SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I9P108

Volume 10 Issue 9, 86-94, September 2023
© 2023 Seventh Sense Research Group®

*Original Article*

# A Hybrid Approach for the Optimization of D.G.s in the Practical Radial Distribution System to Enhance Power Quality and Reliability

Keerthishree V[1], Ravishankar B S[2], Mohan N[3]

[1,2,3]*Electrical and Electronics Engineering, JSS Science and Technology University, Mysore, Karnataka, India.*

[1]*Corresponding Author : keerthishreev1994@gmail.com*

Received: 12 July 2023 Revised: 16 August 2023 Accepted: 09 September 2023 Published: 30 September 2023

***Abstract*** *- The main aim of the proposed work is to reduce the losses and to improve the voltage profile. The multi-objective-based meta-heuristic Artificial Bee Colony (ABC) and Hill Climbing (H.C.) algorithms are developed for optimal planning of multiple D.G.s under different load conditions. The optimal size and location of multiple D.G.s obtained from the proposed algorithm based on a multi-objective index reduces the real and reactive power loss and improves the voltage profile. The optimal solution for D.G. integration varies depending on the type of load. The new algorithm is proposed to address the issues of integration of multiple D.G.s, and the algorithm is validated by applying it to a practical 12-bus system with high voltage losses and poor voltage regulation under different load types.*

***Keywords*** *- Distributed Generators (D.G.s), Power quality, Reliability, Voltage profile, Optimal placement, Artificial Bee Colony (ABC), Hill Climbing (H.C.) algorithms.*

## 1. Introduction

In recent days, the demand for electrical energy has been increasing day by day. Researchers are trying to offer new technology that ensures continuous, consistent, and more reliable power to consumers. Converting conventional transmission and distribution systems to enhance capacity is time-consuming, inefficient, and complex. Traditional methods can be replaced with alternative energy sources available near load centres. Distributed Generators (D.G.s) are the alternate solution to this problem, supplementing the grid's energy supply with alternative energy sources.

Later on, the interface of D.G.s is more commonly used for voltage support, loss reduction, and improving reliability. However, integrating D.G.s into the distribution system is an essential criterion. Improper placement of D.G. creates many problems in the design, including voltage imbalance, circuit breaker malfunction, and stability challenges. Optimal planning of D.G.s is a crucial aspect of power system management, focusing on determining the optimal location, sizing, and operation of D.G.s to improve the overall system's efficiency, reliability, and cost-effectiveness. Still, it can impact adversely if D.G. is not connected optimally. The field of optimal D.G. planning is continuously evolving, and many intelligent algorithms are available for deciding the optimal location and sizing of D.G., which provides appropriate results to enhance the system operation by suggesting optimal location and sizing. The single and multiple objective functions are found in the literature. Optimal planning of multiple D.G.s with the implementation of Particle Swarm Optimization (PSO) algorithms tested for different loads such as residential, commercial, Industrial, and mixed loads have been addressed, and the optimal solution for D.G. planning is other for different load models [1-3].

The distribution network power quality issues are addressed by finding the optimal series capacitor using the Tabu Search (T.S.) and Improved Grey Wolf Optimization method (I-GWO) hybrid algorithm. However, the approached technique has limitations in the distribution system [4]. A detailed survey covers the impact of D.G.s on power quality, relay protection, system reliability and power dispatch, and the solutions addressed by the authors are consolidated. According to the author, the constant load validates their methodologies [5].

The Harris Hawk Optimization (HHO) algorithm is presented to solve the problem of integrating different types of D.G.s, which could include sources like solar Photovoltaics (P.V.), wind turbines, and other renewable and non-renewable sources, into a radial distribution system with constant load [6-8]. The algorithm introduced is termed a "student psychology-based optimization algorithm".

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

It is likely designed to achieve various objectives, such as minimizing power losses, improving voltage profiles, and enhancing system reliability and stability by OPDG [9]. The authors discuss the evaluation of how the integration of D.G. impacts the reliability of a distribution system with the help of reliability indices, utilizing the DIgSILENT power factory software [10]. In paper [11], the IEEE 14 bus system was tested using ETAP software for finding the optimal location and sizing of D.G. also, various reliability indices have been studied. A combination of analytical and PSO approaches is presented for OPDG to reduce power losses.

The proposed technology is validated on IEEE 33 and 69-bus test systems. The computational time is higher because of the analytical approach [12]. The detailed review of OPDG is presented by tabulating the last ten years of research. According to the author, hybrid algorithms are faster, and meta-heuristic approaches are accurate and perform significantly [13]. The topic of optimum D.G. planning in power systems is dynamic, with recent trends developing. Based on previous papers, the authors have proposed several optimization strategies to solve the issue of D.G. integration. However, the load evaluated for the assessment is constant, and the ideal solution varies depending on the kind of load. Few studies in this field give an optimum approach for D.G. planning under various load scenarios.

