RESEARCH ARTICLE

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# Optimal Distributed Generation Placement and Economic Analysis for Enhancing the Active Radial Distribution System using BPSO

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## Abstract

Dispersed generation (DG) are known to improve the reliability of electrical grids. However, to maximize their benefits, it's essential to ensure that DG units are optimally sized and positioned. Poor placement can have adverse effects on power grids, causing voltage profile degradation and an increase in power loss. Various methods have been recommended to determine the best size and location for DG units. This article focuses on establishing a technique for optimal scheduling and operation of DG units to reduce power-loss, improve voltage contour, and enhance network reliability. The Binary particle swarm optimization (BPSO) artificial intelligence method is implemented to find the optimal node and DG size. The applicability of BPSO is demonstrated using the IEEE 33 distribution system with Typ-1 DG, with results compared with other methods. The evidence clearly demonstrates that BPSO reigns supreme over all other methods.

**Keywords:** Distributed generation, BPSO, Active power enhancement, economic analysis, voltage profile enhancement

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## Introduction

Electricity is typically generated by conventional power stations located near the main sources of energy.[1,2,3] The energy is then sent through long transmission lines to users on distribution grids. Unfortunately, power-losses are high due to the current being high and the voltage being low. To improve the voltage profile and decrease distribution grid losses, distributed generation (DG) is becoming a popular solution. [4,5] It's imperative to note that numerous electrical power infrastructures are outdated, and they need to be expanded to cater to the surging energy demand.[27,30] There are multiple cost-effective options are available to expand these networks, including capacitor insertion, reconfiguring network feeders, upgrading conductors, and allocating DG. [10,11]

Distributed generation, is a renewable energy source that is typically small-scale and located close to the area where electricity is being used.[13,14] When DG is connected to the electrical grid, it has the ability to minimize power-loss and enhance the voltage profile [6,7,8]. As concerns about the environment and the cost and availability of traditional fuel sources have increased, DG units have become more common in power distribution systems.[9,12] Distributed generation units (DG) that utilize renewable energy sources such as solar, wind, geothermal, hydro, or biomass are deemed environmentally friendly owing to their minimal carbon footprint, which leads to reduced greenhouse gas emissions. [26] Implementing these "green" energy sources not only aids in reducing the detrimental impact on the environment but also contributes to the sustainability of our planet.[15,16] While this trend has created many prospects in the power sector, it has also presented challenges in terms of planning and controlling the distribution grid.

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The aids of using DG units include improved stability in voltage profile, superior reliability, and lower power-loss. [19,20] However, poorly planned or functioning DG units can cause problems like reverse power flows, overloaded feeders, and undue power loss. [22,24] In systems with a high level of DG penetration, there may be issues with voltage upsurge due to the reverse flow of electricity. [17,18] Additionally, incorrect sizing or positioning of DG units can lead to significant power losses. Therefore, integrating multiple DG units can help address the operational problems that arise in grids. [25,29] However, to maximize these benefits, it is important to accurately calculate the optimum size and position of DG units.

Therefore, it is necessary to explore methods for effectively sizing and allocating DG units in a power system. [37,38] Numerous research studies have been carried out with the aim of enhancing the effective incorporation of optimal Distributed Generation (DG) units into electrical networks. These studies have primarily focused on achieving two main objectives: boosting voltage levels and minimizing power-losses. [33,34] The findings of these studies are expected to facilitate the development of better strategies for integrating DG units into electrical networks, thereby enhancing the overall efficiency and reliability of power systems. [8, 39] Various techniques have been suggested for identifying the appropriate size and DG location in distribution grids. Initially, traditional computational methods were proposed for the ideal allocation of DG in distribution grids [18, 23]. Although these methods considered dynamic loads and addressed the convergence issue, they did not measure the optimal DG sizing.

