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Optimal Distributed Generation Planning Using PSO Algorithm for Economic Benefits of DG Owners and Distribution Companies

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Abstract- This paper proposes a method to solve the optimal placement problem of DGs in distribution networks by using PSO algorithm. The formulation of bi-objective problem has been done for getting maximum benefit for DGs and distribution systems. The objective function takes into account DG owners' revenues from selling electricity and renewable energy incentives. On the other hand, distribution companies experience decreased power losses, better voltage profile, higher reliability, and environmental emissions reduction. In the evaluation of the proposed approach, simulation tests were performed in MATLAB on the IEEE 34-bus system to find the best placement and sizing of DGs. Simulation results indicate remarkable reductions in power losses, improved voltage stability, and huge economic benefits for both parties within operational limits. Thus, it was found out that the proposed PSO algorithm can be used as an efficient way of DG planning.

Keywords: Distribution networks, distributed generation, particle swarm optimization, economic benefits, generation planning.

Nomenclature

DG	Distributed Generation	EV	Electric Vehicle
DISCO	Distribution Company	i,j	Bus indices in the distribution system
PSO	Particle Swarm Optimization	K	Distributed generation unit index
GWO	Gray Wolf Optimization	N	Total number of buses
DE	Differential Evolution	$P_{DG,i}$	Active power generation by DG at bus (i) (kW)
GA	Genetic Algorithm	$Q_{DG,i}$	Reactive power generation by DG at bus (i) (kVAr)
ACO	Ant Colony Optimization	$S_{DG,i}$	Apparent power rating by DG at bus (i) (kVA)
PV	Photovoltaic	$P_{load,i}$	Active power consumption of load at bus (i) (kW)
$Q_{load,i}$	Reactive power consumption of load at bus (i) (kVAr)	R_{DG}	Revenue due to DG generation ($)
V_i	Magnitude of voltage at bus (i) (p.u.)	F_1	Objective function for the DG owner benefit

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V_{min}	Minimum voltage limit (p.u.)
V_{max}	Maximum voltage limit (p.u.)
I_{ij}	Current between buses (i) and (j) (A)
R_{ij}	Resistance of line (i-j) (Ω)
X_{ij}	Reactance of line (i-j) (Ω)
P_{loss}	Total of active power loss (kW)
Q_{loss}	Total of reactive power loss (kVAr)
B_{DG}	Benefit of the DG owner ($)
B_{DISCO}	Benefit of the distribution company ($)
C_{DG}	Cost of DG ($)
C_{loss}	Cost of network losses ($)
F_2	Objective function or the distribution company benefit
F	Total bi-objective optimization function
ω	Inertia weight of PSO
c_1	Cognitive constant coefficient
c_2	Social constant coefficient
r_1, r_2	Random numbers in the range [0,1]
v_i	Velocity of particle i
x_i	Position of particle i
P_{best}	Best position of a particle
G_{best}	Best position found by the swarm

1. Introduction

The increasing integration of DG into current distribution systems has presented new possibilities to enhance the efficiency, reliability, and economic performance of the system. The effectiveness of the use of DG technology is highly dependent upon choosing proper locations and sizes for the DG units. Thus, optimal planning of DG has been identified as an essential research area and has been receiving much interest among scientists and utility companies. Numerous researches have been done to solve planning, control, and optimization problems in DG systems.

Hafez and Bhattacharya [1] have contributed to the study of optimally designing renewable energy power systems for microgrids. Katiraei et al. [2] have studied the independent operation of microgrids under the islanded mode, and A control strategy for voltages in distribution networks with distributed generation has been proposed by Madureira and Lopes [3]. Chowdhury et al. [4] have investigated operation and control of distributed generation power islands in smart grid. Molina and Mercado [5] used superconducting magnetic energy storage to enhance the power flow stability, while Ashabani and Mohamed [6] came up with a versatile control system for grid-tied and autonomous microgrids. Xiong and Ouyang [7] investigated modeling and transient analysis of microgrids. Alobeidli et al. [8] developed a coordinated voltage control system for hybrid microgrids. Liu et al. [9] proposed a coordinated control system for AC/DC hybrid microgrids.

Many researchers have contributed to the area of converter controls and stability analyses. Studies by Kakigano et al. [10] have been conducted on low voltage DC microgrids, Mahmoodi et al. [11] have worked on the design of power transfer control scheme for DC microgrids, while Rocabert et al. [12] have summarized the control schemes of power converters in AC microgrids. Dynamic modeling and stability-related work include Ekanayake et al. [13], Morren and De Haan [14], Coelho et al. [15], Berggren et al. [16], Guerrero et al. [17], and Lee and Wang [18], who have modeled inverters, wind generators, and small signal stability of renewable energy microgrids.