As a result, achieving an ideal solution under different load situations is crucial for enhancing the distribution system's performance. Hence, the proposed research presents a multi-objective hybrid Artificial Bee Colony (ABC) and Hill Climbing (H.L.) algorithm to find an optimal power quality and reliability solution in the practical radial distribution system under different load conditions. The remainder of the article is organized as follows: Section 2 outlines the mythology employed in the proposed work, Section 3 discusses the results, and Section 4 summarizes the conclusion.

## 2. Proposed Methodology

The present work aims to determine multiple D.G. units' optimal location and size to limit voltage variation and reduce line losses. Power quality and reliability analysis are performed for the base case and multiple D.G. connections; the same has been tested for different load conditions. Artificial Bee Colony (ABC) and Hill Climbing (H.C.) algorithms have been used to determine the optimal location and size. The system's performance will be enhanced with the surety of better-quality power, which ensures the reliability of power. The optimal placement of multiple D.G. problems can be determined using optimization algorithms such as the global search algorithm Artificial Bee Colony (ABC) and the local search algorithm Hill Climbing (H.C.). These intelligent algorithms are explained as follows:

### *2.1. Artificial Bee Colony*

Artificial Bee Colony is a swarm-based meta-heuristic algorithm. The ABC is the most effective algorithm because it depends on the objective, constraints, and relevant information and highly depends on the fitness function in the search process. The ABC algorithm consists of four main phases, i.e., initialization, employed bee searching process, onlooker bee searching process, and selection process.

The employer of a particular food location is assigned to look around the area for a new food source. This employer bee searches for the fittest reference. This algorithm works on a fitness function, which provides the most appropriate solution for a particular problem: finding the optimal place and size of multiple D.G. for different types of loads connected to other buses. The fitness function can be calculated as

$$F = \min {}^{f_1}/_{f_2}$$

Employer bees exchange information with onlooker bees so that onlooker bees select foodstuffs the same as the honeybee algorithm. This onlooker bee compares different attempts to choose a better solution by comparing the probability of getting a fitness value [11]. The possibility $Pi$ of the onlooker bee searching a particular food source $xi$ can be defined as

$$P_i = \frac{F(x_i)}{\sum_{j=1}^{s} F(x_j)}$$

Where S is the number of food sources at the preferred food source, efficiency is found by F/T, where F is the amount of food and T is the time spent at a food source that is explored for a certain number of iterations. If there is no improvement, the food source is rejected, and bees at this location search for a new one.

### *2.2. Hill Climbing*

Hill climbing is a local search-based algorithm that continuously moves on a positive slope to find the peak value of the mountain where no neighbour has the highest weight or best solution. It terminates when it reaches its peak value, i.e., the best solution. The algorithm has the following steps to solve the problem:

Step 1 : Initialize the input/output parameters and evaluate the present state. If the current state is the final step, then stop the process.

Step 2 : If it does not reach the expected outcome, keep testing (looping) until the best solution is achieved.

Step 3 : If the best solution is not reached in the above step, the looping process continues, and a new key is obtained.

Step 4 : Evaluate the new solution. If the newly acquired state has a greater value than the current state, which was obtained in steps 1 and 2, then decide whether it is a present state (a better solution).

Step 5 : This process will continue from steps 1 to 4 until a goal state (best solution or fittest value) is attained. If this is the case, then exit the process. Then, exit the process.

### *2.3. ABC-HL Algorithm*

A combination of ABC and H.C. algorithms to solve an optimization problem is known as a hybrid ABC-HC algorithm, which includes the advantages of ABC and H.C. algorithms to solve optimization problems. In this proposed methodology, the ABC-HC hybrid algorithm is an optimization technique used to determine the optimal allocation of multiple D.G. in a radial distribution system. The hybrid architecture of ABC-HC is shown in Figure 1, which follows the steps as follows to arrive at a solution:

Step 1: Run the base caseload flow analysis and obtain the fitness value.

Step 2: Initialize the size, site, and number of D.G.s using a hybrid algorithm.

Step 3: Run a load flow with the connection of D.G.s and obtain the fitness value.

Step 4: Evaluate the fitness function, and if it is fit, the size, site, and number of D.G.s are taken as optimal solutions or the answer will be updated.

Step 5: The process repeats for several iterations.

