Optimal Siting of Different Levels of DG Penetration and Its Impact on the Radial Distribution System Under Different Voltage-Dependent Load Models

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Abstract- By incorporating distributed generators (DG) into the distribution network, the conventional power system's structure is altered, posing new problems to the engineering community. The issues are addressed through the use of both single and multiple goal functions. The present work employs a well-known particle swarm optimization (PSO) technique with a multi-objective function to determine the ideal location of DG at various penetration levels for various voltage-dependent load models. Thus, the influence of DG penetration levels on true and reactive power losses, voltage profile, and deviation in node voltage for different load types will be investigated. The study was performed using the IEEE-33 bus's RDS.

Keywords Radial Distribution System, Optimal Planning of DG, PSO Optimization technique, Voltage-dependent load.

1. Introduction

The current state of the power distribution network is no longer typical due to the significant penetration of small capacity producing units. Distributed generation, often known as "captive power plants," refers to small-scale generating facilities located near load centers. These facilities convert the conventional grid into a bidirectional system of energy flow. This transformation results in a reduction of system power losses, an increase in node voltage, and a decrease in operational costs, among other benefits. Optimal DG planning has been a persistent theme over the last few decades in order to maximize the benefits of DGs. The best planning entails selecting the optimal DG technologies, optimal DG size and location, and optimal fitness functions.

The DG technologies involve solar, wind, fuel cells, diesel generators, microturbines, minihydro, etc., and the fitness functions may be single- or multi-objective functions. The optimization of DG planning is very much needed for the present distribution network. Hence, different optimization approaches have been presented so far.

The voltage-dependent load models are considered to prove that the optimal size and site of DGs are different compared to the constant load model using an artificial hybrid bee colony and hill climbing algorithm [1]. A novel grey wolf algorithm is proposed for OPDG of type-1 and type-2 under various load condition and the voltage profile is enhanced as number of DG penetration increases [2]. P. Gopu et. Al proposed genetic algorithm approach for optimal placement of multiple DGs for IEEE 33 and 69 bus RDS [3]. Particle swarm optimization (PSO) is used to reduce the total power loss by considering various constraints of the system [4]. In [5], the author presents a bat algorithm to minimize the losses by OPDG in RDS, and results proved that the proposed algorithm was suitable to deal with the complex problems involved in OPDG. To reduce computation time, sensitivity analysis is used to identify the sensitive node, and PSO is used for OPDG [6]. The multi-objective function with three indices is derived to minimize the complexity in OPDG with different operating power factors using GWO, the whale optimization algorithm, and PSO [7]. The DG location and rating have been estimated by deriving a power stability index using a novel lightning algorithm and studying the impact of DGs on the distribution network [8]. The performance of the gravitational search algorithm is improved in OPDG and named the "improved gravitational search algorithm" (IGSA) and compared with the popular PSO method [9]. Backtracking algorithm (BSA), PSO-Differential Evaluation (DA), lighting search algorithm (LSA), and cuckoo search algorithm (CSA) [10-13] are examples of heuristic algorithms. The analysis was carried out for the maximum constant load test system. In [14], the different load models are considered to study the impact on OPDG using the butterfly-PSO (BF-PSO) technique, and the results are compared with standard techniques. The simulation approach to evaluating the impact of different types of DG sizes on losses and voltage stability using an index is presented, and the results are compared with intelligent techniques in [15]. The optimization technique is implemented for a building to decide optimal size of PV considering the economic balance [16]. The results in [17] showed that the investigated swarm optimization techniques could achieve quick convergence, avoid local minima, and perform computational efficiency assessments. In this article [18], the planning and control performance of short-term power systems are being explored. Additionally, the dynamic programming (DP) methodology, which is a robust optimization method, is being employed in an effort to reduce power system operating costs. The impact of DG penetration on the distribution network was carried out by considering a constant load. But practically, the loads are voltage-dependent, and the performance of the system with various DG levels for different load models needs to be investigated. There has been no work published so far to investigate the OPDG for various penetration levels of DGs at optimal power factors for different load models.

