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Determination of Optimal Location and Sizing of Distributed Generator in Radial Distribution Systems for Different Types of Loads

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Abstract

In distribution systems, the increased application of distributed generations (DGs) has modified its characteristics from passive to active. Distributed generation can be integrated into distribution systems to meet the increasing load demand. This paper presents the sizing and sitting issue of single DG placement in radial distribution systems using distflow technique for constant power, constant current, constant impedance and composite type of load. The main objective of the work is to minimize the active and reactive power loss and enhance voltage profile of overall system for different types of loads. The effectiveness of the proposed idea has been successfully tested on 12.66 kV radial distribution systems consisting of 33 nodes and the results are found to be in very good agreement.

Key words

Active Power Loss; Distflow Technique; Distributed Generation; Load modeling; Radial distribution networks; Reactive Power Loss; Voltage Profile.

1. Introduction

In the deregulated power market, electric utilities are now continuously searching new technologies to provide acceptable power quality and higher reliability to their valuable customers. Non-conventional generation is growing more rapidly around the world due to its small size, low cost and less environmental impact with high potentiality. Investment in distributed generation (DG) enhances economical, technical and environmental benefits.

Distributed generation is small scale electrical power generation which is normally connected to distribution system. DG may come from a variety of source and technologies. DGs from renewable sources, like wind, solar and biomass are often called as “Green energy”. In addition to this, DG includes micro turbines, gas turbines, diesel engines, fuel cells, stirling engines and internal combustion reciprocating engines. So, optimal placement and proper size of DG attract lucrative research interest.

A “2/3 rule” is presented in [1] to placed DG on a radial feeder with uniformly distributed load, that is to install a DG with approximately 2/3 capacity of the applied load at approximately 2/3 of the radial feeder length. Caisheng and Nehrir [2] have proposed analytical approach to determine the optimal location for the DG with an objective of loss minimization for transmission and distribution networks. An analytical method to placement of DG in radial system as well as meshed system to minimized power loss of the network is presented [2]. Rahman et al. [3] and Jurado and Cano [4] both are discussed the placement and size of DG. Naderi has proposed [5] an idea to minimize the capital costs for network upgrading, operation and maintenance cost and cost of losses for handling the load growth for the system planning. Acharya et al. [6] have used the loss sensitivity equation to determine the optimal size of DG and the exact loss equation to determine the optimal location of DG based on minimum losses. For optimal DG allocation and sizing in distribution system using Genetic Algorithm was proposed by Borges and Falcao [7]. For multi conductor size selection in planning of radial distribution system is done by two step approaches in [8]. Kamel and Kermanshanti [9] have proposed the minimum loss and generation cost (as a parameter) to determine the optimal location and size of the DG in addition to DG power limits. Gozel and Hocaoglu used the loss sensitivity factor based on equivalent current injection using two Bus- Injections to branch current (BIBC) and Branch-current to Bus-Voltage (BCBV) matrix [10] for finding the optimal size and optimal placement of DG. Ghosh et al. presents a simple search approach determining for optimal size and optimal placement of DG using N-R method of load flow study. Both optimal DG size and optimal bus location are determined to obtain the best objective [11]. Singh and Goswami [12] to accommodate DG in a distribution network by maximization of profit, reduction losses and improvement of voltage regulation by GA technique.

Abu Mouti and Hawary [13] proposed bee colony algorithm to determine the optimal location, size and power factor of DG units in order to minimize power losses. Moradi and Abedini [14] proposed a combined solution based on GA and PSO for DG allocation in order to minimize power losses, improve voltage stability, and enhance voltage regulation. Using the simple analytical approach Hamedi and Gandomkar [15] have shown the effect of DG placement on network reliability, power losses reduction and power quality and it has noticed that the optimal DG allocation affects the system reliability and system losses. Aman et al. [16] proposed a new algorithm for distribution generator placement and sizing for distribution system based on a novel index. Zahra and Amir [17] proposed a Cuckoo Search Algorithm for DG placement considering loss reduction and voltage profile improvement of system. Garcia and Mena [18] proposed optimal placement and size of distributed generation units in distribution system with the help of Modified teaching-learning based optimization algorithm. Kayal and Chanda [19] proposed a new constrained multi-objective Particle Swarm Optimization based Wind turbine Generation Units and photovoltaic array placed in a suitable portion for power loss reduction technique and voltage stability improvement of radial distribution system. Sajjadi et al. [20] used combinatorial form of local searching and GA for solving placing problems of DGs and capacitor simultaneously in a radial distribution network with different load levels. Ebrahimi et al. [21] developed the connection of multiple DGs in distribution network according to different types of consumer. A multi-objective approach was proposed to a distribution network planning in [22]. In [23] provides a novel index aiming to avoid complex and computationally expensive statistical analysis for loss assessment. Rao et al. [24] described several benefit like reduction system losses, enhancing voltage profile, shaving peak demand, increasing overall energy efficiency and relieving overloaded distribution lines when distributed generator are incorporate in the networks. Karimyan et al. [25] proposed a new long term scheduling for optimal allocation and sizing of different types of Distributed Generation (DG) units in the distribution networks in order to minimize active power losses. Decision making at the distributed system management based on the cloud approach is described in [26]. Moradi et al. [27] proposed an efficient hybrid method based on imperialist competitive algorithm (ICA) and genetic algorithm (GA) for optimal placement and sizing of DG sources and capacitor banks simultaneously. Banerjee S [28] proposed a new idea about the voltage stability margin of radial distribution systems considering reactive loading index. Chakrabarti et al.[29] described the assessment of voltage stability in longitudinal power system.