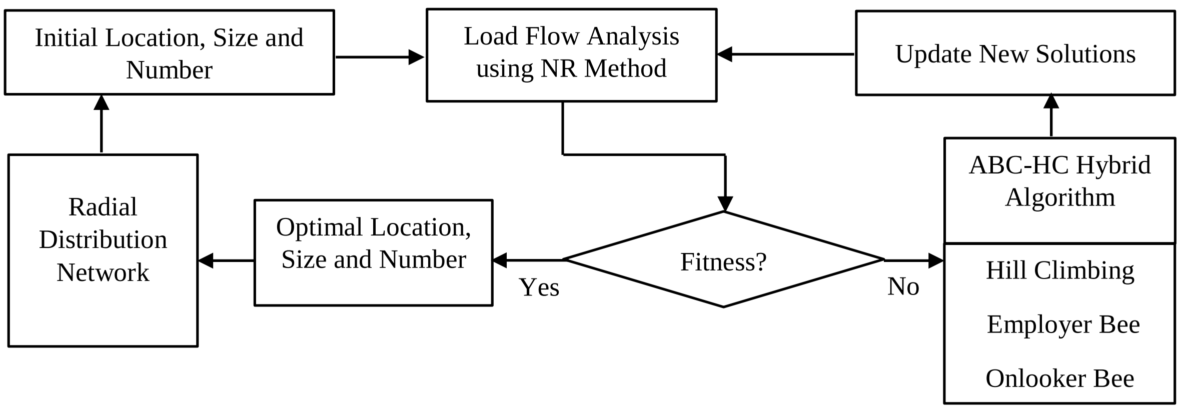


**Fig. 1 Hybrid ABC-HC algorithm model**

#### *2.3.1. Multi-Objective Function*

The three indices, Active Power Loss Indices (PLI), Reactive Power Loss Indices (QLI) and Total Voltage Violation Indices (TVVI), are integrated to produce a multi-objective function, and different weights have been assigned to the OPDG to reduce actual and reactive line losses as well as voltage variation. The fitness function is provided in Equation (7):

Minimum Function = x * PLI + y * QLI + z * TVVI

Where,

$$\mathrm{PLI} = \frac{P_L^{DG}}{P_L^{Base}},$$

$$P_L = \sum_{x=1}^{N_b} I_{(x,x+1)}^2 R_{(x,x+1)}$$

$$\mathrm{QLI} = \frac{Q_L^{DG}}{Q_L^{Base}},$$

$$Q_L = \sum_{x=1}^{N_b} I_{(x,x+1)}^2 X_{(x,x+1)}$$

$$\mathrm{TVVI} = \textstyle\sum_{x=1}^{n} \mathrm{VVI},$$

$$\mathrm{VVI} = \begin{cases} \text{If } 0.95 \le V_x \le 1.05, \text{then VVI} = 0 \\ \text{else,} \quad \mathrm{VVI} = \sum_{x=1}^{n} \frac{1 - V_{DG_x}}{1} \end{cases}$$

### *2.4. Load Models*

Optimal planning of multiple D.G. implementing ABC-HC algorithms tested for different loads such as residential, commercial, industrial, and mixed loads is considered for assessment. All types of loads mentioned above are connected to particular buses for analyzing real and reactive power losses, optimal location, and size of D.G. by considering the base case and combining one, two, three, and four D.G.s at different locations. The natural and reactive power at bus j varies with a change in bus voltage with exponential components a and $\beta$, which can be expressed in equations 1 and 2.

$$P_j = P_{oj} V^{\alpha} \quad (1)$$

$$Q_j = Q_{oj} V^{\beta} \quad (2)$$

Where Pj and Qj are active and reactive power, also $Poj$ and $Q0j$ are operating active and reactive power at node j, respectively. α and $\beta$ are exponential components of active and reactive power as well. The α and $\beta$ are exponential values that are different for different loads and combinations of all loads. The α and $\beta$ values for other loads are specified in Table 1.

**Table 1. α and β are exponential values for voltage-dependent load models**

| Load Type | α Value | β Value |
|---|---|---|
| Constant Load | 0 | 0 |
| Residential Load | 0.92 | 4.04 |
| Commercial Load | 1.51 | 3.4 |
| Industrial Load | 0.18 | 6 |

## 3. Results and Discussion

In the proposed work, an 11kV, 12-bus practical radial system is considered to implement the ABC-HC algorithm. The system consists of 12 buses and 11 branches. The experimental design is a rural feeder of BESCOM, which is located 40 km away from Bengaluru, Karnataka, India. The single-line diagram of a practical 12-bus rural network is shown in Figure 2. The line and load data for this system are provided in Table 2. The performance evaluation of the proposed algorithm is obtained by finding the optimal location and size of multiple D.G.s for different load conditions, and the results are presented as follows:

Case 1: Optimal placement of multiple D.G.s for constant load

Case 2: Optimal placement of multiple D.G.s for residential load

Case 3: Optimal placement of multiple D.G.s for commercial load

Case 4: Optimal placement of multiple D.G.s for industrial load

Case 5: Optimal placement of multiple D.G.s for mixed load

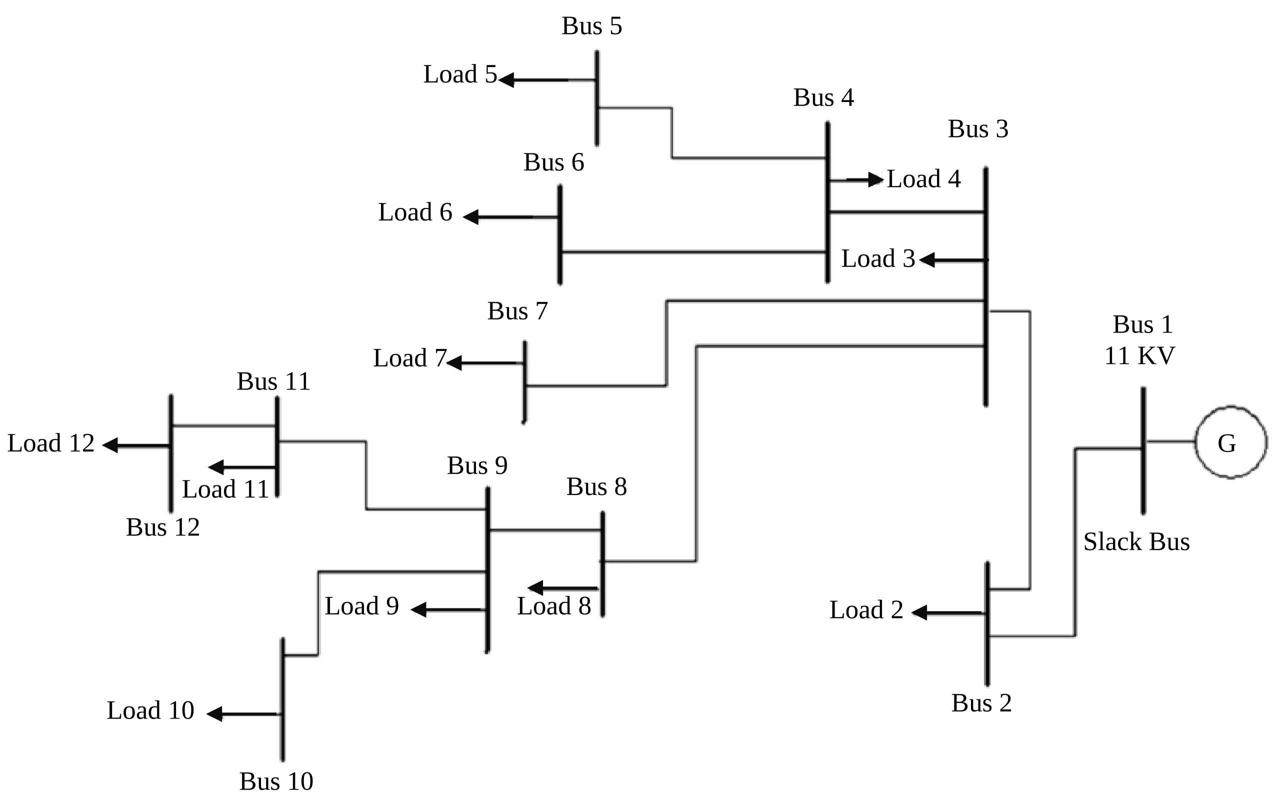


**Fig. 2 12 bus practical radial bus system**

**Table 2. Line data of practical 12 bus RDS**

| From Bus | To Bus | Line Parameter | | Load Details | | |
|---|---|---|---|---|---|---|
| | | Resistance in (p.u) | Inductive Reactance (p.u) | Bus | Real Load (p.u) | Reactive Load (p.u) |
| 01 | 02 | 0.014170 | 0.007670 | 01 | - | - |
| 02 | 03 | 0.002960 | 0.001030 | 02 | 0.87710 | 0.54230 |
| 03 | 04 | 0.005050 | 0.001850 | 03 | 0.80260 | 0.49680 |
| 04 | 05 | 0.000750 | 0.000260 | 04 | 0.21420 | 0.13270 |
| 04 | 06 | 0.003380 | 0.001170 | 05 | 0.02840 | 0.01760 |
| 03 | 07 | 0.009720 | 0.003370 | 06 | 0.11390 | 0.07060 |
| 03 | 08 | 0.004420 | 0.001530 | 07 | 0.07180 | 0.04450 |
| 08 | 09 | 0.002500 | 0.000870 | 08 | 0.48620 | 0.30110 |
| 09 | 11 | 0.003710 | 0.001290 | 09 | 0.41390 | 0.25640 |
| 09 | 10 | 0.003710 | 0.001290 | 10 | 0.07180 | 0.04450 |
| 11 | 12 | 0.001090 | 0.000380 | 11 | 0.22790 | 0.14120 |
| - | - | - | - | 12 | 0.11390 | 0.07060 |

**Table 3. Summary of results for constant load**

| Parameters/ Cases | Base Case | One DG | Two DG | Three DG | Four DG |
|---|---|---|---|---|---|
| Real Power Losses in kW | 160.9 | 62 | 50.3 | 25.5 | 13.1 |
| Reactive Power Losses in kVAr | 82.3 | 32 | 25.6 | 9.7 | 5.8 |