Pogaku et al. [19] examined autonomous inverter-based microgrids, and Liang and Zhuang [20] provided a review on stochastic modeling and optimization approaches. Lopes et al. [21,22] have covered the topic of distributed generation and control schemes in microgrids. Kawachi et al. [23], Basak et al. [24], and Kavousi-Fard [25] investigated power management and energy storage approaches. Zeineldin et al. [26] studied the effect of DG interface control on islanding detection, while Lidula and Rajapakse [27] conducted a review of experimental microgrids. De Brabandere et al. [28], Katiraei and Iravani [29], Barklund et al. [31], Majumder et al. [32], and Bevrani and Shokoohi [33] studied droop control and power-sharing strategies. Pan and Das [30] proposed optimization-based PID tuning for AVR systems.

Additional studies addressed machine modeling, optimization, and robust control. Freitas et al. [34] compared synchronous and induction machines for DG applications, Logenthiran et al. [35] applied evolutionary optimization for microgrid sizing, and Hossain et al. [36] proposed robust power-sharing control for low-inertia microgrids.

Studies on voltage regulation of microgrids were carried out by Vandoorn et al. [37,41], and the use of hybrid fuel cell microgrids was studied by San Martín et al. [38]. Microgrid issues were discussed by Govardhan and Roy [39], and the PV-wind-diesel hybrid system was investigated by Arulampalam et al. [40]. Kim et al. [42] and Ghazanfari et al. [43] suggested energy storage coordination and active power management schemes.

Metaheuristic algorithms have seen an increasing trend of application in optimal placement and sizing of distributed generation in recent times. Bouchikhi et al. [44] suggested a new approach to the GWO optimization algorithm in the context of optimal placement and sizing of the DG. Rajakumar et al. [45] applied Jellyfish Search Algorithm (JSA) in their research and found out the optimal placement and sizing of DGs from the perspective of PV systems and made noteworthy power losses and voltage deviations. Malika et al. [46] presented the quasi-opposition forensic algorithm-based investigation scheme for DG sizing and placement, which was found superior to other techniques.

In addition to that, Rajakumar et al. [47] introduced Osprey Optimization Algorithm (OOA) for DG placement in radial distribution systems, which proved to be very effective in minimizing power losses and improving voltage profile.

A multi-objective optimization approach [48] was recently proposed for the joint placement of distributed generators and shunt capacitors in radial distribution systems using MOPSO technique. Recently, Mohamed et al. [49] have proposed a methodology based on network partitioning for joint placement of distributed generation and electric vehicles charging stations in active distribution networks.

Table 1 indicates that most existing studies consider technical optimization objectives while the new proposed approach considers economic benefits for DG owners as well as the distribution company.

From the reviewed literature, it is evident that much work has been carried out on the control of microgrids, increasing their stability, improving their energy management systems, and integrating the distributed generation units into current distribution networks. Moreover, several optimization algorithms like GA, PSO, ACO, and DE have been applied to the planning and operation of the distributed generation.

Table 1. Comparative analysis of representative studies on DG planning and optimization.

Ref.	Method/Approach	Main Focus	Economic Consideration	Dual Economic Benefits
[1]	Renewable energy planning	Optimal microgrid supply system design	Partial	No
[3]	Coordinated voltage support	DG integration and voltage regulation	No	No
[20]	Stochastic optimization review	Microgrid optimization methods	Partial	No
[21]	DG integration framework	DG integration challenges and opportunities	No	No
[35]	Evolutionary Strategy	Optimal microgrid sizing	Partial	No
[44]	Modified GWO	DG placement and sizing	Partial	No
[45]	Jellyfish Search Algorithm	PV-DG allocation and loss reduction	No	No
[46]	Forensic-Based Investigation Algorithm	DG sizing and allocation optimization	No	No
[47]	Osprey Optimization Algorithm	DG integration and power loss minimization	No	No
[48]	MOPSO	Simultaneous DG and capacitor allocation	Partial	No
[49]	Modified Newman Fast Algorithm	DG and EV charging station planning	Partial	No

These methods have included PSO, which has proved to be one of the best techniques because of its ease, efficiency, and ability to solve nonlinear optimization problems. So far, most of the studies conducted have been done considering the goals of reducing power loss, improving voltage profiles, increasing reliability, and maximizing benefits either for DG owners or distribution companies.

However, insufficient efforts have been paid to the creation of an integrated planning model that would take into account both the interests of investors and the utility. Such a problem is especially relevant for today's intelligent distribution grids, when finding a compromise between the interests of both parties becomes crucial.

To address this issue, the present study proposes a PSO-based bi-objective optimization framework for determining the optimal location and capacity of DG units in distribution systems. The proposed model integrates the economic benefits of DG owners and the operational benefits of distribution companies while satisfying practical network constraints. The effectiveness of the proposed approach is evaluated through simulations on the IEEE 34-bus distribution system using MATLAB.