There are numerous methods for optimizing the apportionment of DG to reduce power loss, contingency, and emissions. [17,21] One such method is simulated annealing (SA), which has been successfully used in previous studies [13, 19]. Another method proposed in aims to curtail costs associated with losses and the number of DGs [16,17]. Enhanced methodical techniques (IA) [21] and machine learning (ML) techniques [32] have also been developed for this purpose. Other optimization techniques, such as artificial bee colony (ABC) [36,37] and cuckoo search (CS) [33], have been anticipated to reduce power loss. However, only a few studies have focused on renewable DGs, including ant lion optimization (ALO) and the Backtracking search algorithm (BSA). The Flower pollination algorithm (FPA) has also been used to define the size and position of DGs [34,35]. Kamarposhti et al. proposed using ABC to find the optimal placement of DGs and capacitors to minimize power loss and ENS [14].

In this study, a method called Binary particle swarm optimization (BPSO) is projected to optimize the sizing and positioning of DG units in distribution grids. This is a complex optimization problem, but the PSO method has proven to be operative in obtaining global solutions and overcoming the limitations of traditional algorithms. The goal is to reduce losses and enhance the profile of the voltage by finding the ideal operation of DG units using BPSO techniques. The Backward/Forward Sweep algorithm is used [28,31]. The performance of the BPSO method is analyzed on a 33-bus network to establish its robustness. The results show that adding DG units to the radial power network ominously progresses the voltage profile and reduces loss. The BPSO method is implemented using MATLAB, and the allocation of two DG unit leads to better improvements than allocating only one. [26,30] In conclusion, the attained results demonstrate noteworthy enrichments in voltage contour, loss reduction, and dependability improvements.

# Problem Formulation

The utilization of Binary-Particle Swarm Optimization (BPSO) is employed in this study to identify the optimal location of Distributed Generation (DG) which can effectively decrease loss of power ($P_{Loss}$) and enhance voltage profile while instantaneously considering various variables. Equation (1) [20] displays the formula for computing $P_{Loss}$ in an electrical network.

This article considers two targets for the use of BPSO in electrical systems. These two goals are:

- Minimize total power loss (PL).
- Maximize the voltage of each bus without violating boundary rule (V).

The main purpose of the feeder reconfiguration is to reduce power loss by:

$$\mathrm{Min}(P_L) = \sum_{y=1}^{Ml} \sum_{x=1}^{N} k|I_x|^2 R_x \text{ ........ } (1)$$

Where,

k= status of the switch.

$I_x$= current at different nodes.

$R_x$= Resistance of each branch.

The equation finds total power loss no. (1)

$P_i = P_{DG} - P_{Li}$

$Q_i = -Q_l$

$$P_L = \sum_{i=1}^{b} G_i (V_j^2 + V_k^2 - 2V_j V_k \cos(\delta_j - \delta_k) \text{ ........ } (2)$$

Where,

b= total branches

$G_i$ = conductance at the sending end and receiving end of the $i^{th}$—branch.

$V_j$=voltage at 'j' bus.

$V_k$ = voltage at 'k' bus.

$\delta_i$, $\delta_k$ = voltage angles of bus 'j' and bus 'k'.

The magnitude of the voltage and phase angle constraints are circumscribed between the upper and lower limits.

The Voltage and angle constraints are as follows:

$$V_j^{Mini} \leq V_j \leq V_j^{Maxi} \quad (3)$$

$$\delta_j^{Mini} \leq \delta_j \leq \delta_j^{Maxi} \quad (4)$$

Where,

$V_j^{Mini}$, $V_j^{Maxi}$ = Minimum and maximum ranges of voltages, respectively.

$\delta_j^{Mini}$, $\delta_j^{Maxi}$ = Minimum and maximum ranges of voltages angle, respectively.