This paper presents determination of optimal location and sizing of distributed generator in radial distribution systems for different types of loads using distflow technique.

2. Computational procedure

1. Run the distflow technique and determine total active and reactive power losses. Determine also the minimum system voltage and corresponding node.
2. Place DG at each node and capacity of DG is varied from 10% to 100% in step of 10% of total DG capacity.
3. Store the size of DG corresponding to minimum loss obtained from each node.
4. Compare the loss for each node.
5. The node at which losses are minimum is considered to be the optimum location for DG placement.
6. Note the optimum capacity of DG corresponding to optimum location.
7. Run the distflow technique again by placing optimum DG capacity at optimum location and determine total active and reactive power losses. Determine also the minimum system voltage.

3. Assumption for DG placement

The following assumptions are made for DG placement.

i) DG is considered as negative load.

ii) DG injects only active power.

iii) The maximum DG size is assumed to be total load demand plus total active power losses of the system.

iv) For DG placement, the source node is not to be taken into account.

4. Distflow technique

In radial distribution system the power flow problem can be solved by distflow technique. Consider that the branch i is connected between nodes p and q. Now the branch i has a series impedance of $Z_S = (R_S + jX_S)$.The active and reactive power flow through the branch near node p (at point m) is P_i and Q_i respectively and the active and reactive power flow through the branch near node q (at point n) is P_{i+1} and Q_{i+1} respectively. The active and reactive loss of branch i is given by

$$P_{loss} = \frac{P_{i+1}^2 + Q_{i+1}^2}{V_q^2} R_S \tag{1}$$

$$Q_{loss} = \frac{P_{i+1}^2 + Q_{i+1}^2}{V_q^2} X_S \tag{2}$$

Hence we can write

$$P_i = P_{i+1} + P_{loss}$$

$$= P_{i+1} + \frac{P_{i+1}^2 + Q_{i+1}^2}{V_q^2} R_S \tag{3}$$

$$Q_i = Q_{i+1} + Q_{loss}$$

$$= Q_{i+1} + \frac{P_{i+1}^2 + Q_{i+1}^2}{V_q^2} X_S \tag{4}$$

Here, $(P_{i+1} + jQ_{i+1})$ is the sum of complex load at node q and all the complex power flow through the downstream branches of node q .

Now, the voltage magnitude at node q is given by

$$V_q^2 = V_p^2 - 2(P_i R_S + Q_i X_S) + \frac{(P_i^2 + Q_i^2)(R_S^2 + X_S^2)}{V_p^2} \tag{5}$$

The power flow solution of a radial distribution feeder involves recursive use of (1) to (5) in reverse and forward direction. Now beginning at the last branch and finishing at the first branch of the feeder, we determine the complex power flow through each branch of the feeder in the reverse direction using (1) to (5). Then we determine the voltage magnitude of all the nodes in forward direction using (5).

5. Load Modeling

For the radial distribution networks, composite load modeling is considered. The real and reactive power loads of node ‘i’ are given as:

$$PL(i) = PL_0(i)\left(c_1 + c_2|V(i)| + c_3|V(i)|^2\right) \tag{6}$$

$$QL(i) = QL_0(i)\left(d_1 + d_2|V(i)| + d_3|V(i)|^2\right) \tag{7}$$

Here (c_1, d_1), (c_2, d_2), and (c_3, d_3) are the compositions of constant power, constant current and constant impedance loads respectively. Now, for constant power load $c_1 = d_1 = 1,$ $c_2 = d_2 = c_3 = d_3 = 0,$ for constant current load $c_2 = d_2 = 1,$ $c_1 = d_1 = c_3 = d_3 = 0,$ and for constant impedance load $c_3 = d_3 = 1,$ $c_1 = d_1 = c_2 = d_2 = 0$. Here, for composite load, a composition of 40% of constant power $(c_1 = d_1 = 0.4)$, 30% of constant current $(c_2 = d_2 = 0.3)$ and 30% of constant impedance $(c_3 = d_3 = 0.3)$ loads are also considered.

6. Results and discussion

The effectiveness of the proposed idea is tested on 12.66 kV radial distribution systems consisting of 33-nodes. The single line diagram of the 33-node system is shown in Fig. 1 and its data is given in appendix (Table I).

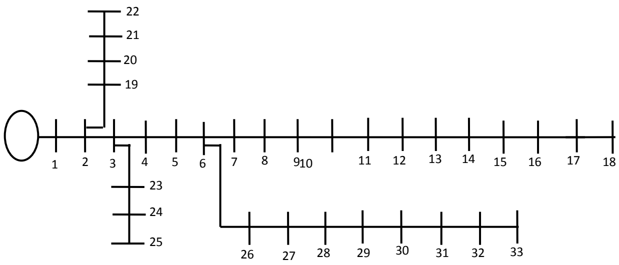

Fig. 1. Single line diagram of a main feeder.