The rest of this paper is organized as follows. Section 2 presents the proposed PSO-based method, Section 3 describes the mathematical formulation, Section 4 discusses the case study and simulation results, and Section 5 concludes the paper.

2. Proposed PSO-Based Optimization Method

Based on the research gap identified in the previous section, the proposed PSO-based optimization method is presented in this section. In 1995, Kennedy and Eberhart, inspired by the collective movement of birds or schools of fish, as illustrated in Figure 1, developed the Particle Swarm Optimization (PSO) algorithm for finding optimal solutions.

Fig. 1. Biological inspiration of PSO algorithm.

The algorithm, also known as the Particle Swarm Optimization (PSO) algorithm or the Bird Algorithm, is one of the successful algorithms in the field of continuous and discrete optimization. Compared to other evolutionary algorithms, the advantages of the PSO algorithm include:

- Clear and intuitive algorithm concepts
- Simple implementation mechanism
- Ability to control and adjust its parameters
- Low memory requirements
- Capability for global random search across the entire problem space

In view of the above benefits, PSO algorithm has gained significant attention for solving various optimization problems in power systems. The PSO algorithm consists of particles that move within the search space, where each particle retains its best personal experience, including its position vector and velocity vector. Additionally, the entire particle swarm collectively builds and maintains the best collective experience.

Suppose X and Velocity represent the position and velocity vectors of the particles in a search space, respectively. Therefore, the i_{th} member of the swarm in an n-dimensional space can be described by the following two characteristics.

$$X_i = [x_{i,1}, x_{i,2}, \dots, x_{i,n}] \quad (1)$$

$$Velocity_i = [v_{i,1}, v_{i,2}, \dots, v_{i,n}] \quad (2)$$

In this algorithm, what is referred to as the velocity vector is actually determined by three factors: the velocity from the previous step, the best personal experience, and the best collective experience. These factors are updated to calculate the next velocity. The next velocity is obtained using the following relationship:

$$Velocity_i^{k+1} = \omega * Velocity_i^k + c_1 * rand(.) * (P_{best,i} - X_i^k) + c_2 * rand(.) * (G_{best} - X_i^k) \quad (3)$$

The position vector obtains its new location through the following relationship:

$$X_i^{k+1} = Velocity_i^{k+1} + X_i^k \quad (4)$$

where ω denotes the inertia weight, c_1 and c_2 denote the learning factors, and *rand(.)* denotes a randomly generated number between 0 and 1. Additionally, k represents the current iteration number. Figure 2 represents the basic principle of operation of the PSO algorithm.

Although there are several benefits of PSO, the effectiveness of this technique is highly dependent on the settings of its parameters and it usually falls into a local optimum and quick convergence problem. The settings of the parameters of PSO algorithm adopted in this study are presented in Table 2.

The above-mentioned settings of the parameters have been established based on well-accepted guidelines of previous DG planning researches, and their effectiveness was confirmed by preliminary simulation tests.

3. Mathematical Modelling of the DG Planning Problem

Once the optimization technique is defined, the mathematical model, objectives, and operational constraints will be defined. In this research, the DG units are considered as dispatchable DGs connected to the grid. The DG units will produce an amount of active power according to the operational constraints of the system. The power values are expressed in kW, the energy values in kWh, and the economical values in USD ($). The economic assumptions are made in this research as shown in the objective function and parameters.

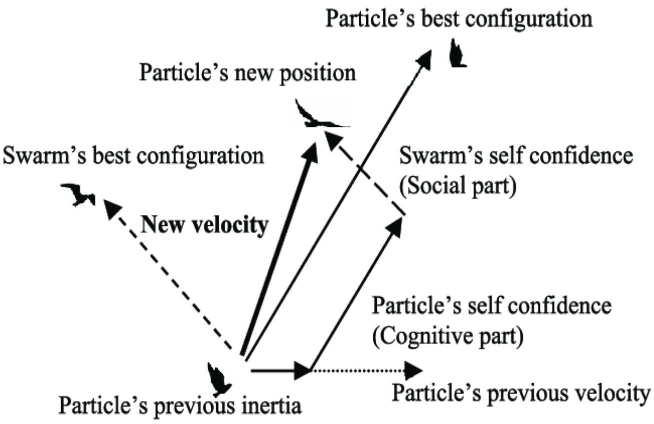

Fig. 2. Fundamental operation of the PSO algorithm.

Table 2. The parameter settings of the PSO algorithm.

Parameter	Symbol	Value
Swarm size	N	30
Maximum iterations	$Iter_{max}$	100
Inertia weight	w	0.7
Cognitive coefficient	c_1	2.0
Social coefficient	c_2	2.0
Random coefficients	r_1, r_2	[0,1]

The considered cost function consists of two parts. The first part is the profit of independent producers, which must be maximized. The second part pertains to the profit of distribution network owners, which also needs to be maximized.

$$\max J = \max[B_{IPS}, B_{DisCo}] \tag{5}$$

These weights were indicative of the level of priority given to the objective functions pertaining to the DG providers and the distribution company. Equal weight was chosen for this case to make a balanced comparison of both parties' gain.