| DG Size in MVA | - | 1.48 | 1.02, 0.5235 | 0.359, 0.426, 0.869 | 0.7540, 0.256, 0.367, 0.308 |
| DG Location | - | 10 | 10 & 1 | 12, 6 & 2 | 10, 8, 6 & 2 |
| Percentage of Reduction in Real Power Loss | - | 61.47% | 68.74% | 84.15% | 91.86% |
| Percentage of Reduction in Real Power Loss | - | 61.12% | 68.89% | 88.21% | 92.95% |
| $V_{min}$ @ Bus | 0.907 @ 12th bus | 0.9522 @ 6th bus | 0.9539 @ 6th bus | 0.9662 @ 12th bus | 0.9874 @ 12th bus |
| TVVI | 0.9388 | 0 | 0 | 0 | 0 |

### *3.1. Optimal Placement of Multiple D.G., Voltage Deviation, and Power Loss Analysis for Constant Load*

The results obtained for optimal planning of multiple D.G.s of constant load through the ABC-HC approach are summarized in Table 3. Type-3 DGs are considered for optimal planning at an optimum power factor of 0.92. It is examined that the total voltage deviation for the base case is 0.9388, which was reduced to zero, indicating the voltage at all the buses lies between 0.95 and 1.05pu. The drop in actual and reactive power losses occurs due to the integration of numerous D.G.s. The placement of four D.G.s reduces real and reactive power losses by 91.86 percent and 92.95

percent, respectively, as shown in Table 3. This is because when D.G. contributes to the local load, the power received from the substation is considerably reduced, and the distribution system losses also decrease. It can be seen in Figure 3 that the penetration of D.G.s contributes to the enhancement of the voltage magnitude while also maintaining the voltage magnitude within the standard limits of the system under test.