Case A: Constant Power (CP) Load

Run the load flow program and record active power loss, reactive power loss and minimum voltage profile. In nominal loading condition, the active power loss is 203.0 kW and reactive loss is 135.0 kVAr. Under this condition, the minimum system voltage is 0.9130 pu.

Now we insert unity power factor DG in the existing 33-node system. DG is considered as an active power source and hence DG is considered as negative load. The maximum size of the DG is assumed to be total load demand of the system. For this test case, DG capacity is assumed to be 3715 kW.

DG is considered to be an active power source. The node where load is connected is considered to be the location of DG. DG is placed at each node and optimal size of DG is calculated. Figure 2 shows active power losses of 33 node system after inserting 2600.5 kW DG at each node individually. From Figure 2, we noticed that active power losses are minimum if we place 2600.5 kW DG at node 6 using distflow technique. Now, active power loss is 104.1 kW and reactive power loss is 74.8 kVAr if we place 2600.5 kW unity power factor DG at node 6. Under this condition, the minimum system voltage is 0.9514 pu.

Figure 3 shows active power losses versus DG capacity for 33 node network when DG is placed at node 6. Figure 4 shows reactive power losses versus DG capacity for 33 node networks when DG is placed at node 6.

From Figures 3 and 4, it is clear that if DG capacity increases, the overall system losses are decreasing in nature up to certain value. If DG capacity still increases, then losses begin to increase. At higher DG capacity, losses can become larger than those without DG connected.

Figure 5 shows voltage magnitude versus node number for 33 node network when DG is placed at node 6. From Figure 5, it is seen that the voltage profile has improved after inserting DGs at node 6.

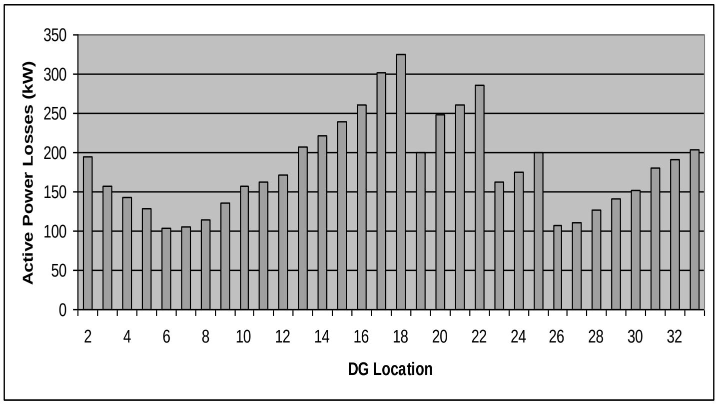

Fig 2: Active power losses of 33 node system after inserting 2600.5 kW DG at each node individually for constant power (CP) type of load.

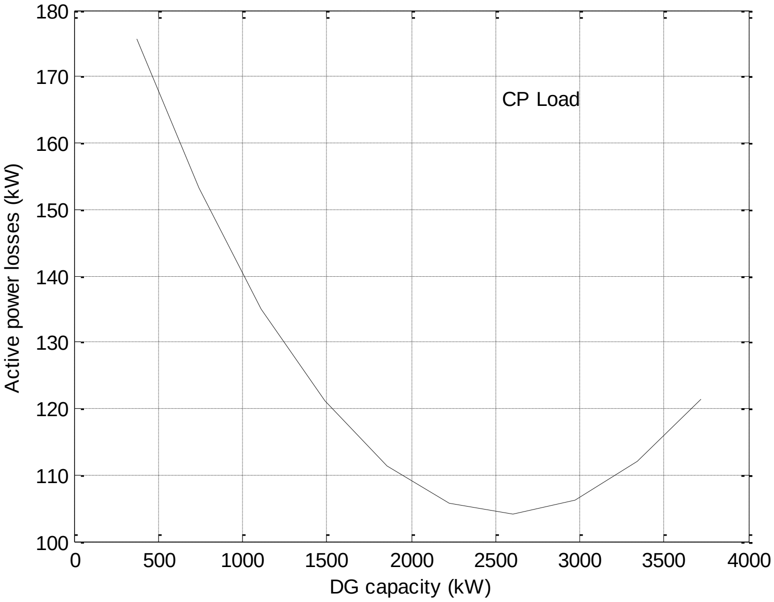

Fig 3: Active power losses versus DG capacity for 33 node network for constant power (CP) type of load when DG is placed at node 6.