3.1. Economic Objective for DG Owners

For the producers and owners of the Distributed Generation (DG), the cost-to-profit ratio can be described as the ratio of the annual profit to the annual cost of Distributed Generation (DG). This profit includes the revenue gained from selling the electrical energy produced as well as the incentive earned from the use of renewable energy by the government. The aforementioned cost includes the investment cost, maintenance cost, and fuel cost.

$$B_{IPS} = \frac{B_{ANN}}{C_{INV}} \tag{6}$$

$$B_{ANN} = 8760\sum_{i=1}^{N}(\rho_{DGi} + \rho_{APi})P_i^{rate}CF_i \tag{7}$$

$$C_{INV} = \sum_{i=1}^{N}\alpha_{DGi} * P_i^{rated} * C_i^{fixed} + 8760\sum_{i=1}^{N}C_i^{op} * P_i^{rated} * CF_i \tag{8}$$

where, B_{ANN} is the average annual investment profit and C_{INV} is the annual investment cost.

3.2. Economic Benefits for Distribution Companies

This benefit is divided into several components. Reduction of losses, improvement of voltage, mitigation of environmental issues, and enhancement of reliability are among the factors contributing to this benefit.

$$B_{DisCo} = \Delta B_{Ploss} + \Delta B_{Impu} + \Delta B_{Reli} + \Delta B_{Upda} + \Delta B_{Envi} + \Delta B_{Sub} \tag{9}$$

3.2.1. Benefit from power loss reduction

The total losses are decreased by using the concept of Distributed Generation (DG) in the grid network. This annual profit is calculated as follows.

$$\Delta B_{Ploss} = \rho_{GP}\Delta P_{loss}\tau_{\max} \tag{10}$$

This relationship consists of three parameters. The first parameter is the price of purchased energy. The second parameter is the difference in power losses before and after the installation of DG. The third parameter is the number of hours during which the maximum load is present in the network.

3.2.2. Benefit from voltage profile improvement

The quality of power delivered to the consumer is of great importance, and failure to comply with its standards will result in penalties. Additionally, poor power quality can reduce the lifespan of consumer devices. The formula for calculating the annual profit derived from improving the voltage profile is provided below.

$$\Delta B_{Impu} = \sum_{j\in\Phi}(\lambda_{wj} - \lambda_{woj})B_{jmu} \tag{11}$$

$$\lambda_j = \begin{cases} 1 & V_j^{rated}(1-\alpha) \leqslant V_j \leqslant V_j^{rated}(1+\alpha) \\ 0 & \text{others} \end{cases} \tag{12}$$

where λ is a binary number, B_{jmu} and the annual revenue derived from improving power quality benefits both the producer and the consumer.

3.2.3. Benefit from reliability enhancement

The use of DG in islanded systems can improve the reliability of the loads in situations where automatic sectionalizing and recloser switches operate, as well as reduce the extent of damage caused to the network due to faults occurring in one-phase. It means that the availability of DG can mitigate a part of the cost suffered due to presence of excess power in the distribution network. The costs of missing energy represent the costs incurred due to power outage or load shedding of the customers.

$$\Delta B_{Reli} = \rho_{uc} * (EENS_{woi} - EENS_{wi}) \tag{13}$$

$$EENS = \sum_{i=1}^{n}(\lambda_i * T_i * P_i) \tag{14}$$

where EENS refers to the "Expected Energy Not Supplied", ρ_{uc} refers to the cost of "expected unsupplied energy", λ_i refers to the load failure rate, n refers to the number of nodes within the independent island, T_i refers to the average time for faults, and P_i refers to the load in the independent island.

3.2.4 Benefit from network capacity improvement

The addition of distributed generation (DG) in the grid reduces the power flow in the lines, and this helps in transmitting high power.

$$\Delta B_{Upda} = \sqrt{3}C_{mar}U_{av}\sum_{i=1}^{N_b}(|I_{wi} - I_{woi}|) \tag{15}$$

where C_{mar} is the annual investment for the modernization of transmission lines. U_{av} is the average network voltage. I_w is the line current before and after the installation of DG.

3.2.5. Environmental benefits

By installing DG, transmission power losses can be reduced. Additionally, power can be generated in a distributed manner, resulting in lower and more dispersed pollution. The annual profit derived from these environmental benefits can be calculated as follows.

$$\Delta B_{Evin} = (E_{woi} - E_{wi})C_{Envi}\beta \tag{16}$$

where E_w represents total amount of electricity purchased annually from the main grid. β represents the amount of C_{O2} produced per kilowatt-hour of electrical power generation. C_{Envi} represents the tax rate for C_{O2} emissions.

