Optimal Distributed Generation Sizing and Placement Via Single-Objective Optimization Approach

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Abstract : Installing DG in an electrical distribution system has numerous positive impacts, but these impacts can be further enhanced if the DG units are installed at a proper place and in a proper size. Non optimal placement and sizing of DG units can cause significant negative repercussions on distribution systems. In this paper, the optimal DG placement (or siting) and sizing problem is investigated using a single objective function that is subjected to equality and inequality constraint equations. The optimal DG size problem is handled via the SQP deterministic method and by performing this method at all candidate buses. The bus with a minimum DG size will be selected as the optimal location to install the DG. The proposed technique succeeds in solving single and multiple DG installations for standard ieee 33 bus radial distribution systems.

IndexTerms - Distributed Generation, single objective function, optimal placement, system performance.

I. INTRODUCTION

The term Distributed Generation, or DG, refers to the use of small-scale electric power generators dispersed within the distribution network level, whether located on the utility system near customers or at an isolated site not connected to the power grid [1]. The efficiency of DG technologies is high, e.g. 40 to 55% for fuel cells, compared to 28 to 35% for traditional large central power generators [5].

Various DG technologies are involved in power systems. Some of these technologies have been in use for a long time while others are newly emerging. Nonetheless, the features that all DG technologies have in common are to increase efficiency and decrease costs related to installation, running and maintenance. DG technologies are loosely categorized into two types: renewable technologies (e.g., photovoltaic and wind turbine) and non-renewable technologies (e.g., mini and micro-turbines, combustion turbines and fuel cells). DG technologies have a significant impact on the selection of the appropriate size and place of a DG unit to be connected to a grid or customer loads. The following sections provide details on the most popular DG technologies currently in the market.

Solution techniques for DG deployment can be obtained via optimization methods in order to maximize DG benefits. Several optimization techniques have been presented by researchers in determining the optimal location and size of DG. Such optimization methods can be classified into deterministic methods such as analytical and SQP methods and heuristic methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), etc., or into single- and multi-objective, based on the number of objectives. The major objective of DG placement techniques used in the literature is to minimize power system losses. However, other objectives, like improving the voltage profile and reliability and maximizing DG capacity and cost minimization have also been considered.

Numerous advantages attained by integrating Distributed Generation (DG) in distribution systems. These advantages include decreasing power losses and improving voltage profiles. Such benefits can be achieved and enhanced if DGs are optimally sized and located in the systems.

II. PROBLEM OBJECTIVE

The objective function to be minimized to solve the optimization problem is the total active power loss of a distribution system.

Minimize Ploss (x)

The equation of the real and reactive power losses in the system can be given in terms of exact loss formula as state below

The power loss is given by

$$P_L = \sum_{i=1,j=1}^{n} [\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Where $\alpha_{ij} = \frac{r_{ij}}{V_iV_j} Cos(\partial_i - \partial_j)$ and $\beta_{ij} = \frac{r_{ij}}{V_iV_j} Sin(\partial_i - \partial_j)$

Where

Vi - Voltage magnitude at bus i

Vj - Magnitude of voltage at bus j

Vmin and Vmax are the minimum and maximum voltage limits respectively.

P_L and Q_L are active and reactive power losses

P_i and Q_i are the active and reactive powers at bus i

P_j and Q_j are the active and reactive powers at bus j.

∂_i, ∂_j voltage angle at bus *i* and bus *j*.

The SQP solution method is proposed for the nonlinear DG sizing problem. The technique involves successive iterations of approximating the Lagrangian function by a Quadratic Programming (QP) subproblem. The QP solution is employed in developing a search direction for the line search process which in turn leads to a better approximation [15]. Among other methods SQP uses Newton's iterations in dealing with nonlinear equations. Most general purpose optimization commercial software utilizes the SQP technique in solving nonlinear constrained optimization problems [16], and Matlab® is no exception

A voltage deviation index was calculated in all tests and cases to show improvements in the voltage profiles. The voltage deviation is mathematically formulated as follows

$$VD\% = (\sum_{i=1}^{NB}(V_{ref} - V_i) \div NB) \times 100$$

where *Vref* is the voltage reference (*Vref* = 1 *p.u.*),

The assumption made in the test is that all available DGs are of 4 MW capacities with a 0.85 power factor, and that the bus voltages are to be maintained within ±10% of the nominal voltage throughout the optimization process.

