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Distributed Generation Allocation and Sizing in different Radial Distribution Test System using Voltage Stability Index

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Abstract—*The distributed generation (DG) is the best alternative to fulfill the soaring demand of electrical energy. The placement of DG in existing electrical network impart significant impact on operational characteristics of network system. This paper presents a load flow based methodology to find the optimum allocation of DG in IEEE 33 and IEEE 69 bus test configuration. The Voltage stability index based approach for optimum multi-DG (distributed generation) placement and sizing based on voltage improvement and reduction in power loss.. The proposed method is tested on standard 33 and 69bus test systems. This paper will also show the effectiveness of the proposed method in terms of reduction in power system losses and voltage quality improvement.*

1. INTRODUCTION

Distributed generation, also referred to as dispersed generation is a small scale generation being used to meet the ever increasing demand of electricity. Distributed energy is generated by small grid connected generators known as distributed energy resources (DER). Conventional power plants such as thermal, nuclear, hydro power plants are centralized whereas distributed generation resources are decentralized, located near to the load centers. Distributed generation prominently uses renewable resources such as solar power, wind energy, biomass, small hydro and photovoltaic systems. Various other technologies may also be adopted in distributed generation such as fuel cells battery, micro turbines, small gas turbines and reciprocating engines [1-3].

The optimal placement and sizing of DGs in the distribution network based on different objectives have been reported in the literature. Several researchers did work in this area which is given as follow. An analytical technique based on exact loss formula is discussed in [5]. A loss sensitivity based method has been discussed in [6]. A multi-objective optimization approach for maximizing voltage profile in a deregulated electricity market has been discussed in [7]. A grid search algorithm to attain the optimal position and capacity of multiple DG units in the radial distributed system network is presented in [8]. An optimization technique based on weighting factor which stabilizes the cost and loss factors has been demonstrated in [9]. A Genetic Algorithm (GA) based methodology for optimal allocation and capacity of DG has been presented in [10]. A combination of Particle Swarm Optimization (PSO) and clonal algorithm has been suggested in [11]. A PSO and sensitivity analysis based method for deducing the best location and size of DG in order to mitigate the real power losses and total harmonic distortions (THD) has been presented in [12]. The optimal placement of DG can reduce system losses, installation costs and lead to better voltage profile.

In this paper work, a voltage stability index (VSI) technique is used for optimal placement of DG in radial distribution systems. After identifying the optimal bus allocation for DG placement, the search technique is used to determine optimal size of DG to minimize total power loss. In this paper, operation of the DG at unity, 0.9 lagging and combined load power factors are considered. Voltage stability margin (VSM) values are computed for distribution network with and without installation of DGs. The cost of energy loss, cost of loss savings and cost of power supplied from DGs are also calculated and comparison has been provided. The results have been obtained on IEEE-33 and IEEE-69 bus systems.

2. DG IMPACT ON VOLTAGE PROFILE AND SYSTEM LOSSES

A. Voltage profile improvement

Optimal location of DG source in a distribution network is a very critical factor in the operation of the active power system network. In distributed network feeder system the voltage levels drop along the length of the feeder. Improper placement of DG along the feeder may induce the voltage to rise above the voltage limit. The installation of DG at improper location may result in sudden voltage rise in the system. Voltage rise above the voltage limit may be reduced by restricting the size of DG source, controlling the reactive power, regulating the node voltages and by placing the DG being used as a voltage control device at an optimum location.

B. Minimization of real and reactive power losses of the system

Optimum allocation of DG impart the positive impact on electrical losses of the system. Power losses are mainly divided into two categories, first one is real power losses and the other is reactive power losses. Real power losses occur due to resistance of the lines whereas the reactive power losses are caused by the reactive elements in the system. Real power losses draw more attention than reactive losses as the real losses lessen the overall efficiency of the system. However, reactive power losses are not less important. Reactive power flow in the system maintains a certain voltage level of the system. System losses can be reduced significantly by proper allocation of DG unit in the system [13].

3. VOLTAGE STABILITY MARGIN (VSM)

Due to economic, voltage and power constraints power systems are being operated closer to their stability limits. So stable and secure operation of a power system is therefore a very major and challenging issue. Voltage instability results because of inability of the system to provide the power requested by loads. The voltage stability margin is a parameter that determines the near fatigue buses. The bus with small stability indices are called weak nodes and then should be reinforced by injecting reactive power. In the present analysis voltage stability margin is calculated for time variant realistic ZIP load model. The impact of DG on voltage stability improvement has also determined. The optimal location of DG in distribution network, will increase the bus voltages and voltage security.