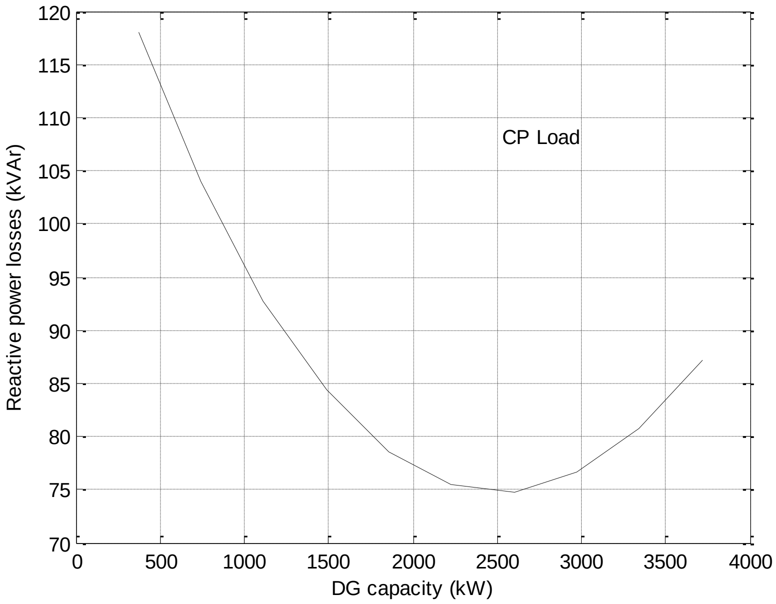

Fig 4: Reactive power losses versus DG capacity for 33 node network for constant power (CP) type of load when DG is placed at node 6.

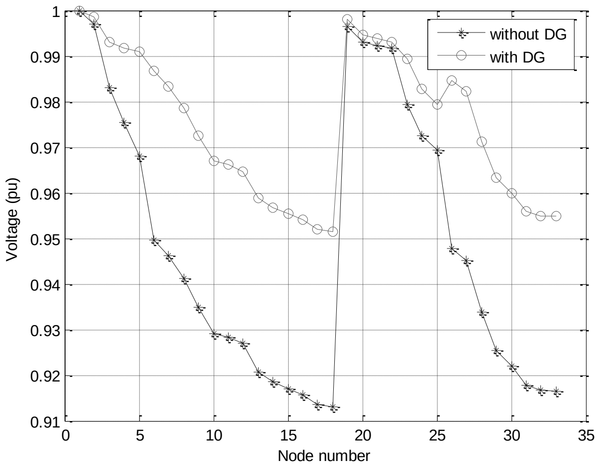

Fig 5: Voltage magnitude versus node number for 33 node network for constant power (CP) type of load when DG is placed at node 6.

Case B: Constant Current (CI) Load

Run the load flow program and record active power loss, reactive power loss and minimum voltage profile. In nominal loading condition, the active power loss is 176.9 kW and reactive loss is 117.4 kVAr. Under this condition, the minimum system voltage is 0.9193 pu.

Now we insert unity power factor DG in the existing 33-node system. DG is placed at each node and optimal size of DG is calculated. Figure 6 shows active power losses of 33 node system after inserting 2600.5 kW DG at each node individually. From Figure 6, we noticed that active power losses are minimum if we place 2600.5 kW DG at node 6 using distflow technique. Now, active power loss is 97.2 kW and reactive power loss is 69.9 kVAr if we place 2600.5 kW unity power factor DG at node 6. Under this condition, the minimum system voltage is 0.9540 pu.

Figure 7 shows active power losses versus DG capacity for 33 node network when DG is placed at node 6. Figure 8 shows reactive power losses versus DG capacity for 33 node networks when DG is placed at node 6.

From Figures 7 and 8, it is clear that if DG capacity increases, the overall system losses are decreasing in nature up to certain value. If DG capacity still increases, then losses begin to increase. At higher DG capacity, losses can become larger than those without DG connected.

Figure 9 shows voltage magnitude versus node number for 33 node network when DG is placed at node 6. From Figure 9, it is seen that the voltage profile has improved after inserting DGs at node 6.

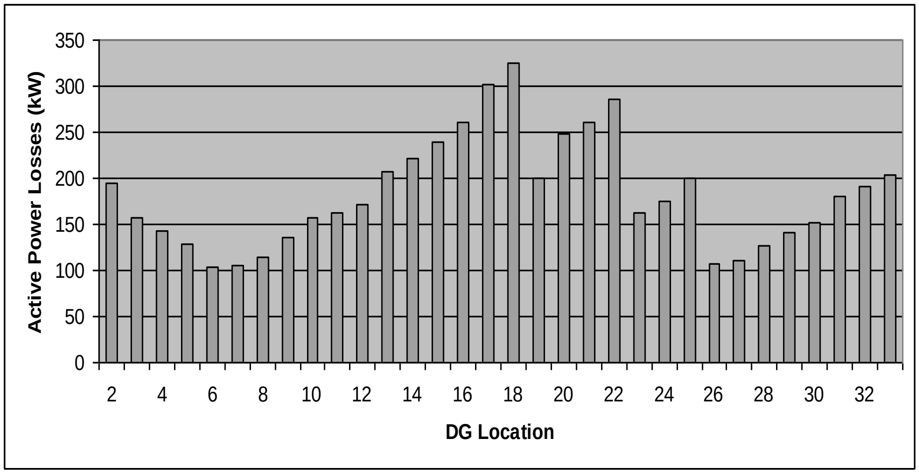

Fig 6: Active power losses of 33 node system after inserting 2600.5 kW DG at each node individually for constant current (CI) type of load.