3.3. Renewable Energy Incentive Benefits

The cost of power produced by renewable sources of energy is relatively high compared to non-renewable sources. However, the government encourages the use of renewable energy through incentives.

The annual profit from this component is calculated as follows.

$$\Delta B_{Sub} = \rho_{GP}(E_{woi} - E_{wi}) - 8760\sum_{i=1}^{N}\rho_{DGi}P_i^{rate}CF_i \tag{17}$$

3.4. Operational Constraints

After achieving these objectives, certain conditions must be evaluated. These constraints include simple factors that are essential for network stability.

The result obtained from the optimization algorithm must satisfy the power equations as follows.

$$P_{sub} + \sum_{i=1}^{N} P_{DGi} = P_{Loss} + P_{Load} \tag{18}$$

The voltage limit is between 0.95 and 1.05 per unit. The power electricity transmitted in the line must not exceed the maximum limit of the capacity of the line.

From the details provided in the above section, the flowchart of the algorithm will be as illustrated in Figure 3.

4. Case Study and Simulation Setup

To validate the effectiveness of the proposed technique, simulation studies have been carried out using IEEE 34-bus distribution system with various configurations of DGs. In this paper, the IEEE 34-bus distribution system is employed (Figure 4).

The network operating constraints were selected according to standard distribution system requirements. DG capacities were limited based on the loading level of the IEEE 34-bus test system. These constraints ensure practical and technically feasible DG installation scenarios throughout the optimization process. The line data and the production and consumption of buses are presented in Tables 3 and 4, respectively.

By executing the simulation program, which is coded in MATLAB, the algorithm determines the optimal buses and production values for installation based on the cost function and the described constraints. The outcomes of the algorithm are given in Table 5.

Subsequently, by simulating the installation of the obtained DGs, voltage drop and power losses are evaluated.

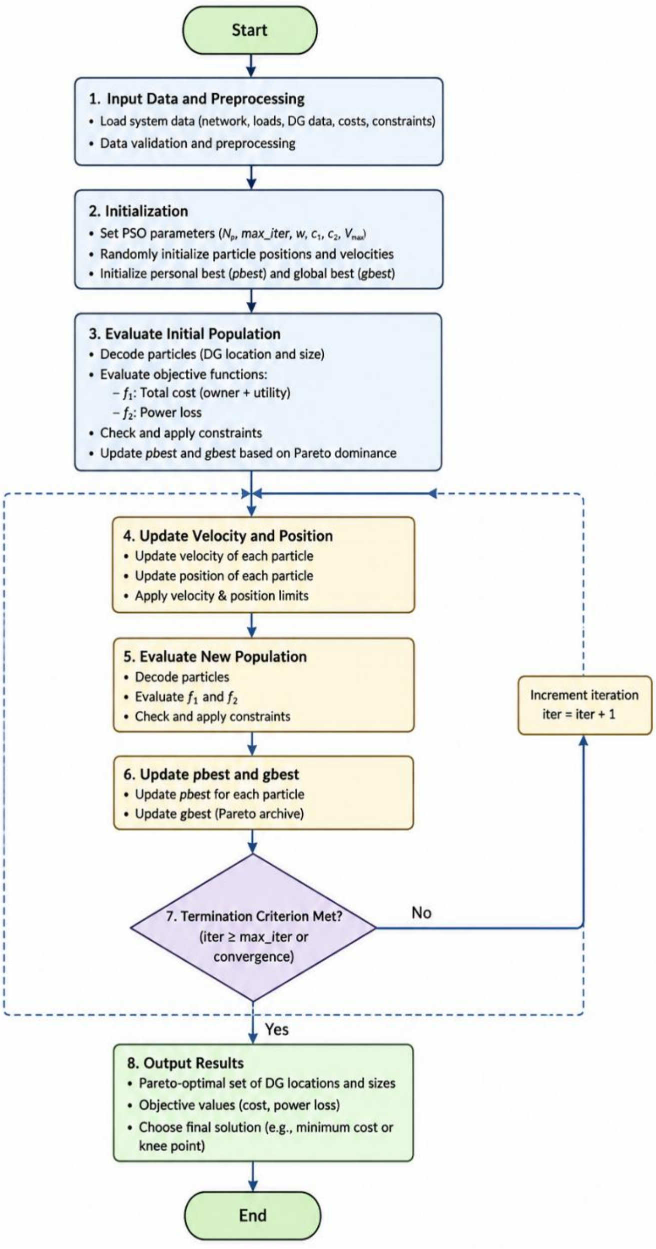

Fig. 3. Flowchart for the proposed PSO-based multi-objective optimization model.