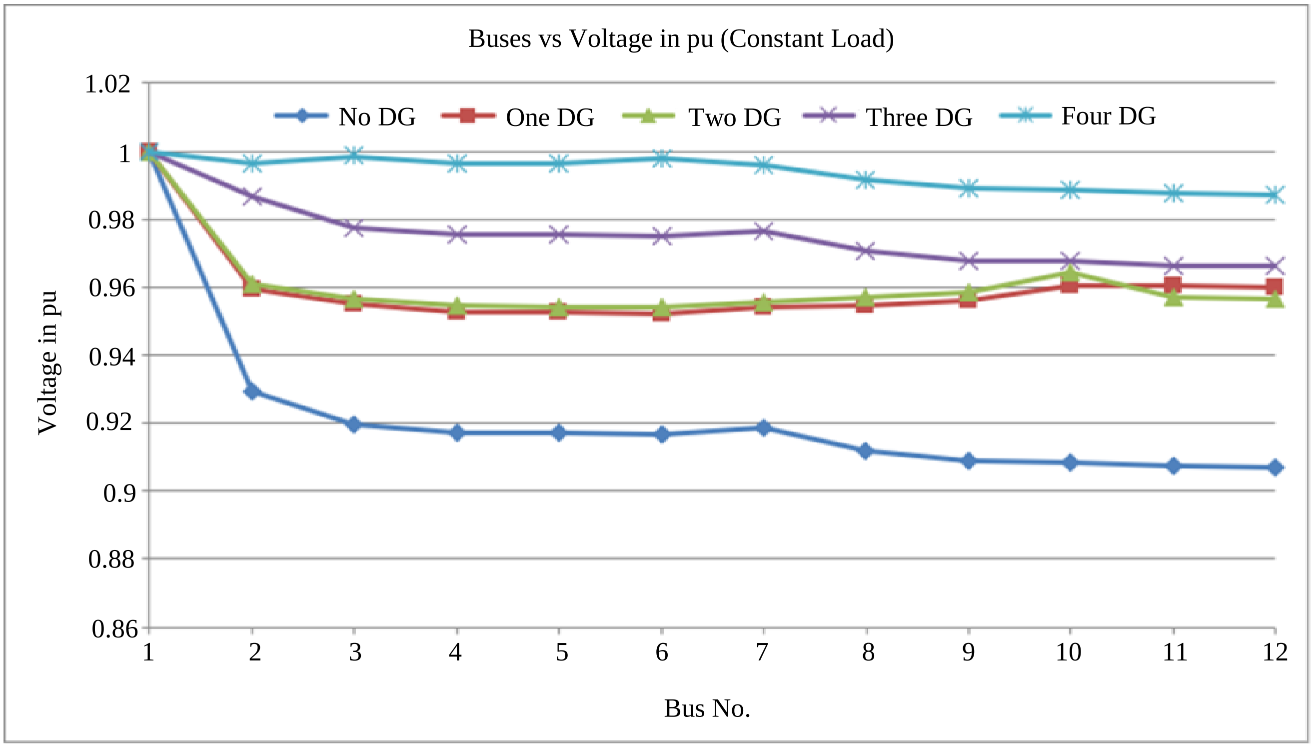


**Fig. 3 Voltage profile with & without D.G.s for constant load**

**Table 4. Summary of results for residential load**

| Parameters/Cases | Base Case | One DG | Two DG | Three DG | Four DG |
|---|---|---|---|---|---|
| Real Power Losses in kW | 118.4 | 44.2 | 23.1 | 17 | 7.2 |
| Reactive Power Losses in kVAr | 60.6 | 22.8 | 10.1 | 7.6 | 4.4 |
| DG Size in MVA | - | 1.32 | 0.935, 0.4136 | 0.4002, 0.8553, 0.1709 | 0.2056, 0.162, 0.1102, 0.9862 |
| DG Location | - | 10 | 11 & 5 | 6, 11 & 9 | 3, 8, 2 & 5 |
| Percentage of Reduction in Real Power Loss | - | 62.67% | 80.49% | 85.64% | 93.92% |
| Percentage of Reduction in Real Power Loss | - | 62.38% | 83.33% | 87.46% | 94.58% |
| Vmin @ Bus | 0.92 @ $12^{th}$ bus | 0.956 @ $6^{th}$ bus | 0.96 @ $6^{th}$ bus | 0.981 @ $6^{th}$ bus | 0.986 @ $12^{th}$ bus |
| TVVI | 0.808 | 0 | 0 | 0 | 0 |

### *3.2. Optimal Placement of Multiple D.G., Voltage Deviation, and Power Loss Analysis for Residential Load*

The optimal placement and sizing of multiple D.G.s of residential loading results through the ABC-HC approach are summarized in Table 4. It is observed that the total voltage deviation for the base case is 0.808 and reduced to zero, indicating the voltage at all the buses lies between 0.95 and 1.05 pu. Also, it can be observed from Table 4 the severe reduction in actual and reactive power losses that occurs as a result of the integration of numerous D.G.s. Placing multiple D.G.s reduces real and reactive power losses by 93.91 percent and 94.58 percent, respectively. This is because as local loads are supplied by D.G., the power extracted from the receiving station is substantially decreased, resulting in the reduction of power loss of the distribution system.

### *3.3. Optimal Placement of Multiple D.G., Voltage Deviation, and Power Loss Analysis for Commercial Load*

The results obtained for the best location and size of multiple D.G.s of commercial load through the ABC-HC approach are summarized in Table 5. Type-3 DGs are considered at an optimum power factor of 0.92 for optimal planning. It can be illustrated that the total voltage variance for the base case is 0.781 and was reduced to zero, indicating the voltage at all the buses lies between 0.95 and 1.05 pu. The drop in actual and reactive power losses occurs due to the integration of numerous D.G.s. It should be noted that by placing multiple D.G.s, real and reactive power losses are reduced 94.58 percent and 95.47 percent, respectively. It can also be observed that the penetration of D.G.s contributes to enhancing the voltage magnitude while maintaining the voltage magnitude within the standard limits of the system under test.