Voltage stability margin is determined for each bus using Eq. (1) and the bus with minimum VSM is determined. VSM of each bus is a number between 0 and 1.

$$VSM\big(re(i)\big) = V\big(se(i)\big)^4 - 4[P(i)x(i) - Q(i)r(i)]^2 - 4[V(se(i))^2(P(i)r(i) + Q(i)x(i)]$$

for i =1,2,3….Nb (1)

Where P is the sum of the real power loads of all the nodes beyond each bus, plus the real power load at each node itself, plus the sum of real power losses of all branches beyond each node. Q is the sum of the reactive power loads of all the nodes beyond each node, plus the reactive power load at each node itself, plus the sum of reactive power losses of all branches beyond each node.

In this study the above simple stability criterion, given in eq.1, is used to find the stability index for each line receiving end bus in radial distribution networks. After the load flow study, the voltages of all nodes and the branch currents are known, therefore P and Q at the receiving end of each line can easily be calculated and hence using eq. 5 the voltage stability index of each node can easily be calculated. The node, at which the value of the stability index is at minimum is the most sensitive to the voltage collapse

4. RESULT AND DISCUSSION

Based on the proposed VSI approach, DGs are placed for voltage profile improvement and to reduce total power losses. The results for IEEE 33-bus, IEEE-69 test systems have been obtained for voltage profile, total power losses, voltage stability margin profile, real and reactive power flow patterns without and with installation of DGs.

(I) IEEE 33 bus test system

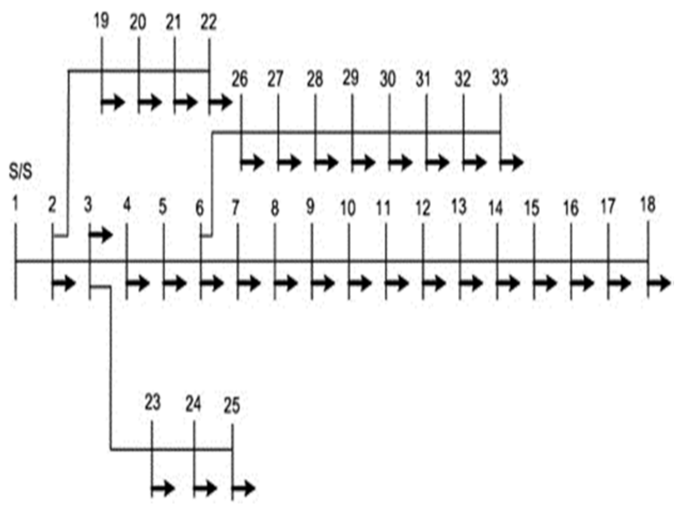

Figure 1 Single line diagram of 33 bus system

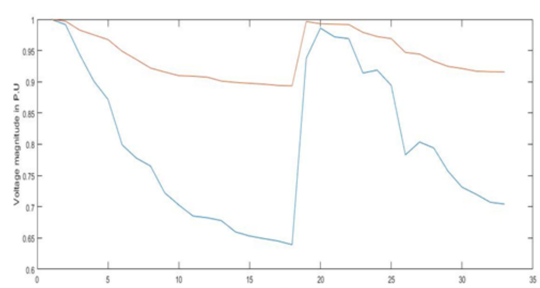

Figure 2 VSM profile with single DG in IEEE 33 bus system

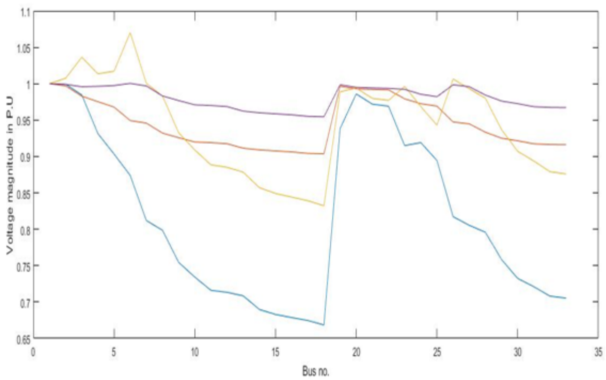

Figure 3 VSM profile with multiple DG for IEEE 33 bus system

As we see from above figure2 which show the case with single DG placement and figure3 show the multiple DG placement for VSM profile improvement. The placement of DG has been done at bus no. 17 because the voltage magnitude is very low there. So for improving the voltage profile the DG is placed where there is large drop in the system.