The Power limit is as follows:

$$P_{T,Loss} + \sum P_{D_i} = \sum P_{DG_i} \quad (5)$$

# BPSO Algorithm

Many researchers have considered using the algorithm of animals, such as fish schooling and bird flocking, to search for food due to its proven strength, ease of execution, and ability to explore numerous applications. The BPSO (Binary Particle Swarm Optimization) technique models potential solutions as individuals, wherein each individual symbolizes a candidate solution. Collectively, these individuals form a swarm, representing a group effort in solving optimization problems. Through iterative steps, each particle's position in the search space corresponds to a unique solution. Particles collaboratively navigate the search space by sharing information about their personal best and the globally best solution within the swarm, adjusting their positions based on various factors. This process emulates the cooperative behavior of particles in a swarm, guiding them to converge toward optimal or near-optimal solutions for the given optimization problem. Kennedy and Eberhart first developed this algorithm in 1995. In the PSO algorithm, each individual has a local best position (Pbest) and a global best position (Gbest). The velocity (Vi) and position (Xi) from Pbest to Gbest of the agents are changed using equations (7) and (8).

## Process for optimum reconfiguration using BPSO

**Step 1**: Initializes the amount of items nominated for the radial electrical system from the dependent variation matrix.

**Step 2**: Randomize the speed of the selected coupling mode using equation (5) and update the position of each of the corresponding buses using Equation 6 [1].

$$V_{ij}^{t+1} = \omega V_{ij}^{t} + c_1 r_{1j}^{t}\left[P_{best,i}^{t} - x_{ij}^{t}\right] + c_2 r_{2j}^{t}\left[G_{best,i}^{t} - x_{ij}^{t}\right] \quad (5)$$

$$X_i^{k+1} = X_i^{k} + V_i^{k+1} \quad (6)$$

$$S(V_{ij}) = \frac{1}{(1+e^{-v_{ij}})} \quad (7)$$

$$X_{ij} = \begin{cases} 1 \; if \; rand(s) \le S(v_{ij}) \\ 0 \; otherwise \end{cases}$$

**Step 3**: Base combination is taken for local optimum for IEEE 33; Pbest is obtained when the radiality of the mesh is not affected. And these values are stored in local memory as historical values to be compared with subsequent data.

**Step 4**: With reference to the bus voltage sensitivity index, place the DG on the suitable bus and repeat steps 2 and 3 until the target is reached.

**Step 5**: Repeat Step 3 until you reach the maximum reps.

**Step 6:** Pick the best configuration among all configurations (i.e. $G_{best}$).

$$G_{best} = \min\{P_{best,t}^{t}\}$$

# Results And Discussion

An efficient algorithm utilizing MATLAB and MATPOWER Library is proposed in this study to effectively operate one and two DG units for reducing the overall loss and voltage contour enrichment. It is strongly recommended to utilize solar photovoltaics as the DG source. The detailed results pertaining to the IEEE 33 bus can be found below.