### *3.4. Optimal Placement of Multiple D.G., Voltage Deviation, and Power Loss Analysis for Industrial Load*

The simulation results attained for optimal planning of multiple D.G.s of industrial load through the ABC-HC approach are summarized in Table 6. It is recognized that the total voltage deviation for the base case is 0.8274, and it was reduced to zero, which indicates the voltage at all the buses lies between 0.95 and 1.05 pu.

**Table 5. Summary of results for commercial load**

| Parameters/Cases | Base Case | One DG | Two DG | Three DG | Four DG |
|---|---|---|---|---|---|
| Real Power Losses in kW | 110.7 | 41.4 | 21.6 | 14.1 | 6 |
| Reactive Power Losses in kVAr | 56.7 | 21.6 | 11 | 7.4 | 2.567 |
| DG Size in MVA | - | 1.26 | 0.453, 0.827 | 0.9517, 0.354, 0.013 | 0.318, 0.196, 0.8063, 0.057 |
| DG Location | - | 8 | 5 & 8 | 8, 2 & 10 | 8, 9,5 & 11 |
| Percentage of Reduction in Real Power Loss | - | 62.6% | 80.49% | 87.26% | 94.58% |
| Percentage of Reduction in Real Power Loss | - | 61.9% | 80.6% | 86.95% | 95.47% |
| Vmin @ Bus | 0.923 @ 12$^{th}$ bus | 0.955 @ 12$^{th}$ bus | 0.975 @ 12$^{th}$ bus | 0.9826 @ 6$^{th}$ bus | 0.9931 @ 12$^{th}$ bus |
| TVVI | 0.781 | 0 | 0 | 0 | 0 |

It can also be observed that the drop in actual and reactive power losses occurs due to the integration of numerous D.G.s. Placing multiple D.G.s reduces real and reactive power losses by 92.19 percent and 92.85 percent, respectively.

This is because when D.G. contributes to the local load, the power received from the substation is considerably reduced, and the distribution system power losses will be reduced. The penetration of D.G.s contributes to enhancing the voltage magnitude while maintaining the voltage magnitude within the standard limits of the system under test.

### *3.5. Optimal Placement of Multiple D.G., Voltage Deviation, and Power Loss Analysis for Mixed Load*

The simulation results for optimal planning of multiple D.G.s for mixed load through the ABC-HC approach are summarized in Table 7. It is found that the total voltage deviation for the base case is 0.8384 and was reduced to zero, indicating the voltage at all the buses lies between 0.95 and 1.05 pu.

The drop in active and reactive power losses occurs due to the integration of numerous D.G.s. Placing multiple D.G.s reduces real and reactive power losses by 92.94 percent and 93.42 percent, respectively. It can also be observed that the penetration of D.G.s contributes to enhancing the voltage magnitude while maintaining the voltage magnitude within the standard limits of the system under test. The findings demonstrated the efficacy of the suggested approach in resolving D.G. integration challenges and determining the appropriate location and size of D.G.s. The results show that the ideal distribution system solution differs depending on the load.

**Table 6. Summary of results for industrial load**

| Parameters/Cases | Base Case | One DG | Two DG | Three DG | Four DG |
|---|---|---|---|---|---|
| Real Power Losses in kW | 125.5 | 46 | 24.3 | 13.1 | 9.8 |
| Reactive Power Losses in kVAr | 64.3 | 23.8 | 10.1 | 6.3 | 4.6 |
| DG Size in MVA | - | 1.35 | 0.968, 0.493 | 0.395, 0.438, 0.679 | 0.413, 0.209, 0.796 0.085 |
| DG Location | - | 11 | 2 & 11 | 5, 11 & 8 | 4, 12, 8 & 7 |
| Percentage of Reduction in Real Power Loss | - | 63.35% | 80.64% | 89.56% | 92.19% |
| Percentage of Reduction in Real Power Loss | - | 62.99% | 84.29% | 90.2% | 92.85% |
| Vmin @ Bus | 0.9179 @ 12$^{th}$ bus | 0.9556 @ 6$^{th}$ bus | 0.9675 @ 12$^{th}$ bus | 0.9835 @ 6$^{th}$ bus | 0.9885 @ 12$^{th}$ bus |
| TVVI | 0.8274 | 0 | 0 | 0 | 0 |