Thus, the proposed work investigates the effect of optimal DG site at various penetration levels on distribution system power losses and voltage profiles using the PSO technique. The active and reactive power indices are constructed to define a multi-objective function with the goal of minimizing the complexity associated with decision-making. The proposed approach is examined in MATLAB 2017a on IEEE 33-bus RDS.

The paper has been well documented as follows: the proposed fitness function and the load modelling are described in Section 2. Section 3 explains the steps to be followed to obtain the best solution for the fitness function. Implementation of the test system and results obtained are discussed in detail in Section 4, followed by a conclusion in Section 5.

2. Problem Formulation

The main objective of the proposed work is to find the optimal siting for different penetration levels of DG and also analyse the impact of it on system power loss and voltage profile. The objective is achieved by using the multi-objective fitness function (MOF) represented in (1). The distribution load flow analysis is used to calculate the fitness value.

$$MOF=Min(a*APLI+b*RPLI) \quad (1)$$

Where a =b=0.5 given equal weightage for both real and reactive loss minimization for DG placement.

Where, APLB and APLDG and are the active power loss without and with DG, RPLB and RPLDG are the active and reactive power loss without and with DG.

$$Active\ Power\ Loss\ Index\ (APLI) = \frac{APL_{DG}}{APL_B} \quad (2)$$

$$Reactive\ Power\ Loss\ Index(RPLI) = \frac{RPL_{DG}}{RPL_B} \quad (3)$$

2.1. Total Voltage Deviation Index (TVDI)

The deviation in node voltage at different penetration level of DG is calculated for different loads using equation (4).

$$TVDI = \sum_{i=1}^{n} |1 - V_i| \quad (4)$$

Where Vi represents the voltage at node i.

2.2. Load Models

The various voltage-dependent load models are considered to analyse the impact of DG penetration levels on the distribution power network. In most of the cases, researchers have done the analysis by considering the load constant, but in real-time, the loads are voltage-dependent and are classified as residential (RS), commercial (CM), and industrial (ID) loads. The mathematical expression of different load models is expressed in (5-6):

$$P_L = P_{OL}{}_i^x\, V_i^y \quad (5)$$

$$Q_L = Q_{OL}{}_i^x\, V_i^y \quad (6)$$

Where P_L and Q_L are the actual real and reactive load respectively, POL_i and QOL_i are the real and reactive power load at node i, x and y are relationship value to relate different load types and is tabulated in Table 1:

3. Proposed Methodology

The PSO optimization methodology is used in conjunction with the distribution load flow method to determine the effect of varying DG penetration levels on losses and voltage profiles. The PSO algorithm's step-by-step process is described in detail [11], and Figure 1 shows how the proposed method is used.

Table 1. Relationship values of Voltage-dependent load models

Load Type	x	y
CON	0	0
RS	0.92	4.04
CM	1.51	3.4
ID	0.18	6

4. Results and Discussions

The proposed technique has been evaluated on IEEE 33-bus RDS under a variety of load conditions. The base case real and reactive power losses for the Con, Rs, Cm, and Id loads are 206.73 kW, 137 kVAr, 151.526 kW, 100.63 kVAr, 144.702 kW, 96.0322 kVAr, and 156.638 kW, 104.129 kVAr, respectively. The optimal position of DG is determined in this work using a multi-objective function and the PSO technique for varying DG penetration levels, system losses, and voltage profiles. The ideal location for DG with penetration levels ranging from 0% to 80% with a 10% step was determined using the objective function, and the influence of DG penetration under various load situations on distribution system losses and voltage profile was also analysed. The system losses at various penetration levels are summarized in Tables 2-3, along with the ideal position of DG. As the penetration level of DG increases, the losses decrease dramatically, and the highest advantage is realized at a penetration level of 60% with a high percentage of loss reduction. Additionally, as illustrated in Fig.2, increasing the integration of DG results in a rise in system losses (2-3). As a result, the maximum advantage for all sorts of loads may be obtained when DG is installed on bus 27 and the penetration level is set to 60% of the total system load. Additionally, Fig. 4 depicts the fitness function values for various integration levels.