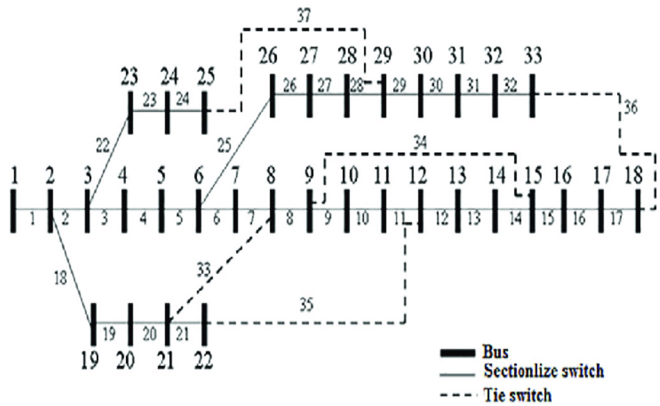

**Figure 1:** IEEE 33-bus radial structure [1]

**Table 1:** loss profile and voltage magnitude for each bus for 33-bus without insertion of DG

| No. of Buses | Voltage in p.u. | Power loss in kW |
|---|---|---|
| 1 | 1.0000 | 202.26 |
| 2 | 0.9982 | 2.641 |
| 3 | 0.9909 | 13.398 |
| 4 | 0.9863 | 7.602 |
| 5 | 0.9807 | 3.477 |
| 6 | 0.9673 | 7.043 |
| 7 | 0.9620 | 1.513 |
| 8 | 0.9572 | 4.592 |
| 9 | 0.9468 | 6.534 |
| 10 | 0.9372 | 4.810 |
| 11 | 0.9361 | 4.109 |
| 12 | 0.9342 | 1.479 |
| 13 | 0.9263 | 5.322 |
| 14 | 0.9222 | 1.755 |
| 15 | 0.9190 | 2.479 |
| 16 | 0.9156 | 1.727 |
| 17 | 0.9116 | 3.030 |
| 18 | 0.9110 | 1.298 |
| 19 | 0.9908 | 4.390 |
| 20 | 0.9902 | 37.751 |
| 21 | 0.9889 | 9.525 |
| 22 | 0.9888 | 15.829 |
| 23 | 0.9859 | 8.722 |
| 24 | 0.9841 | 17.886 |
| 25 | 0.9824 | 11.847 |
| 26 | 0.9595 | 1.313 |
| 27 | 0.9416 | 1.710 |
| 28 | 0.9303 | 7.019 |
| 29 | 0.9224 | 4.136 |
| 30 | 0.9194 | 3.073 |
| 31 | 0.9134 | 3.028 |
| 32 | 0.9115 | 0.725 |
| 33 | 0.9097 | 0.487 |

## IEEE 33 bus

The data in [28] provides information on three different scenarios in this study. These scenarios include no DG, one DG, and two DG, and they are used to showcase how the presented BPSO algorithm solves the DG placement problem. The analysis of all instances is compared to identify the most effective solution.

### *Scenario 1: without insertion of DG*

The base case shows that buses 17, 18, 32, and 33 had the lowest voltage, with readings of 0.9117, 0.9112, 0.9156, and 0.9098. The system's load was $P_{load}$=3720 kW and $Q_{load}$=2345 kVAr, and the total loss was 202.26 kW incorporating DG.

### *Scenario 2: with one DG*

The BPSO technique was used to define the optimal candidate node and DG sizing for reducing loss and enhancing voltage contour in IEEE 33. To evaluate the effectiveness of PSO, results obtained from other techniques such as GA, HSA, BA, and CSA were compared. The installation of DG size of 620.59 kW on Bus 4 using BPSO resulted in a substantial reduction in power loss from 202.26 to 123.88 kW, which was the lowest compared to other algorithms as shown in Table-2 and Figure 2. The reduction in the loss was approximately 38.75% compared to the scenario with base case [1]. The results demonstrate that BPSO offers the best outcome among all algorithms.

After the installation of the DG, the voltage contour improved significantly as presented in Figure 4.

**Table 2:** Examining BPSO efficiency for DG placement

| *Techniques* | *Power loss (kW)* | *% Power-Loss* | *Location of DG* | *Size of DG (kW)* |
|---|---|---|---|---|
| Base case | 203.27 | 0 | | |
| BPSO | 124.49 | 38.76 | 4 | 623.69 |
| PSO | 130.68 | 35.71 | 3 | 595.05 |
| GA. | 133.3 | 34.42 | 6 | 2391.90 |
| HSA | 144.95 | 28.69 | 18 | 898.57 |
| BA | 137.89 | 32.16 | 15 | 820.38 |
| CSA | 132.76 | 34.68 | 8 | 2547.37 |