III. CONSTRAINTS

The objective function is minimized subject to various operational constraints to satisfy the electrical requirements for the distribution network and constraints on DG operation.

Power Balance Constraints*:* Power balance is given by nonlinear power flow equations, which state that the sum of complex power flows at each bus in the distribution system injected into a bus minus the power flows extracted from the bus should equal zero.

$P_{DGi} - P_{di} - Pl_{oss} = 0$

Generation Capacity Constraints*:* Limiting the DG size so as not to exceed the power supplied by the substation and the output power of each DG unit is constrained by lower and upper limits.

$P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max}$

where P_{DGi}^{min} and P_{DGi}^{max} are the minimum and maximum operating outputs of unit *i*, respectively.

Voltage constraints : The voltage at the nodes should be within the limits

$$V\,min \leq |Vi| \leq V\,max$$

IV. RESULTS AND DISCUSSION

The presented technique is tested on the standard IEEE 33 bus test system using MATLAB simulation. The results obtained are discussed.

IEEE 33 Bus test system

IEEE 33 bus distribution system was used to investigate the proposed optimization problem in finding the optimal DG size and place. The 33-bus meshed distribution system is a 12.66 kV voltage level and has 33 bus and 37 branches. The total active and reactive loads are 3715 kW and 2300 kvar, respectively. The corresponding single line of the distribution system is shown in Figure . The optimization problem was solved for single and Two DG installations.