Table 1 Results with installation of DG at optimal location for 33 bus system

Total real power demand	3715.0000
Total reactive power demand	2295.000
Minimum voltage and bus	0.9036 and 17
Minimum voltage with DG and bus	0.9546 and 17
Minimum stability index and bus	0.6686 and 17
Minimum stability index1 and bus	0.8323 and 17
Total real power with 1 DG placement	3016.533
Total real power with 2 DG placement	2564.070
Total real power loss base case in PU	0.503
Total real power loss index with 1_dg placement case	0.178
Total index power loss with 2_dg placement case	0.134

Table 2 Results for Voltage at various bus and Stability in PU

Bus no.	V bus in PU	Stability index in PU
1	1.0000	1.0000
2	0.9991	1.0075
3	0.9958	1.0363
4	0.9964	1.0135
5	0.9974	1.0172
6	1.0004	1.0701
7	0.9969	1.0005
8	0.9832	0.9830
9	0.9768	0.9326
10	0.9709	0.9089
11	0.9701	0.8885
12	0.9685	0.8851
13	0.9623	0.8785
14	0.9600	0.8572
15	0.9586	0.8492
16	0.9572	0.8442
17	0.9552	0.8392
18	0.9546	0.8323
19	0.9985	0.9888
20	0.9949	0.9940
21	0.9942	0.9799
22	0.9936	0.9771
23	0.9922	0.9963
24	0.9855	0.9686
25	0.9822	0.9430
26	0.9985	1.0065
27	0.9959	0.9931
28	0.9844	0.9801
29	0.9761	0.9369
30	0.9726	0.9071
31	0.9684	0.8938
32	0.9674	0.8792
33	0.9672	0.8760

