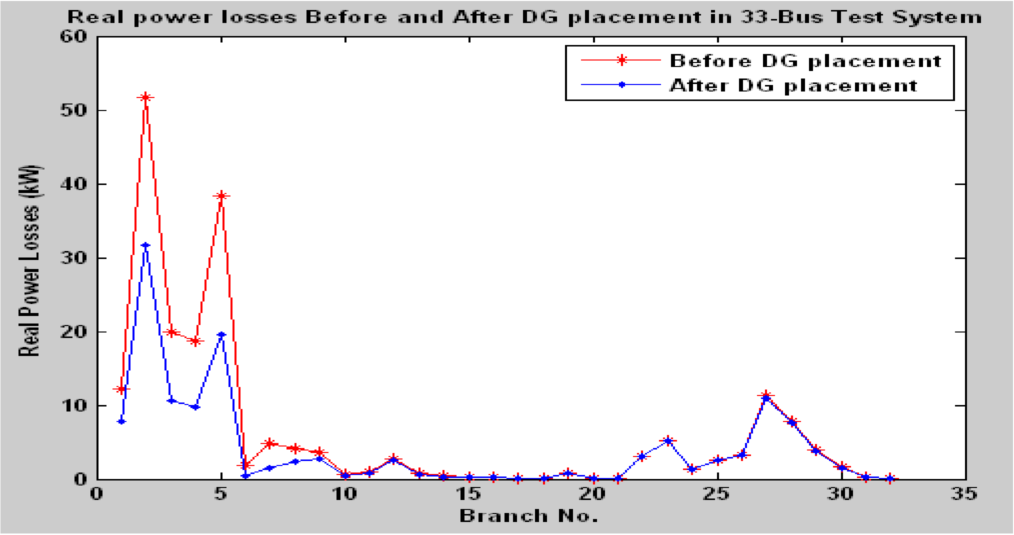

Fig. 5 Optimal Real Power Production Before and After Optimal DG Installation in the 33-Bus System

The voltages before and after optimal DG installation is shown in Fig. 3, from which it is clear that voltage profile is improved by optimal placement of DG. The branch currents before and after DG placement is shown in Fig. 4 and from this it is observed that the branch currents are decreases after placing DG compared to before placing DG. The Fig. 5 shows the optimal real power production before and after DG placement. It is clearly observed that the optimal real power loss is reduced after DG placement. From the results it can be observed that the voltages obtained from after placing DG is greater than before placing DG and the active power losses reduced from 225.02 to 129.46 KW which results in 42.4673 % real power loss reduction and the reactive power losses reduced from 102.18 to 61.34 KVAr which results in 39.9686 % reactive power loss reduction and minimum voltage is increased to 0.94326 from 0.90918 (p.u).

V. CONCLUSION

This paper presents methodology to place wind turbine DG optimally in primary distribution systems with the view of minimizing the real power loss in the system while considering its characteristic. The methodology is fast and accurate in determining the size and location of DG. In this paper, it is assumed that the DG installed at one location at a time, which is a valid assumption. It is observed that the optimal DG placement in the radial distribution system improves the voltage profile. Losses of the system are also reduced with a good percentage, after placing DG.

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