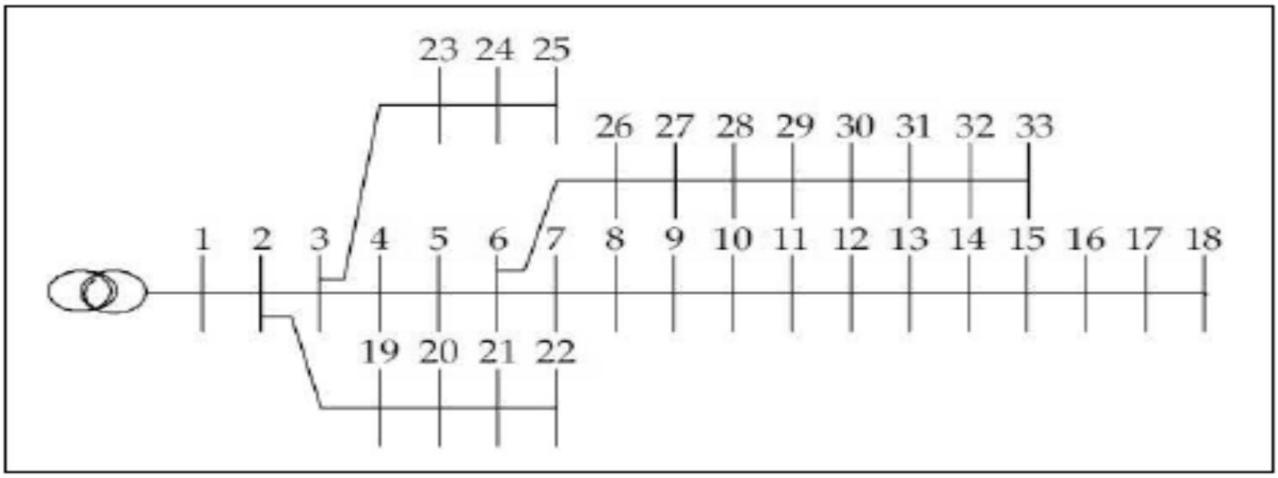

Figure 1: IEEE33 bus test system

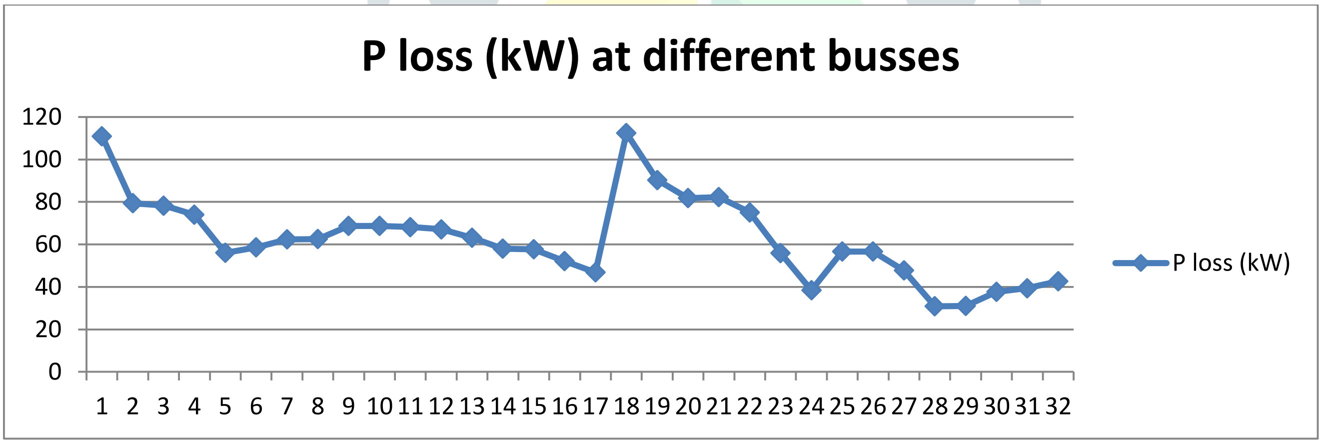

Fig.2: Power loss profiles of the system when different capacities of DGs are installed at different buses

bus with DG	DG size (kW)	P loss (kW)	Losses reduction%	VD %
2	3711.208	110.94	10.068	2.8
3	3006.457	79.382	35.65	2.075
4	2446.301	78.283	36.541	2.014
5	2247.294	74.005	40.009	1.884
6	2320.597	56.086	54.535	1.35
7	2207.223	58.638	52.466	1.361
8	1959.784	62.382	49.431	1.316
9	1773.961	62.564	49.283	1.249
10	1584.946	68.674	44.331	1.384
11	1586.072	68.693	44.315	1.38
12	1612.039	68.204	44.711	1.361
13	1492.105	67.157	45.56	1.359
14	1555.862	63.139	48.817	1.253
15	1670.43	57.997	52.986	1.117
16	1599.876	57.7	53.226	1.155
17	1616.504	52.098	57.767	1.104
18	1690.069	46.871	62.005	1.037
19	2236.962	112.415	8.872	2.788
20	1688.086	90.315	26.788	2.101
21	1775.509	81.825	33.669	1.831
22	1538.33	82.292	33.291	1.811
23	2406.231	75.128	39.098	2.017
24	2227.792	55.917	54.671	1.654
25	2283.963	38.425	68.851	1.23
26	2217.459	56.624	54.099	1.377
27	2119.876	56.62	54.102	1.401
28	2093.641	47.743	61.298	1.269
29	2357.809	30.889	74.96	0.966
30	2160.214	31.076	74.809	0.979
31	1884.635	37.653	69.477	0.98
32	1828.466	39.395	68.065	0.974
33	1763.651	42.671	65.409	0.992