Because the power injection has increased as a result of the increased DG penetration, the system's voltage profiles have improved for all studied loads, and as a result, all node voltages are nearing 1pu, as illustrated in Figures (5-8). As a result, the total voltage deviation (TVD) for Con, Rs, Cm, and Id loads decreases from 2.047 to 0.8378, 1.79 to 0.61, 1.76 to 0.586, and 1.79 to 0.62, respectively, as illustrated in Figure 9.

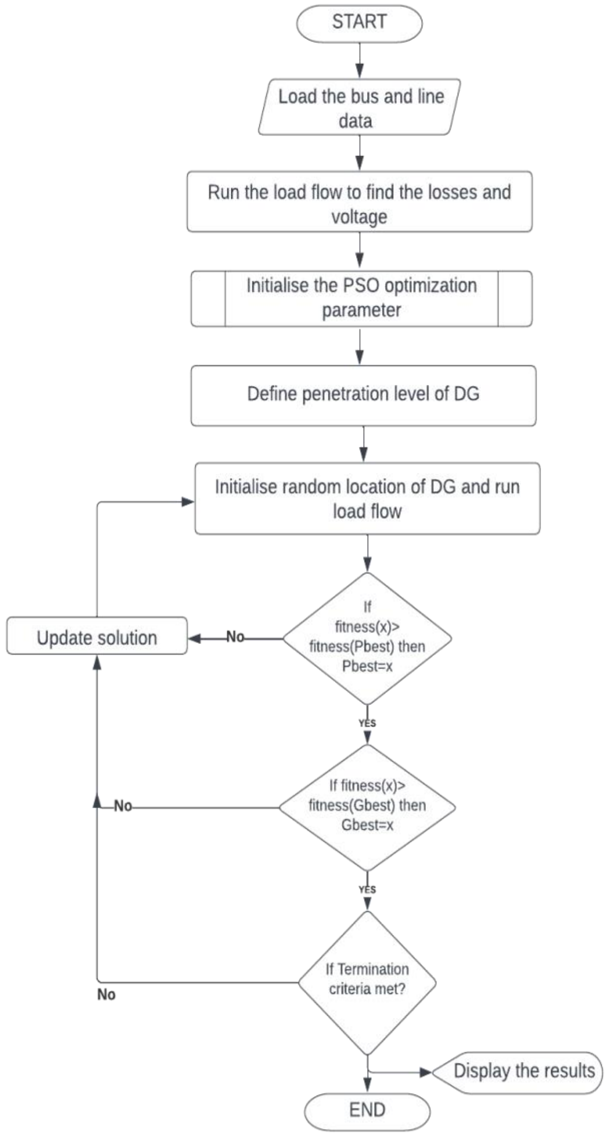

Fig. 1. PSO Optimization Technique

5. Conclusions

In IEEE 33-bus RDS, the impact of optimal DG planning on system losses and the voltage profile of the distribution network with varied penetration levels was investigated. The ideal DG placement is obtained by calculating the multi-objective fitness function for each penetration level using the PSO technique for various load models. Regardless of the type of load, the largest reduction in losses is achieved at a DG penetration level of 60% of the total system load, and the ideal location for DG is at bus 27. The analysis also shows that a high penetration of DGs might raise the voltage profile of the system while simultaneously increasing the losses. As a result, loss minimization will be given more weight in the multi-objective function than other indices. With a rise in DG penetration, the total voltage variation of the system is greatly reduced due to an increase in real power injection. In the future, the time-varying load as well as real-time variable irradiance and wind speed DGS will be able to be taken into consideration for the analysis to see the impact that the positioning of DGs has on RDS.