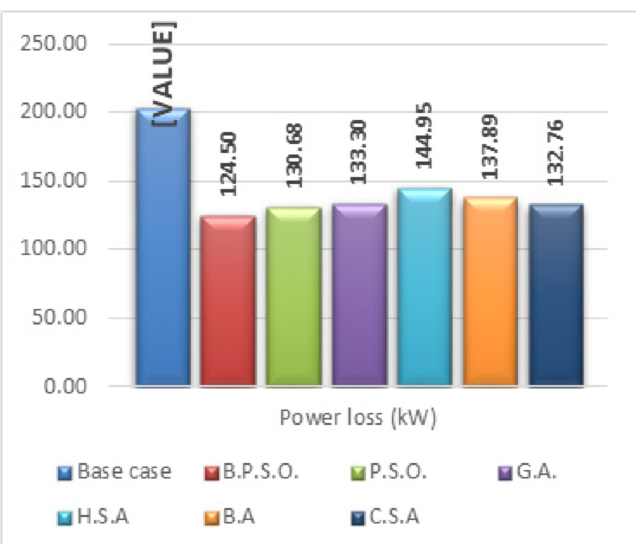


**Figure 2:** Loss comparison after and before incorporating one DG.

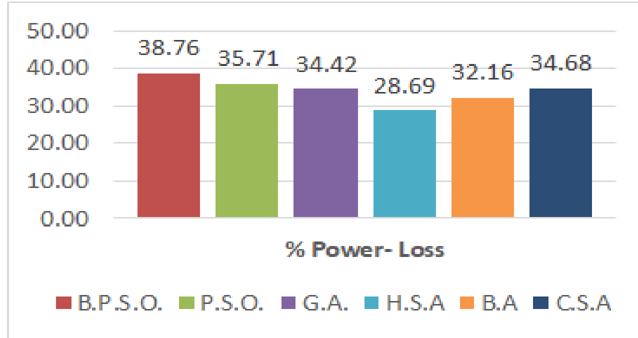


**Figure 3:** Comparisons of percentage power loss reduction incorporating two DG

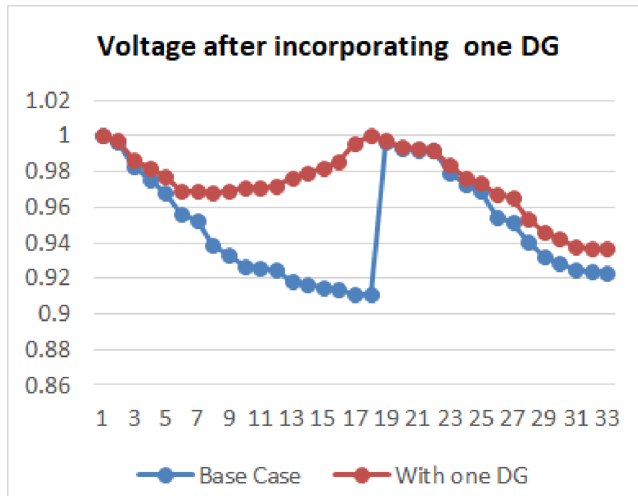


**Figure 4:** Voltage with and without one DG incorporation using BPSO

**Table 3:** Examining BPSO efficiency for two DG placement

| *Techniques* | *DG node* | *DG-size (kW)* | *PLoss (kW)* | *% PLoss* |
|---|---|---|---|---|
| Base case | - | - | 202.26 | 0 |
| BPSO | 18, 31 | 633.81, 200.19 | 72.8954 | 63.95 |
| PSO | 18,33 | 438.55, 394.69 | 86.12 | 57.42 |
| GA | 6, 8 | 1718.0, 840.0 | 96.58 | 52.22 |
| HSA | 17, 18 | 693.19, 201.3 | 141.14 | 30.21 |
| BA | 15, 25 | 952.4, 952.4 | 112.88 | 44.11 |
| CSA | 16, 26 | 1073.4, 1326.3 | 103.90 | 48.65 |

### *Scenario 3: with two DG*

The BPSO technique is used to attain the goal of loss minimization (*PLoss*) and voltage enrichment of the IEEE 33 bus by incorporating DG. Table 3 exhibits the results acquired using BPSO. To compare the effectiveness of the presented BPSO technique with others as presented in the literature, results attained by BPSO were compared to