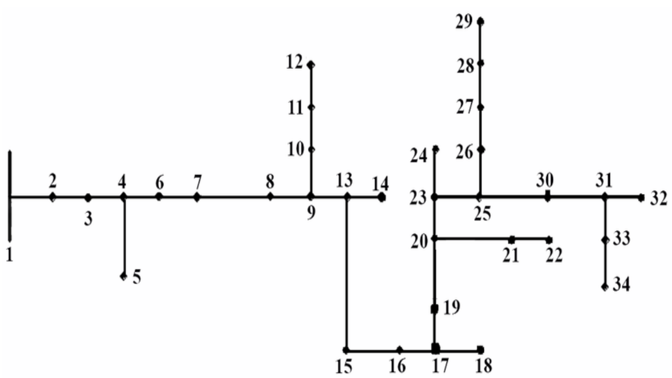

Fig. 4. IEEE standard 34-bus system.

Table 3. Consumer load data of the IEEE 34-bus system.

Bus No.	Voltage (p.u.)	Active Load (MW)	Reactive Load (MVAr)
1	1	0	0
2	1	1.7	1.12
3	1	0	0
4	1	0.0015	0.0009
5	1	0.0012	0.0008
6	1	0.033	0.04
7	1	0.0004	0.0002
8	1	0	0
9	1	0.0015	0.0009
10	1	0.04	0.026
11	1	0.02	0.0125
12	1	0.0018	0.0011
13	1	0	0
14	1	0	0
15	1	0.1713	0.1132
16	1	0	0
17	1	0.0035	0.0022
18	1	0.002	0.0012
19	1	0.015	0.0096
20	1	0.0022	0.0014
21	1	0.0064	0.004
22	1	0.218	0.149
23	1	0	0
24	1	0	0
25	1	0.0008	0.0005
26	1	0.0345	0.0222
27	1	0.0011	0.0002
28	1	0.0002	0.0001
29	1	0.002	0.0012
30	1	0	0
31	1	0.0795	0.0505
32	1	0	0
33	1	0.0041	0.0026
34	1	0.4569	0.2973

Table 4. Line parameters of the IEEE 34-bus system.

From Bus	To Bus	Resistance, R (p.u.)	Reactance, X (p.u.)
1	2	0.035	0.035
2	3	0.079	0.079
3	4	0.146	0.146
4	5	0.1406	0.1406
5	6	0.0195	0.0195
6	7	0.128	0.128
7	8	0.0216	0.0216
8	9	0.374	0.374
9	10	0.1543	0.1543
10	11	0.1439	0.1439
11	12	0.0325	0.0325
12	13	0.1191	0.1191
13	14	0.1219	0.1219
14	15	0.5622	0.5622
15	16	0.024	0.024
16	17	0.1158	0.1158
17	18	0.039	0.039
18	19	0.0135	0.0135
20	21	0.0856	0.0856
21	22	0.1843	0.1843
22	23	0.0979	0.0979
23	24	0.0946	0.0946
24	25	0.0025	0.0025
25	26	0.033	0.033
26	27	0.299	0.299
27	28	0.0449	0.0449
28	29	0.0232	0.0232
29	30	0.1367	0.1367
30	31	0.62	0.62
31	32	0.0413	0.0413
32	33	0.3021	0.3021
33	34	0.0824	0.0824

Table 5. Optimal DG placement results obtained by PSO.

Case	DG Capacity (kW)	Optimal Bus Location
1	254	13
2	300	13
3	149	13
4	143	10
5	91	8
6	47	16
7	49	4

4.1. Scenario 1: DG Installation at Bus 13 (245 kW)

In this scenario, the producer's profit is calculated as 364 USD, and the annual profit of the distribution network is obtained as 419,345 USD. Figure 5 illustrates the per-unit voltage of the buses, and Figure 6 shows the active power losses.

Figures 5 and 6 show that the installation of a 245 kW DG unit at Bus 13 enhances the voltage profile and decreases the active power loss in the distribution system.

4.2. Scenario 2: DG Installation at Bus 4 (49 kW)

In this scenario, the producer's profit is calculated as 8,387 USD, and the annual profit of the distribution network is obtained as 58,708,398 USD. Figure 7 illustrates the per-unit voltage of the buses, and Figure 8 shows the active power losses.

Figures 7 and 8 indicate that the 49 kW DG unit installed at Bus 4 maintains acceptable voltage levels while contributing to power loss reduction.