Table 2. Optimization Results for Constant and Residential Load

Load type	Constant Load				Residential Load			
DG penetration level	P_L in kW	Q_L in kVAr	DG Site	MOF value	P_L in kW	Q_L in kVAr	DG Site	MOF value
Without DG	206.73	137.9	NIL	1	151.526	100.638	NIL	1
10%	152.743	97.2095	30	0.722	115.051	72.8306	31	0.741
20%	122.32	80.8672	19	0.589	92.0434	61.788	19	0.611
30%	112.388	73.7287	30	0.539	85.7602	57.209	27	0.567
40%	103.587	70.3225	27	0.506	73.8557	50.1133	27	0.493
50%	92.792	63.9088	27	0.456	67.5334	46.5512	27	0.454
60%	87.5791	61.0287	27	0.433	66.7937	46.5227	27	0.452
70%	87.948	61.6822	27	0.436	71.6364	50.0279	27	0.485
80%	93.9005	65.8695	27	0.466	82.061	57.0668	27	0.554

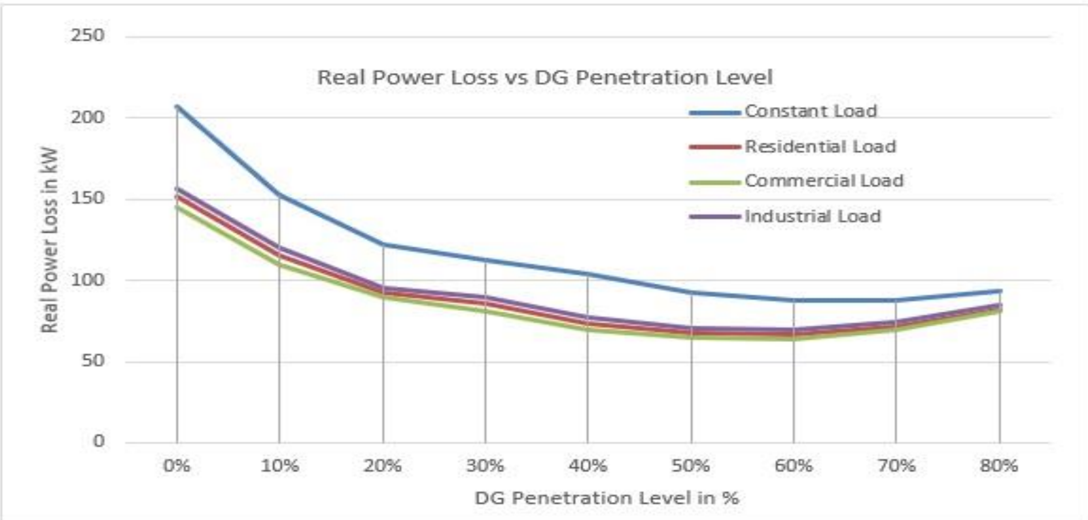

Fig. 2. Real power losses for voltage-dependent load with different penetration level

Table 3. Optimization Results for Commercial and Industrial Load

Load type	**Commercial Load**				**Industrial Load**			
DG penetration level	**P_L in kW**	**Q_L in kVAr**	**DG Site**	**MOF value**	**P_L in kW**	**Q_L in kVAr**	**DG Site**	**MOF value**
Without DG	144.702	96.0322	NIL	1.000	156.638	104.129	NIL	1.000
10%	109.617	69.34	31	0.740	119.913	75.5237	19	0.745
20%	89.434	58.3017	32	0.613	95.1499	63.6068	19	0.609
30%	81.285	54.232	27	0.563	89.9134	59.9706	27	0.575
40%	70.048	47.559	27	0.470	77.656	52.6529	27	0.501
50%	64.393	44.819	27	0.456	70.9812	48.868	27	0.461
60%	64.3204	44.813	27	0.456	69.888	48.6185	27	0.457
70%	69.83	48.74	27	0.495	74.3788	51.9018	27	0.487
80%	80.922	56.2014	27	0.572	84.4512	58.7187	27	0.552