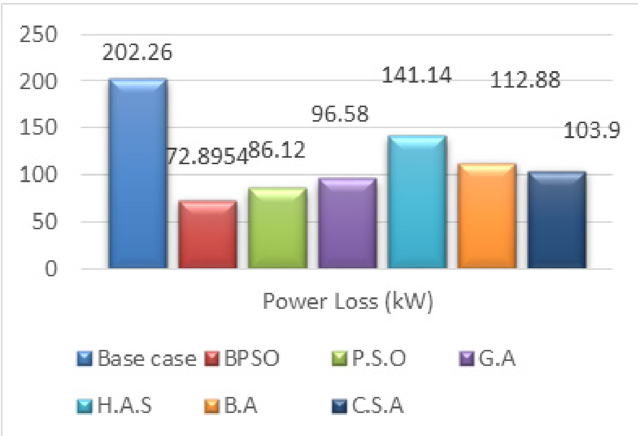


**Figure 5:** Power-Loss comparison before and after incorporating two DG.

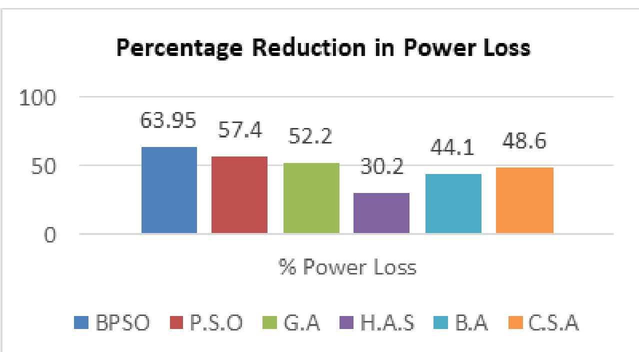


**Figure 6:** Comparisons of percentage power loss reduction installing two DG.

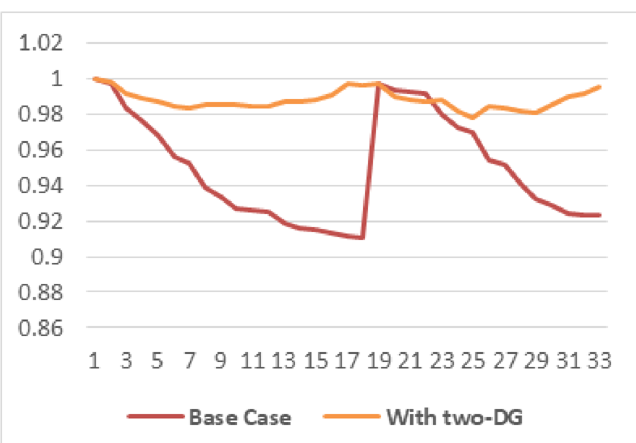


**Figure 7:** Voltage contour for two different case using BPSO

**Table 4:** Voltage contour for IEEE 33-bus under different scenarios using BPSO

| *Node* | *Scenario-1* | *Scenario-2* | *Scenario-3* |
|---|---|---|---|
| 17 | 0.9114 | 0.9454 | 0.9968 |
| 18 | 0.9108 | 0.9444 | 0.9955 |
| 32 | 0.9236 | 0.9951 | 0.9972 |
| 33 | 0.9233 | 0.9782 | 0.9899 |