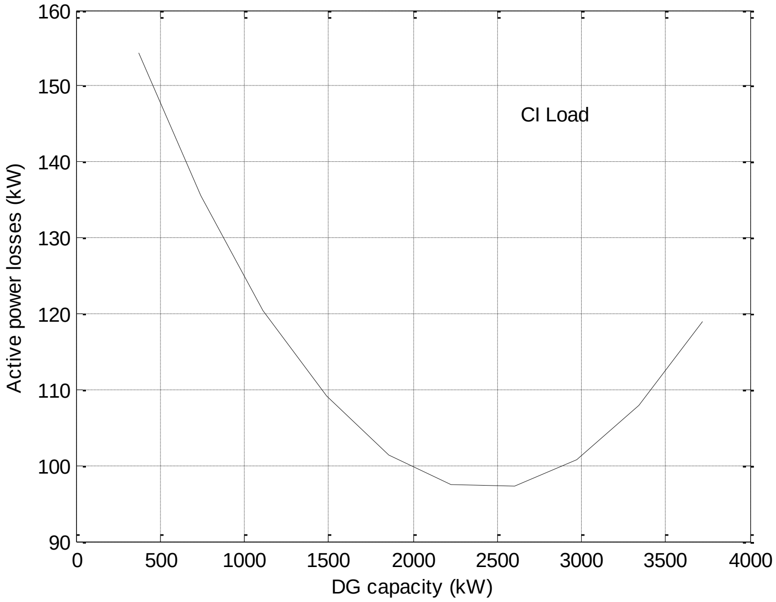

Fig 7: Active power losses versus DG capacity for 33 node network for constant current (CI) type of load when DG is placed at node 6.

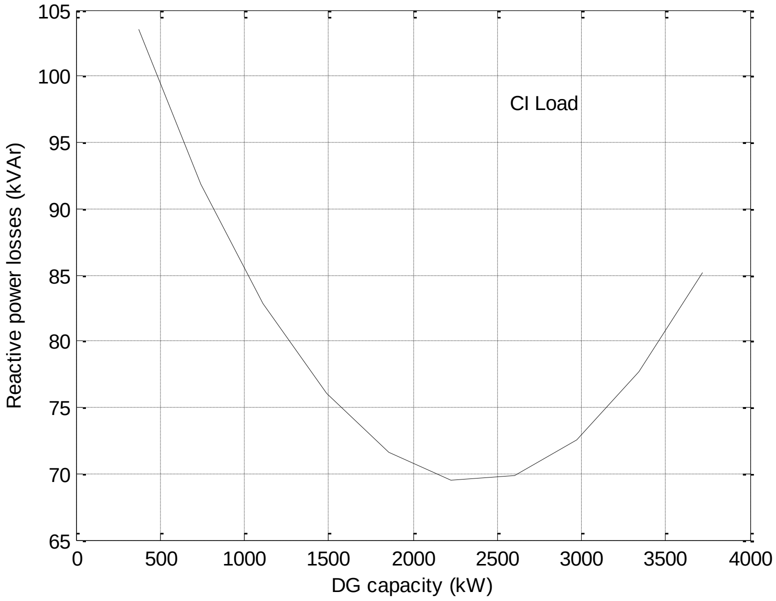

Fig 8: Reactive power losses versus DG capacity for 33 node network for constant current (CI) type of load when DG is placed at node 6.

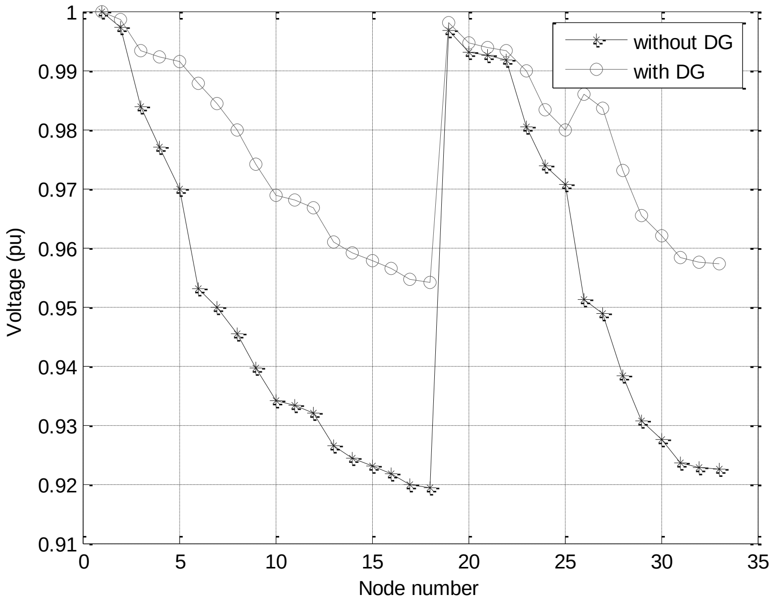

Fig 9: Voltage magnitude versus node number for 33 node network for constant current (CI) type of load when DG is placed at node 6.

Case C: Constant Impedance (CZ) Load

Run the load flow program and record active power loss, reactive power loss and minimum voltage profile. In nominal loading condition, the active power loss is 157.1 kW and reactive loss is 104.0 kVAr. Under this condition, the minimum system voltage is 0.9244 pu.

Now we insert unity power factor DG in the existing 33-node system. DG is placed at each node and optimal size of DG is calculated. Figure 10 shows active power losses of 33 node system after inserting 2229.0 kW DG at each node individually. From Figure 10, we noticed that active power losses are minimum if we place 2229.0 kW DG at node 6 using distflow technique. Now, active power loss is 90.6 kW and reactive power loss is 64.7 kVAr if we place 2229.0 kW unity power factor DG at node 6. Under this condition, the minimum system voltage is 0.9516 pu.