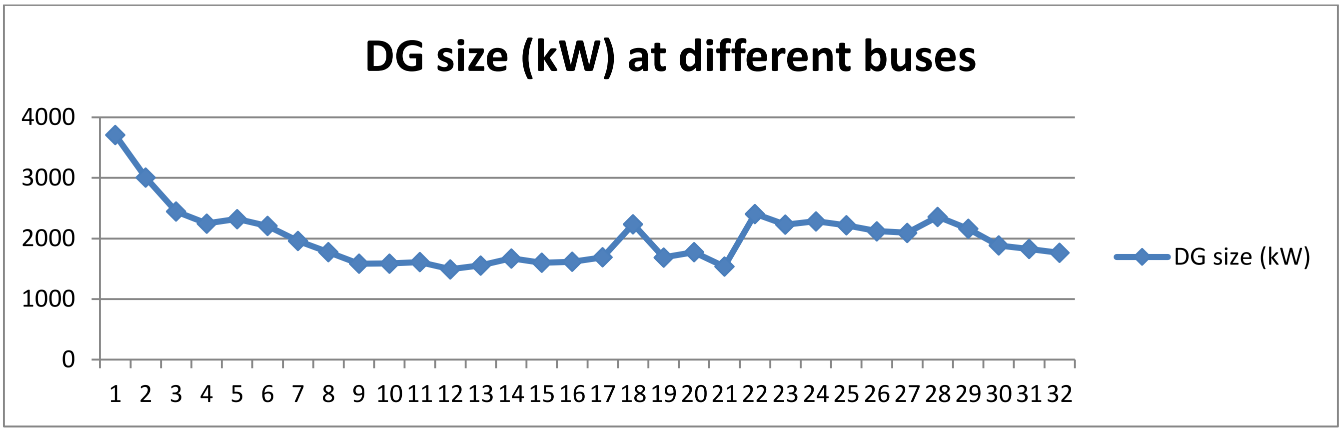

Fig.:3 Different capacities of DGs at different buses of the test system

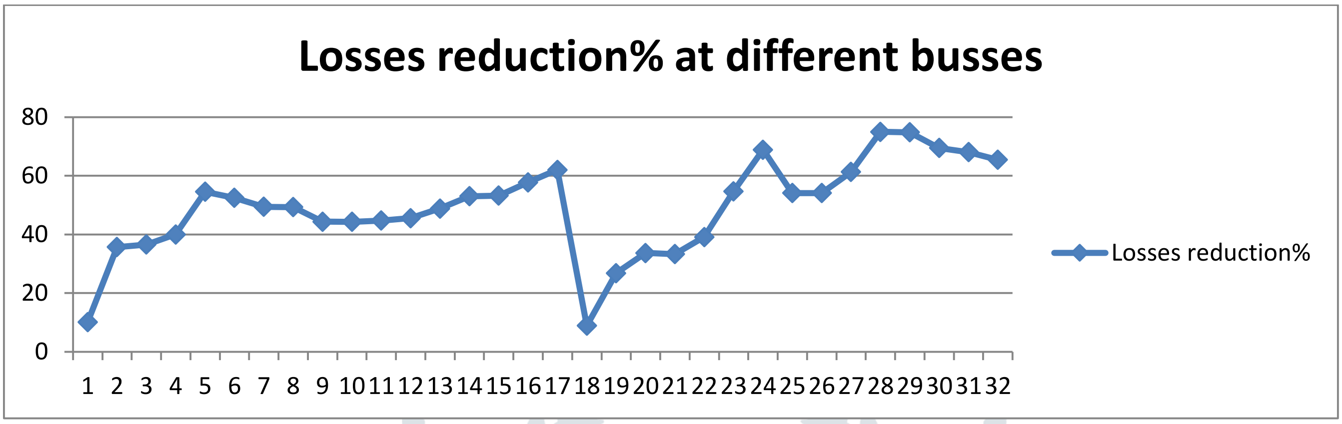

Fig.4: Power loss reduction profiles of the system when different capacities of DGs are installed at different buses