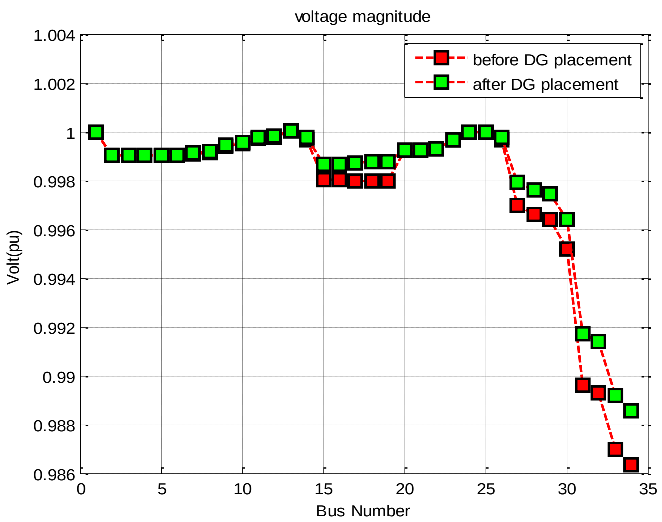

Fig. 5. Per-unit voltage of the buses in scenario 1.

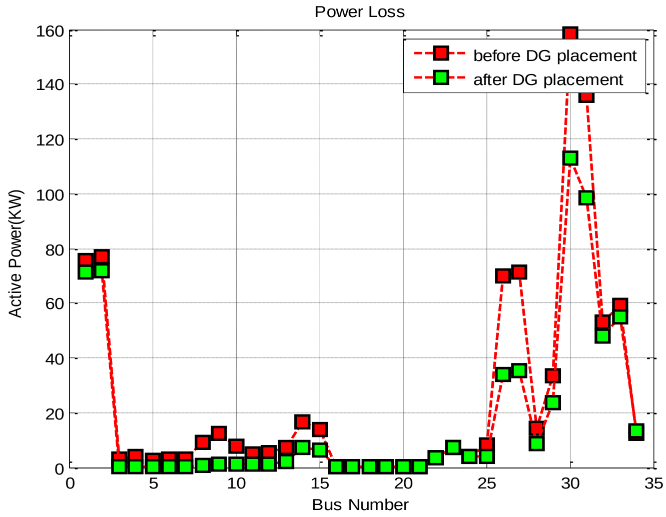

Fig. 6. Active power losses in scenario 1.

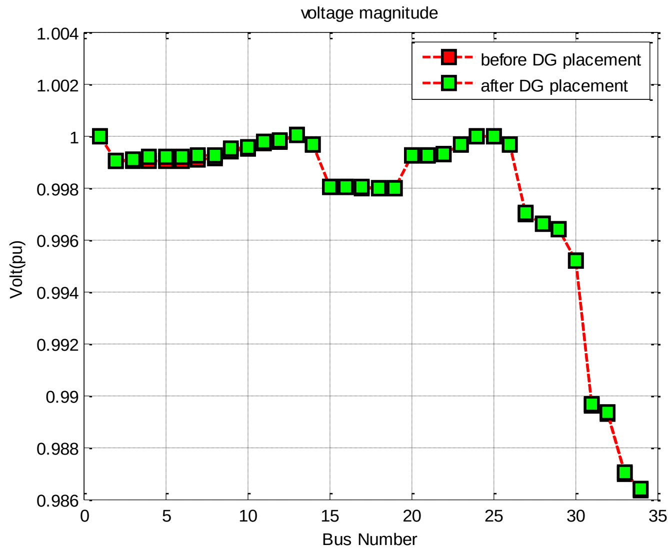

Fig. 7. Per-unit voltage of the buses in scenario 2.

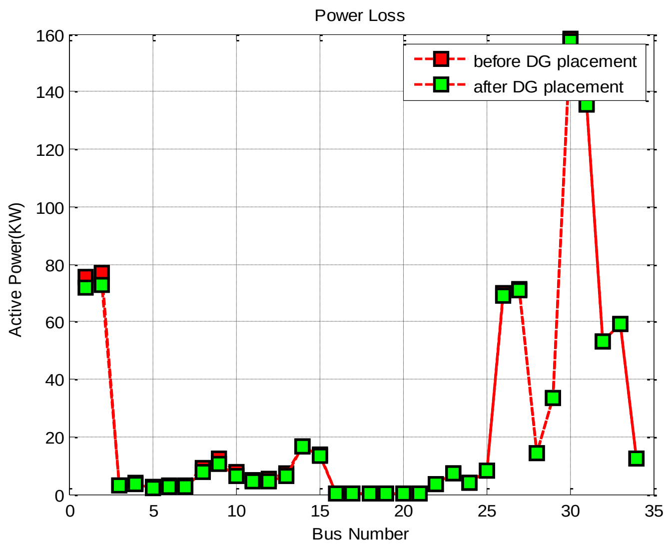

Fig. 8. Active power losses in scenario 2.

4.3. Scenario 3: DG Installation at Bus 10 (140 kW)

In this scenario, the producer's profit is calculated as 3,355 USD, and the annual profit of the distribution network is obtained as 167,738 USD. Figure 9 shows the voltage for each bus, while Figure 10 depicts active power loss.

It is clear from Figures 9 and 10 that the installation of the 140 kW DG generator at Bus 10 improves voltage profile and reduces active power loss.