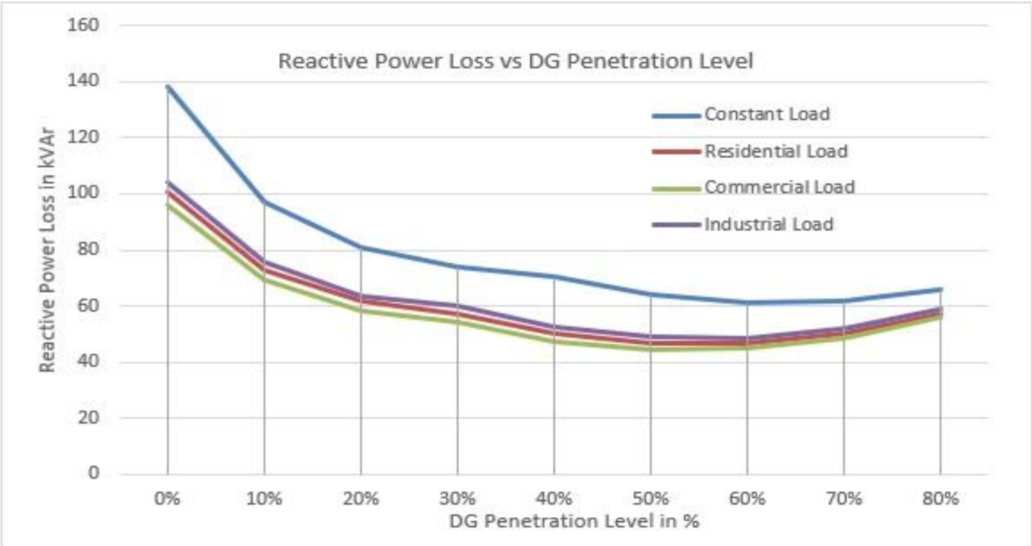

Fig. 3. Reactive power losses for voltage-dependent load with different penetration level.

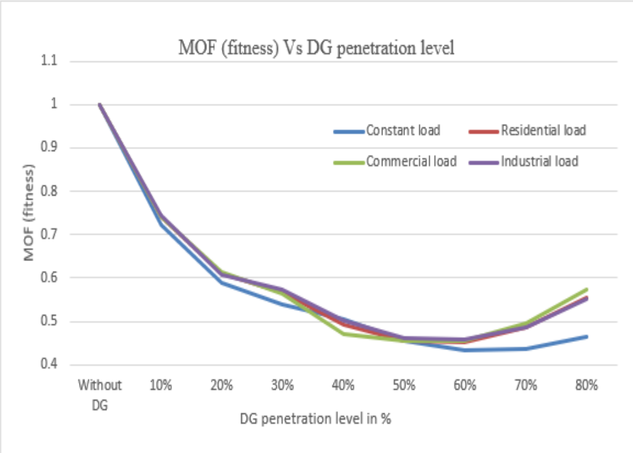

Fig. 4. fitness value for voltage-dependent load with different penetration level