Figure 11 shows active power losses versus DG capacity for 33 node network when DG is placed at node 6. Figure 12 shows reactive power losses versus DG capacity for 33 node networks when DG is placed at node 6.

From Figures 11 and 12, it is clear that if DG capacity increases, the overall system losses are decreasing in nature up to certain value. If DG capacity still increases, then losses begin to increase. At higher DG capacity, losses can become larger than those without DG connected.

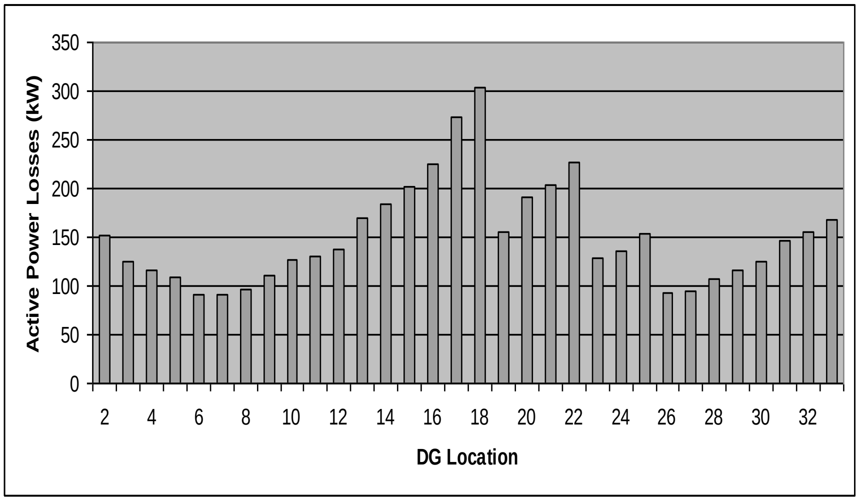

Fig 10: Active power losses of 33 node system after inserting 2600.5 kW DG at each node individually for constant impedance (CZ) type of load.

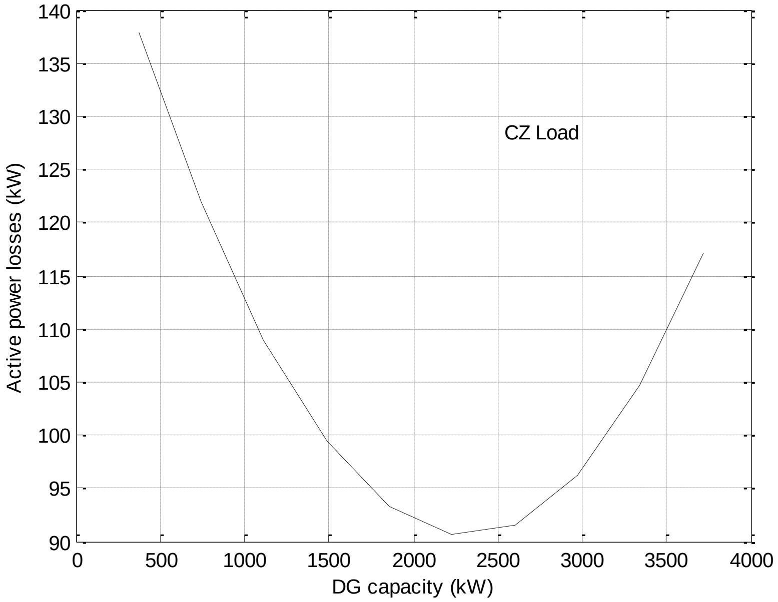

Fig 11: Active power losses versus DG capacity for 33 node network for constant impedance (CZ) type of load when DG is placed at node 6.

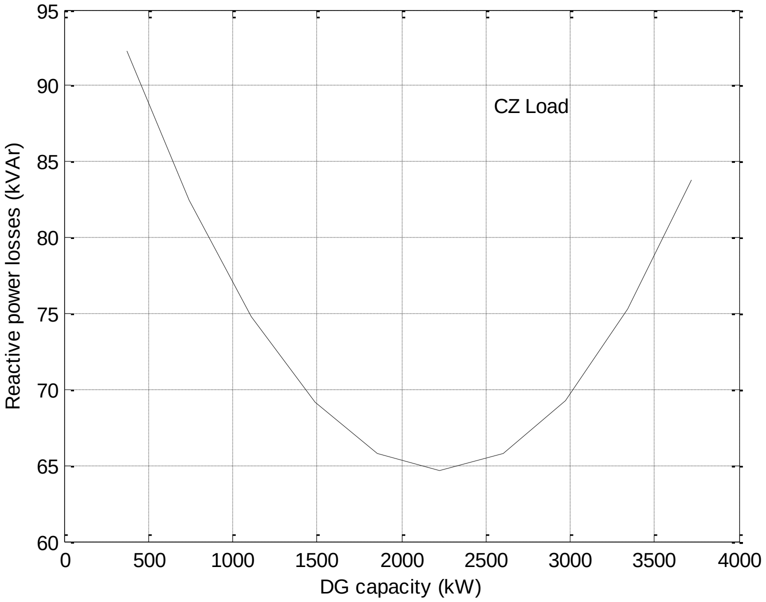

Fig 12: Reactive power losses versus DG capacity for 33 node network for constant impedance (CZ) type of load when DG is placed at node 6.