**Table 5:** Voltage profile for IEEE 33-bus under three different conditions

| *Bus No.* | *Base Case* | *With one-DG* | *With two-DG* |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 0.997 | 0.9971 | 0.9982 |
| 3 | 0.9829 | 0.987 | 0.9913 |
| 4 | 0.9755 | 0.9825 | 0.9891 |
| 5 | 0.9681 | 0.9782 | 0.9873 |
| 6 | 0.9561 | 0.9717 | 0.9843 |
| 7 | 0.9526 | 0.9711 | 0.9836 |
| 8 | 0.939 | 0.9605 | 0.985 |
| 9 | 0.9328 | 0.9562 | 0.9854 |
| 10 | 0.927 | 0.9552 | 0.9849 |
| 11 | 0.9261 | 0.9551 | 0.9843 |
| 12 | 0.9246 | 0.9658 | 0.9844 |
| 13 | 0.9185 | 0.9633 | 0.9868 |
| 14 | 0.9162 | 0.9625 | 0.9872 |
| 15 | 0.9148 | 0.9501 | 0.9882 |
| 16 | 0.9134 | 0.9483 | 0.9907 |
| 17 | 0.9114 | 0.9454 | 0.9968 |
| 18 | 0.9108 | 0.9444 | 0.9958 |
| 19 | 0.9965 | 0.9951 | 0.9972 |
| 20 | 0.9929 | 0.9782 | 0.9899 |
| 21 | 0.9922 | 0.9736 | 0.988 |
| 22 | 0.9916 | 0.9709 | 0.9865 |
| 23 | 0.9794 | 0.9834 | 0.9877 |
| 24 | 0.9727 | 0.9768 | 0.9811 |
| 25 | 0.9694 | 0.9735 | 0.9778 |
| 26 | 0.9542 | 0.9699 | 0.9838 |
| 27 | 0.9516 | 0.9676 | 0.9832 |
| 28 | 0.9403 | 0.9571 | 0.9815 |
| 29 | 0.9321 | 0.9496 | 0.9806 |
| 30 | 0.9286 | 0.9464 | 0.9846 |
| 31 | 0.9245 | 0.943 | 0.9895 |
| 32 | 0.9236 | 0.9423 | 0.9917 |
| 33 | 0.9233 | 0.9441 | 0.9955 |