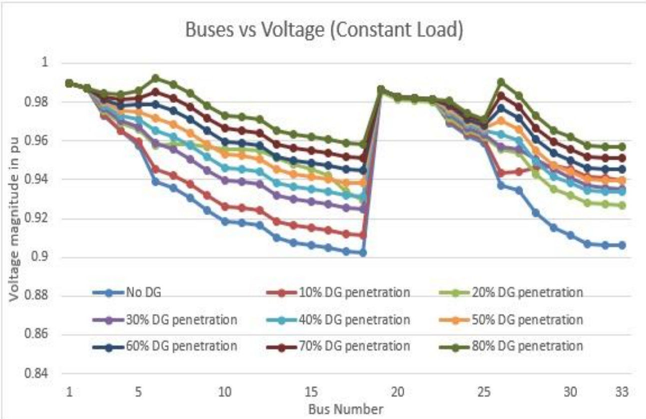

Fig. 5. The voltage magnitude for constant load with different penetration level

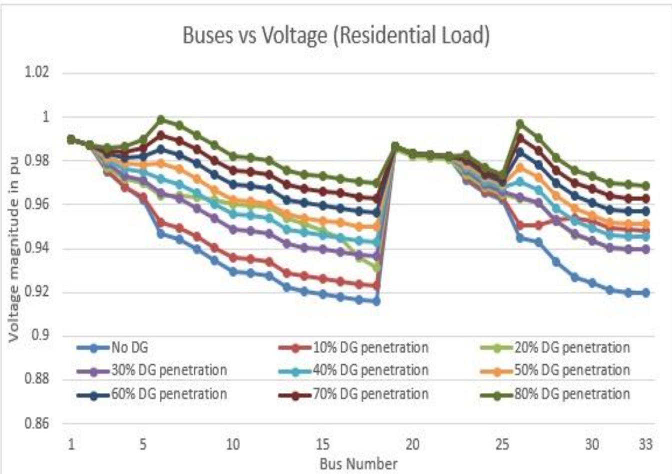

Fig. 6. The voltage magnitude for residential load with different penetration

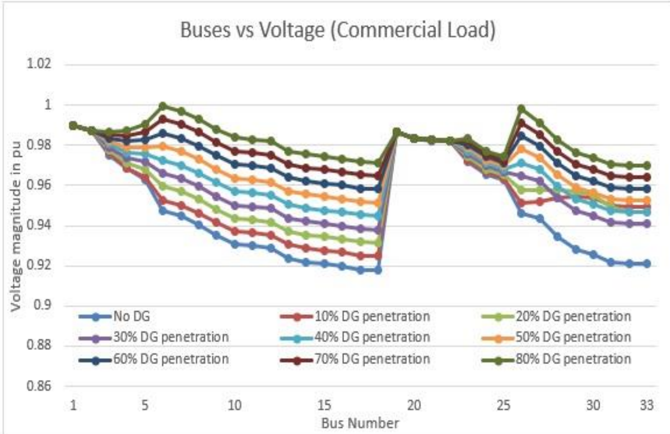

Fig. 7. The voltage magnitude for commercial load with different penetration level**.**

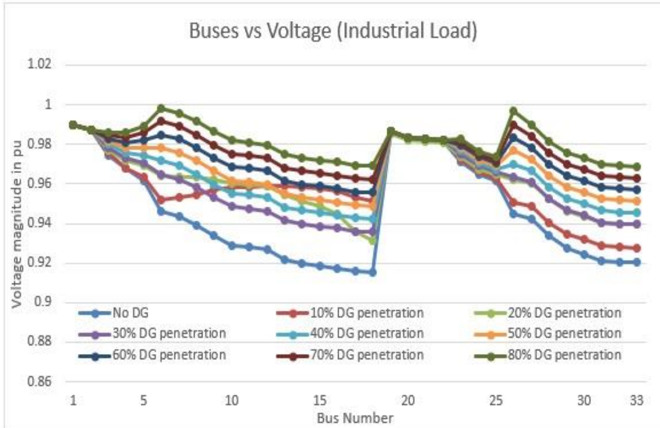

Fig. 8. The voltage magnitude for industrial load with different penetration level

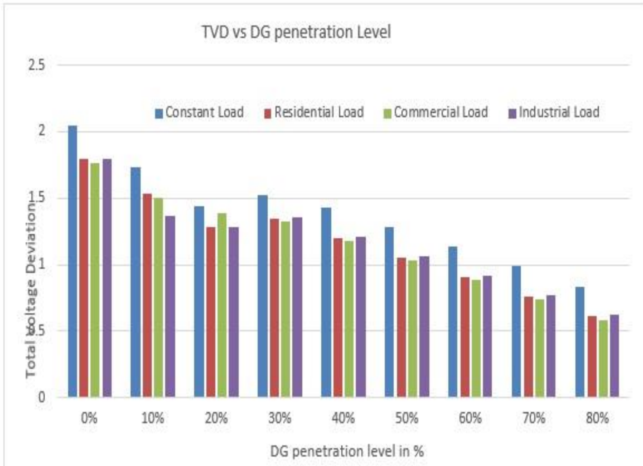

Fig. 9. The TVD for various loads with different penetration level

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