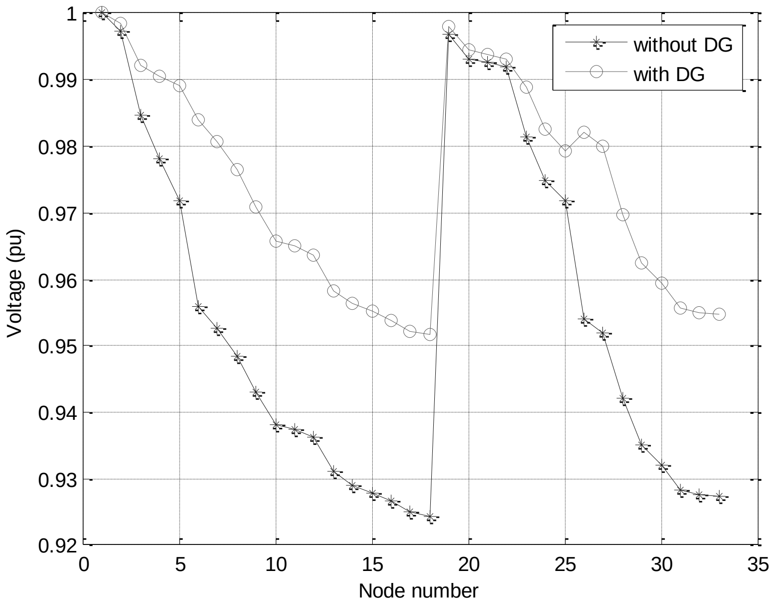

Fig 13: Voltage magnitude versus node number for 33 node network for constant impedance (CZ) type of load when DG is placed at node 6.

Figure 13 shows voltage magnitude versus node number for 33 node network when DG is placed at node 6. From Figure 13, it is seen that the voltage profile has improved after inserting DGs at node 6.

Case D: Composite Load

Run the load flow program and record active power loss, reactive power loss and minimum voltage profile. In nominal loading condition, the active power loss is 179.8 kW and reactive loss is 119.3 kVAr. Under this condition, the minimum system voltage is 0.9186 pu.

Now we insert unity power factor DG in the existing 33-node system. DG is placed at each node and optimal size of DG is calculated. Figure 14 shows active power losses of 33 node system after inserting 2600.5 kW DG at each node individually. From Figure 14, we noticed that active power losses are minimum if we place 2600.5 kW DG at node 6 using distflow technique. Now, active power loss is 98.0 kW and reactive power loss is 70.4 kVAr if we place 2600.5 kW unity power factor DG at node 6. Under this condition, the minimum system voltage is 0.9537 pu.

Figure 15 shows active power losses versus DG capacity for 33 node network when DG is placed at node 6. Figure 16 shows reactive power losses versus DG capacity for 33 node networks when DG is placed at node 6.

From Figures 15 and 16, it is clear that if DG capacity increases, the overall system losses are decreasing in nature up to certain value. If DG capacity still increases, then losses begin to increase. At higher DG capacity, losses can become larger than those without DG connected.

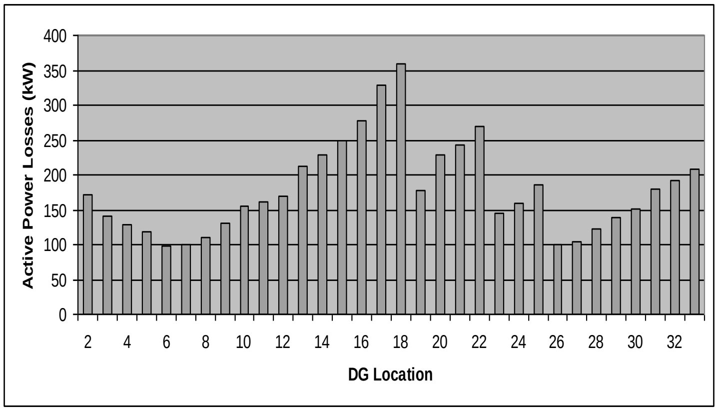

Fig 14: Active power losses of 33 node system after inserting 2600.5 kW DG at each node individually for composite type of load.

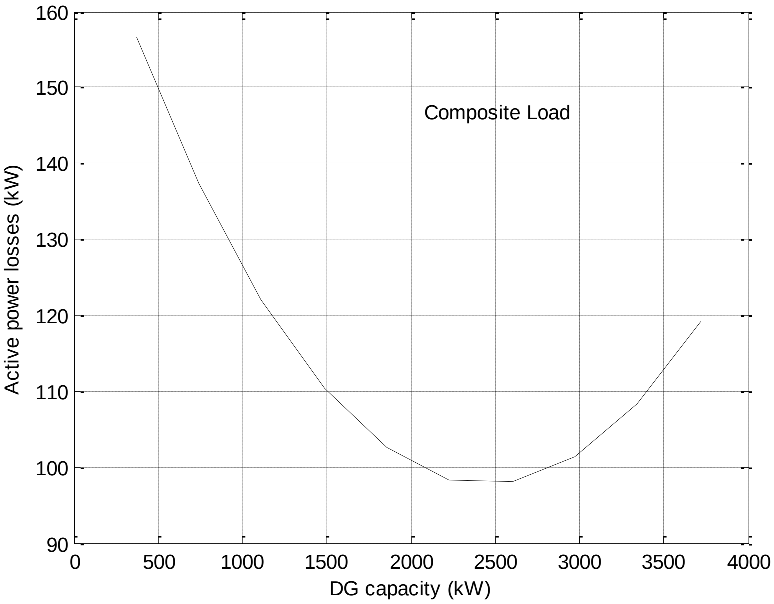

Fig 15: Active power losses versus DG capacity for 33 node network for composite type of load when DG is placed at node 6.