(II) IEEE 69 bus system

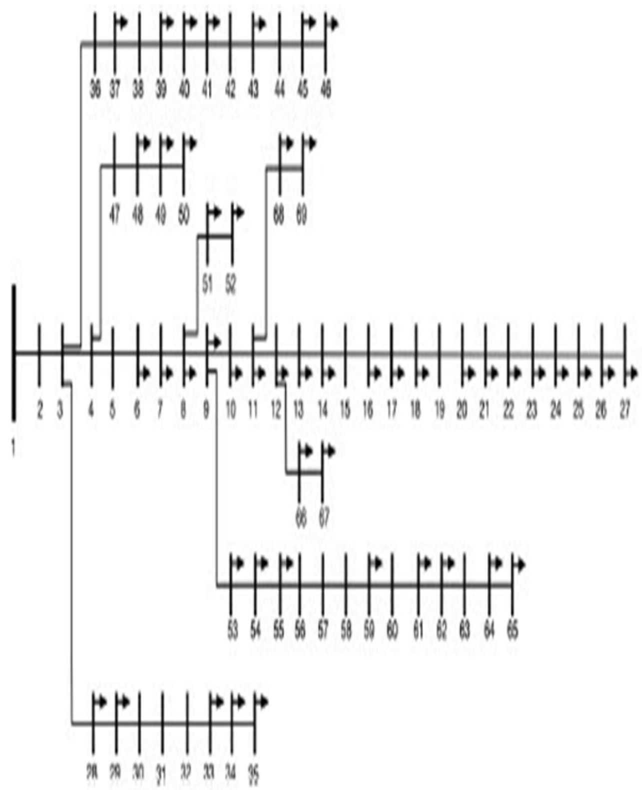

Figure 4 Single line diagram for IEEE 69 bus system

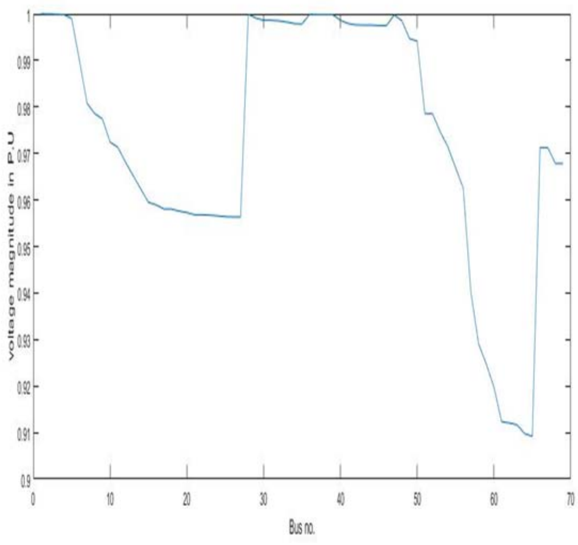

Figure 5 VSM profile without DG for IEEE 69 bus system

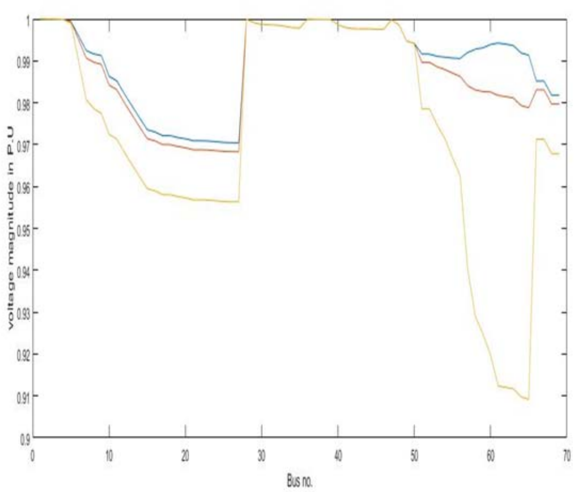

Figure 6 VSM profile with multiple DG for IEEE 69 bus system

The above result of VSM profile for 69 bus system with and without DG shown in the figure 5 and figure 6. As we see from above figure that the VSM profile at bus 61 is very low. So the placement of DG has been done at bus no.61 for voltage profile improvement and for reduction of losses.

Table 3 Results of power flow With and Without DG allocation

Total real power loss(KW)	224.8688
Total reactive power loss(Kvar)	102.1044
Total real power loss(KW) with DG	83.13942
Total reactive power loss(Kvar)with DG	40.50004
Minimum bus voltage	0.909202
Minimum VSI	0.68335
Total load Power (KW)	3801.39
Total load reactive power (Kvar)	2693.6
Location of DG	61
Minimum bus voltage with DG	0.968675
Minimum VSI with DG	0.86585

Table 4 Results of voltage magnitude and stability index in PU

Bus no.	V bus in PU	Stability index in PU
1	1.0000	1.0000
2	1.0000	1.0000
3	0.9999	1.0000
4	0.9998	1.0000
5	0.9990	0.9994
6	0.9901	0.9938
7	0.9808	0.9588
8	0.9786	0.9248
9	0.9774	0.9167
10	0.9724	0.9124
11	0.9713	0.8940
12	0.9682	0.8898
13	0.9653	0.8783
14	0.9624	0.8677
15	0.9595	0.8573
16	0.9581	0.8471
17	0.9581	0.8452
18	0.9576	0.8421
19	0.9573	0.8421
20	0.9568	0.8405
21	0.9568	0.8394
22	0.9568	0.8377
23	0.9567	0.8377
24	0.9566	0.8374
25	0.9564	0.8369
26	0.9563	0.8363
27	0.9563	0.8360
28	0.9999	0.9996
29	0.9991	0.9998
30	0.9986	0.9965
31	0.9986	0.9946
32	0.9985	0.9946
33	0.9983	0.9941
34	0.9979	0.9931
35	0.9979	0.9918
36	0.9999	0.9996
37	0.9999	0.9998
38	0.9998	0.9996
39	0.9998	0.9995
40	0.9986	0.9948
41	0.9979	0.9946
42	0.9976	0.9918
43	0.9976	0.9907
44	0.9976	0.9905
45	0.9975	0.9905
46	0.9975	0.9901
47	0.9998	0.9973
48	0.9985	1.0082
49	0.9974	1.0329
50	0.9942	1.0261
51	0.9785	0.9127

52	0.9785	0.9168
53	0.9747	0.9353
54	0.9714	0.9015
55	0.9669	0.8893
56	0.9626	0.8730
57	0.9401	0.8534
58	0.9290	0.7797
59	0.9248	0.7445
60	0.9197	0.7310
61	0.9123	0.7152
62	0.9121	0.6926
63	0.9117	0.6917
64	0.9098	0.6905
65	0.9092	0.6848
66	0.9713	0.8791
67	0.9713	0.8898
68	0.9678	0.8694
69	0.9678	0.8772

5. CONCLUSIONS

This paper presents a voltage profile improvement and stability index for optimal DG allocation in radial distribution test system for IEEE 33 and 69 bus system. From above results we see that by the optimal placement of DG the improvement in voltage profile and reduction in power losses take place. The results have been obtained with and without consideration of DG for real and reactive power losses, voltage profile, voltage stability margin profile, real and reactive power flow patterns. It can be conclude that there is much reduction in real, reactive power losses, and improvement in voltage profile with DG at lagging power factor due to its reactive power supply to the system. Results show that the proposed index is robust and can provide useful information for the most sensitive bus to the voltage collapse at any operating point of radial networks. The Voltage profile and stability index is giving better results for both the above mentioned configurations.

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