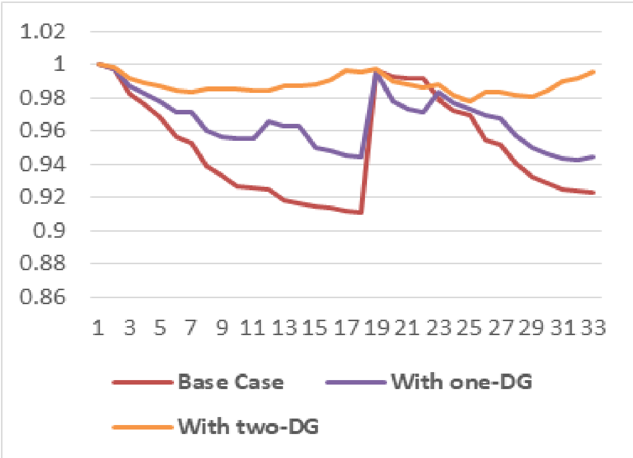


**Figure 8:** Voltage contour with three scenarios for IEEE 33-bus using BPSO

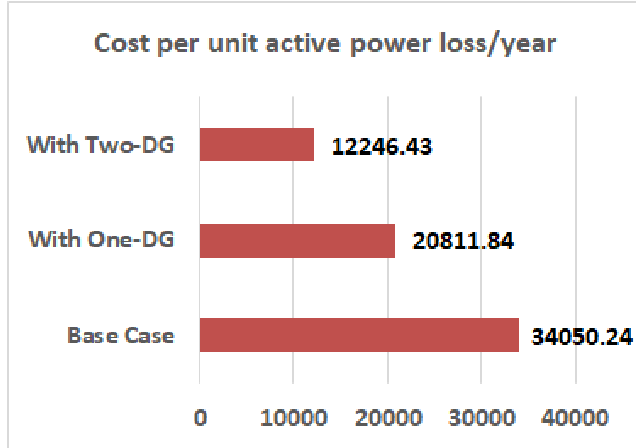


**Figure 10:** Comparison of cost per unit active power with three scenarios for IEEE 33-bus using BPSO

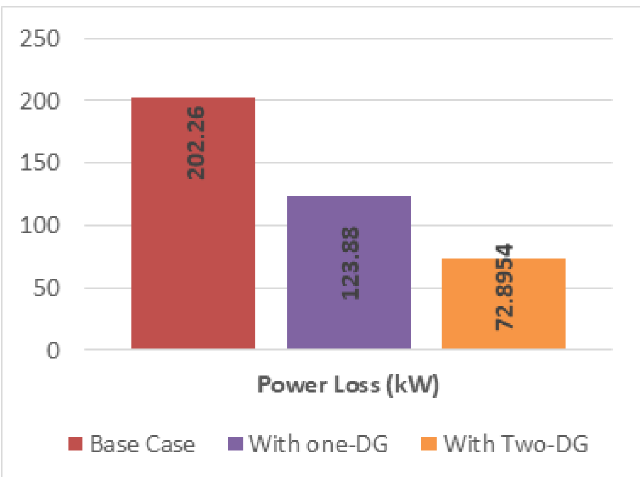


**Figure 9:** Loss comparison with three scenarios for IEEE 33-bus using BPSO

**Table 6:** Economic analysis under three different conditions

| Scenario | Power Loss (kW) | Cost per unit active power loss/year | Savings in cost ($/Year) |
|---|---|---|---|
| Base Case | 202.68 | 34,050.24 | |
| With One-DG | 123.88 | 20,811.84 | 13,238.40 |
| With Two-DG | 72.8954 | 12,246.43 | 21,803.81 |

those attained by PSO, HSA, BA, CSA, and GA. The global loss of power was significantly abridged from 202.26 to 72.8954 kW after incorporating 633.81 kW for the 1st DG on Bus-18 and 200.19 kW for the 2nd DG on Bus-31 using BPSO. The reduction in power- loss is almost 63.95% compared to different scenarios. Table-3 and Figure 5 demonstrate that BPSO delivers the lowest power- loss and superior outcomes among all other methods.

The system's nodes 17, 18, 32, and 33 saw significant improvement in performance after two DG units were installed. Their original values of 0.9114, 0.9108, 0.9236, and 0.9233, respectively were enhanced to 0.9968, 0.9955, 0.9971, and 0.9955. This improvement was much faster compared to both scenarios. The voltage at all nodes also showed a considerable increase, as seen in Figure 7.

### *Three scenarios comparison*

Adding a Distributed Generation (DG) unit can improve the voltage levels across all buses in the system while also reducing power loss. This can lead to a more consistent and higher-quality distribution network, resulting in increased consumer and supplier satisfaction. While one DG unit can improve voltage at lower levels, adding a second unit can further enhance voltage levels across buses, as depicted in Figure 7. Table-4 also shows substantial improvements in minimum voltage levels for different case, with the installation of two DG leading to substantial improvements at buses 17, 18, 32, and 33.

After comparing the total power loss in three different scenarios, it was noted that the power loss decreased from 202.260 kW in the base case to 130.04 kW with the installation of single DG unit and to 86.1258 kW with the installation of two DG units. It was also observed that connecting two DG units caused the highest reduction in power loss. Additionally, it was found that the anticipated BPSO algorithm outperformed other processes in the literature in terms of least voltage, power loss reduction (%), and loss of power in 'kW' in all scenarios.

Significant reduction in cost can be attained by minimizing losses over and done with the incorporation of DG units. The feasibility of placing two DG is evident from Figure 10, demonstrating a substantial cost reduction.

## Conclusion

A highly efficient method was implemented to define DG's ideal size and placement within a power grid to minimize power loss and improve the voltage contour. The BPSO-based approach was employed as a reliable tool for optimization to decrease the power loss contour ($P_{Loss}$) and enhance the voltage profile by identifying the optimal location and capacity of DGs. The IEEE-33-bus system was used to exhibit the validity of this approach, and it included various scenarios such as single and multiple DG deployment cases and a no-DG system comparison. The results exhibited that DGs' capacity and position significantly impacted minimizing power loss and improving the voltage contour. Furthermore, the proposed solution provided notable results compared to other processes in the literature. The BPSO method successfully identified the suitable location and DG capacity in all scenarios, as demonstrated by the study's findings.

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