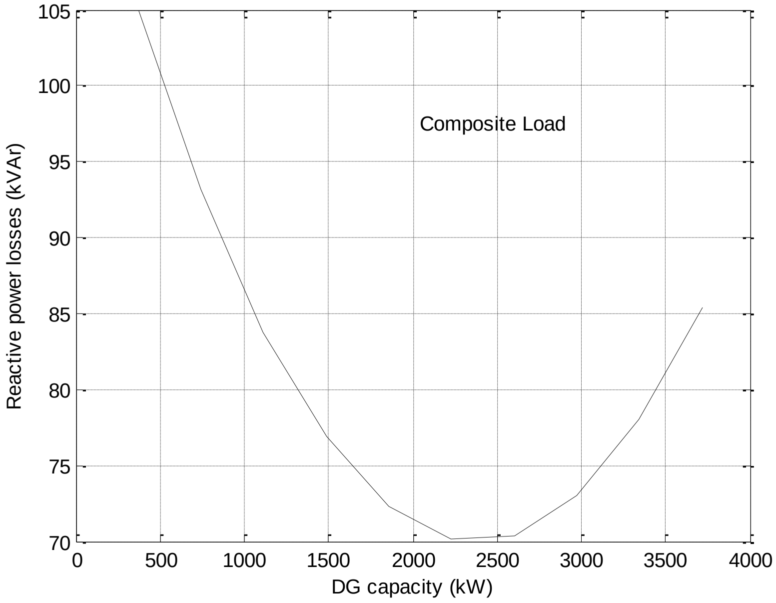

Fig 16: Reactive power losses versus DG capacity for 33 node network for composite type of load when DG is placed at node 6.

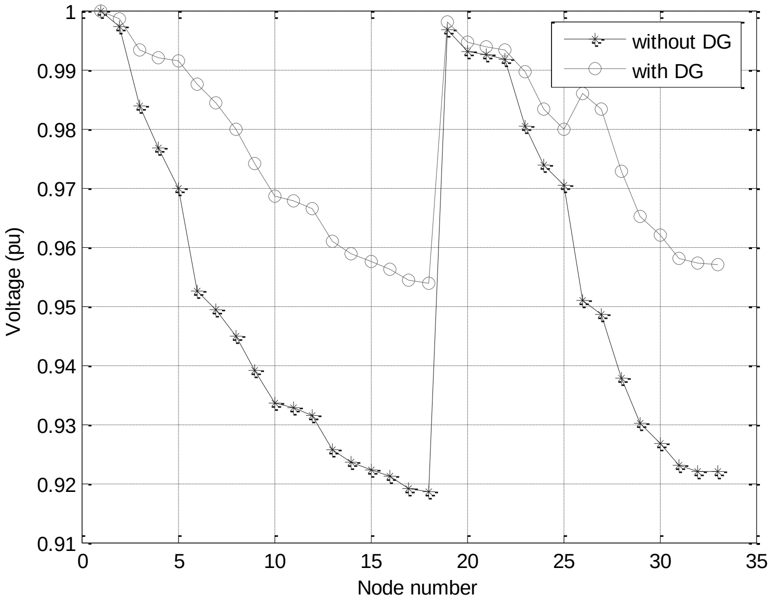

Fig 17: Voltage magnitude versus node number for 33 node network for composite type of load when DG is placed at node 6.

Figure 17 shows voltage magnitude versus node number for 33 node network when DG is placed at node 6. From Figure 17, it is seen that the voltage profile has improved after inserting DGs at node 6.

Conclusion

The paper presents the different capacity of DG at various nodes using distflow techniques for constant power, constant current, constant impedance and composite types of loads. The node at which total active power losses is minimum is considered to be the optimum location and size of DG placement for loads of different types. Analysis also reveals that with the insertion of DGs, there is a significant reduction of power loss in the distribution network. The effectiveness of the proposed idea has been successfully tested on 12.66 kV radial distribution systems consisting of 33 nodes and the results are found to be in very good agreement.

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APPENDIX

Table I: Line data and nominal load data of 33 node radial distribution system.

Line No.	From Bus	To Bus	Branch resistance (ohm)	Branch reactance (ohm)	Load at Receiving end node	
					PL_0 (kW)	QL_0(kVAr)
1	1	2	0.0922	0.0477	100.0	60.0
2	2	3	0.4930	0.2511	90.0	40.0
3	3	4	0.3660	0.1840	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7000	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.0300	0.7400	60	20

9	9	10	1.0400	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	90	40
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600

30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40