4.4. Results and Discussion

This section discusses the results of the optimization process and provides a comparison between the PSO, GA, DE and GWO algorithms. Table 6 shows a comparative analysis between the suggested PSO approach to GA, DE and GWO approaches for solving DG planning problem.

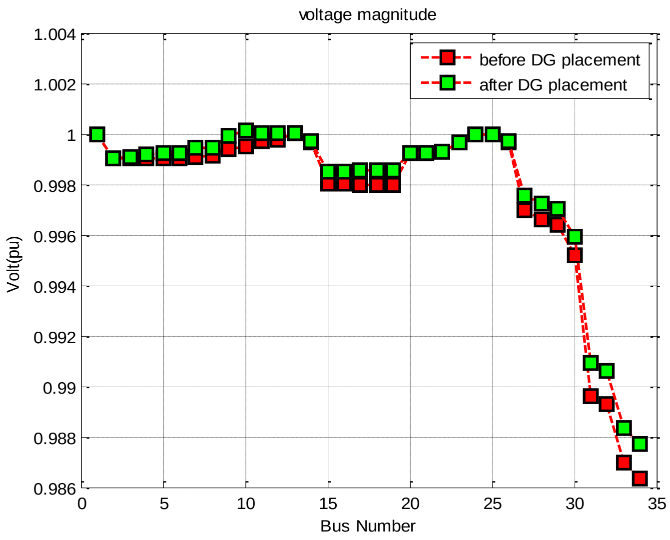

Fig. 9. Per-unit voltage of the buses in scenario 3.

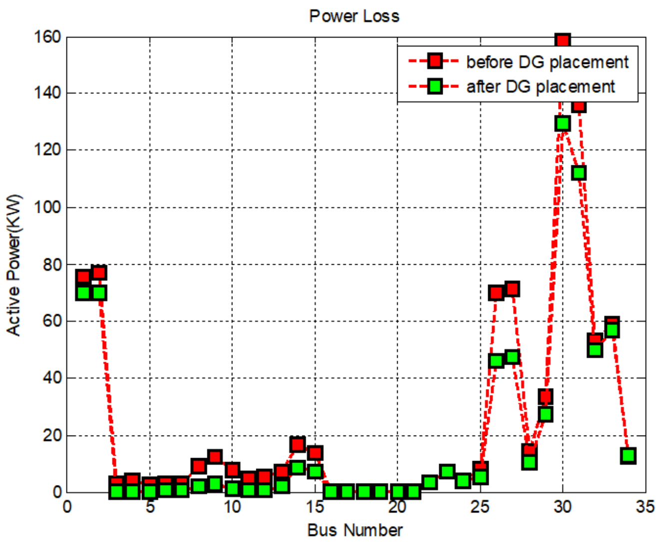

Fig. 10. Active power losses in scenario 3.

Table 6. Comparative performance of algorithms

Method	Optimal DG Size (kW)	Optimal Bus	Objective Function Value ($/year)	CPU Time (s)
GA	286	12	57,842,100	11.8
DE	291	13	58,105,420	9.7
GWO	295	13	58,314,500	8.6
PSO	300	13	58,716,785	6.9

To guarantee the statistical accuracy of the results, all the optimization approaches were run 30 times under the same settings. The best results are listed below in order to demonstrate the effectiveness of the proposed PSO algorithm in comparison with GA, DE and GWO. The PSO algorithm provided the best value of the objective function and spent the least amount of time for the calculation. Moreover, the optimal bus location provided by the PSO is the same as that of the GWO approach but with more economic advantages.

5. Conclusion

The developed algorithm in this study provided an optimization framework for the planning of distributed generations based on PSO algorithm with two objectives that provide economic advantages to DG owners as well as distribution companies. To prove the effectiveness of the developed technique, simulation results were provided for IEEE 34-bus distribution system taking into consideration all operational constraints. It is seen from these simulation results that power losses were reduced significantly and the economic advantage was increased along with the improvement of voltage profiles without violating operating limits. This proves that the PSO-based planning technique introduced in this work is a promising and feasible solution for DG planning problem.

Author Contributions

M.A.K. conceptualized the study, developed the methodology and software, performed the validation, formal analysis, and investigation, contributed to the resources and data curation, prepared the original draft of the manuscript, reviewed and edited the manuscript, performed the visualization, supervised the research, and administered the project; P.N. contributed to the conceptualization, methodology, software development, validation, formal analysis, investigation, resources, and data curation, prepared the original draft of the manuscript, reviewed and edited the manuscript, and performed the visualization; M.J. contributed to the conceptualization, methodology, software development, validation, formal analysis, investigation, resources, and data curation, prepared the original draft of the manuscript, reviewed and edited the manuscript, performed the visualization, supervised the research, and administered the project. All authors have read and approved the final version of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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