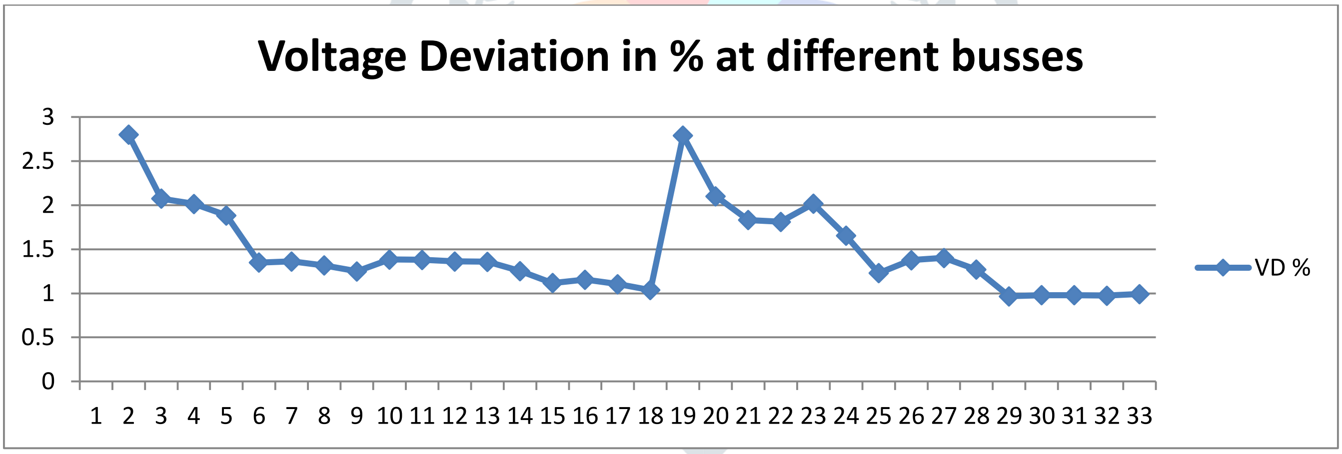

Fig.5: Voltage deviation at different buses of the system when different capacities of DGs are installed at different buses

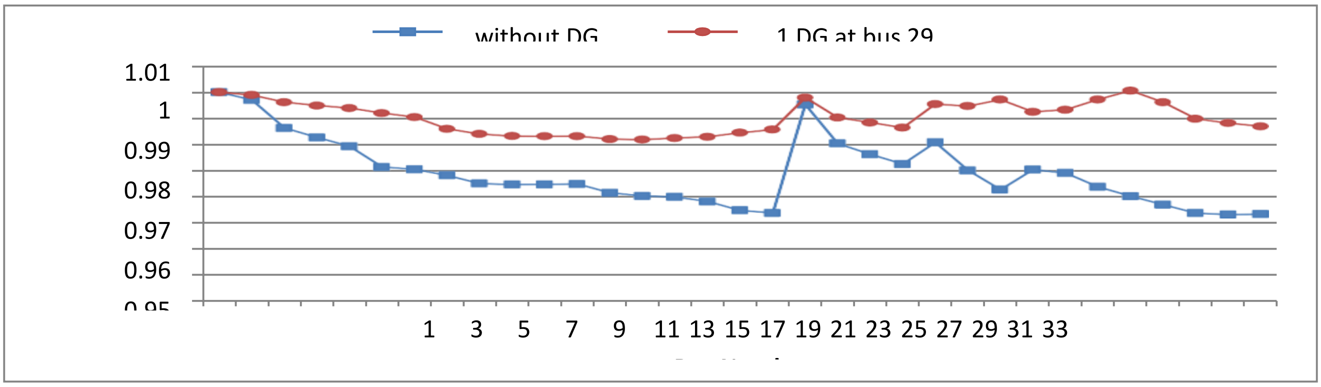

Fig.6: Voltage **profiles of** the system at different buses with DG at bus 29 and without **DG.**

Installing Two DGs

Here all combinations for installing two DGs were examined. Table 2 shows the best ten solutions for optimal DG size and placement. Installing two DG units at 15 with an output of 919.063 kW and at 29 with an output of 1831.496 kW caused a reduction in the total real power system to a minimum value. This value, as shown in the mentioned table, is 15.673 kW, which signifies an 87.295% reduction in the system's losses compared to original losses. Moreover, a significant improvement in the voltage profile occurred, as shown Figure , where the voltage deviation was 0.355%.

Table 2 : Best ten optimal solutions for installing two DGs.

DG1 Bus	DG1 size (kW)	DG2 bus	DG2 size (kW)	P loss (kW)	Losses reduction %	VD%
15	919.063	29	1831.5	15.673	87.295	0.355
9	979.217	29	1877.89	16.145	86.912	0.384
14	857.256	29	1883.2	16.295	86.791	0.382
8	1076.38	30	1721.04	16.532	86.598	0.435
9	973.616	30	1720.61	16.595	86.548	0.399
12	895.387	29	1936.43	16.785	86.393	0.387
8	1057.12	29	1873.09	17.005	86.215	0.447
11	878.399	29	1940.05	17.007	86.214	0.397
13	818.129	29	1923.61	17.077	86.156	0.409
10	873.192	29	1944.72	17.099	86.139	0.4

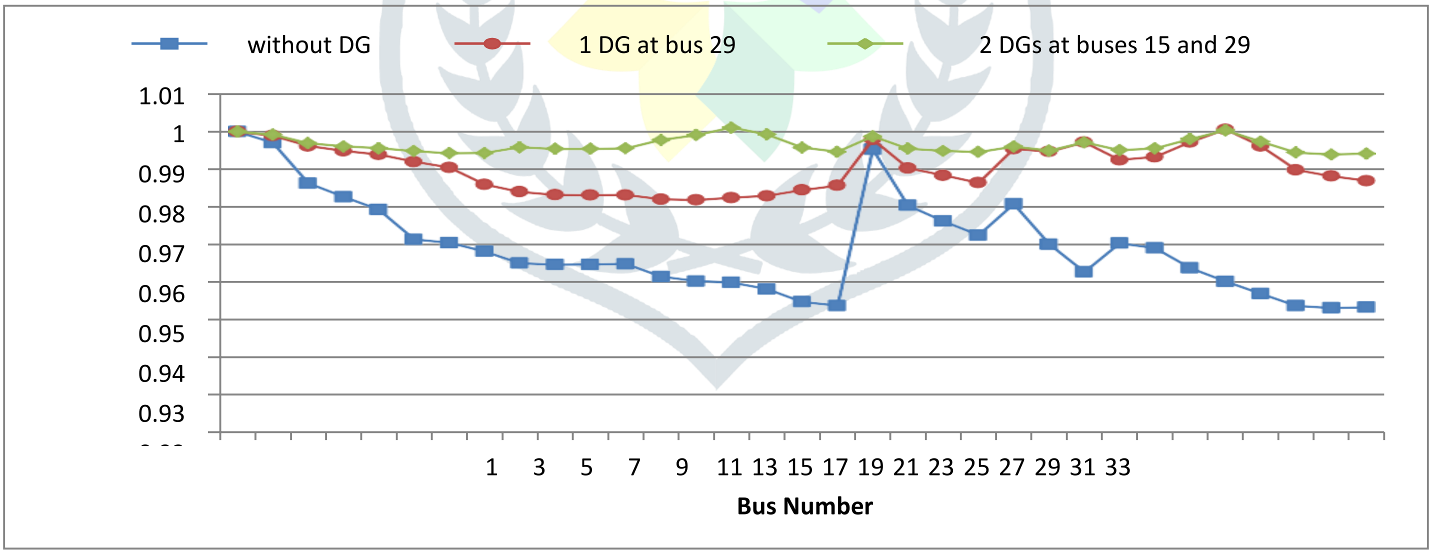

Figure 7: Voltage profiles for 33-bus meshed distribution system without DG and With single DG at bus 29 and with Two DGs at bus 15 &29

V. CONCLUSION

a deterministic method to find optimal DG sizing and placement in a distribution network was proposed, where the total real power losses of the network were employed as the objective to be minimized. The proposed method was formulated as a constrained nonlinear programming problem and applied to IEEE 33bus distribution systems topologies to show its applicability. Additionally, single and Two DG installation cases were performed for each test system and compared to the case without DG. The results demonstrated that DG size and placement have a significant influence in minimizing power losses as well as improving voltage profiles. It was also demonstrated that integrating two DGs reduces the system power losses more than integrating only one DG.

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