**Table 7. Summary of results for mixed load**

| Parameters/Cases | Base Case | One DG | Two DG | Three DG | Four DG |
|---|---|---|---|---|---|
| Real Power Losses in kW | 127.5 | 49.4 | 29.2 | 11.3 | 9 |
| Reactive Power Losses in kVAr | 65.3 | 25.7 | 15.2 | 5.1 | 4.3 |
| DG Size in MVA | - | 1.408 | 0.406, 1.0012 | 0.314, 0.283, 0.8279 | 0.1413, 0.429, 0.0901, 0.7892 |
| DG Location | - | 8 | 7 & 8 | 10, 5 & 8 | 10, 9, 8 & 3 |
| Percentage of Reduction in Real Power Loss | - | 61.25% | 77.1% | 91.14% | 92.94% |
| Percentage of Reduction in Real Power Loss | - | 60.64% | 76.72% | 92.19% | 93.42% |
| Vmin @ Bus | 0.9169 @ 12$^{th}$ bus | 0.9504 @ 12$^{th}$ bus | 0.9839 @ 12$^{th}$ bus | 0.9836 @ 6$^{th}$ bus | 0.9838 @ 12$^{th}$ bus |
| TVD | 0.8384 | 0 | 0 | 0 | 0 |

## 4. Conclusion

This paper presents optimal planning of multiple D.G.s in the distribution system, addressing power quality and reliability. A novel hybrid ABC-HC algorithm was developed to plan multiple D.G.s. The optimal size and site of the D.G.s are selected based on the value of the multi-objective function. The proposed algorithm is applied to an authentic Indian 12-bus radial distribution system heavily loaded with poor voltage regulation and high power losses. The results show that the interfacing of D.G.s to the system reduces line losses, improves the voltage profile, and regulates the voltage limit to 1.05 p.u. From the results, the total size of the D.G. for constant load is 1.6850MVA, residential load is 1.4658MVA, commercial load is 1.3773MVA, industrial load is 1.503MVA, and mixed load is 1.496MVA. This indicates the optimal solution for D.G. planning, considering maximum constant load is not the perfect solution to avail the ultimate benefit of D.G.s. The obtained results also show that the best size of D.G.s and the best location of D.G.s are different for different load models.

## References


[1] Lokesh Mallaiah et al., "The Optimal Integration of Multiple DGs under Different Load Models Using Artificial Bee Colony-Hill Climbing Algorithm," *Trends in Sciences*, vol. 19, no. 13, pp. 1-14, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[2] R. Parthiban, and S. Manikandan, "Robust Digital Image Watermarking Using Artificial Bee Colony Optimization with Dual-Tree Complex Wavelet Transform Based SVD Approach," *International Journal of Engineering Trends and Technology*, vol. 71, no. 7, pp. 279-289, 2023. [CrossRef] [Publisher Link]

[3] Thanpitcha Atiwanwong, Adirek Jantakun, and Adisak Sangsongfa, "Optimizing Long Short-Term Memory Network Parameter with Artificial Bee Colony Algorithm for PM2.5 Prediction," *International Journal of Engineering Trends and Technology*, vol. 71, no. 2, pp. 323-333, 2023. [CrossRef] [Publisher Link]

[4] Mohamed Abd-El-Hakeem Mohamed et al., "Optimum Estimation of Series Capacitors for Enhancing Distribution System Performance via an Improved Hybrid Optimization Algorithm," *Energy Science & Engineering*, vol. 11, no. 6, pp. 1906- 1924, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Dong Zhang et al., "A Systematic Review of Optimal Planning and Deployment of Distributed Generation and Energy Storage Systems in Power Networks," *Journal of Energy Storage*, vol. 56, Part A, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[6] K.B. Veeresha, M.G. Manjula, and A.H. Thejaswi, "Enhancement of Power Quality Using Single Phase Generalised Unified Power Quality Conditioner in Distribution System," *International Journal of Recent Engineering Science*, vol. 10, no. 4, pp. 1-6, 2023. [Google Scholar] [Publisher Link]

[7] Ponnam Venkata K. Babu, K. Swarnasri, and Wei Meng, "Optimal Integration of Different Types of DGs in Radial Distribution System by Using Harris Hawk Optimization Algorithm," *Cogent Engineering*, vol. 7, no. 1, 2020. [CrossRef] [Publisher Link]

[8] M.G. Manjula, and S. Surendra, "Integration of Multi-Terminal Unified Power Quality Conditioner in Microgrid System," *International Journal of Recent Engineering Science*, vol. 10, no. 4, pp. 7-13, 2023. [Google Scholar] [Publisher Link]

[9] Korra Balu, and V. Mukherjee, "Optimal Siting and Sizing of Distributed Generation in Radial Distribution System Using a Novel Student Psychology-Based Optimization Algorithm," *Neural Computing and Applications*, vol. 33, pp. 15639–15667, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] A.T. Mohamed, A.A. Helal, and S.M. El Safty, "Distribution System Reliability Evaluation in Presence of DG," *2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, Genova, Italy, pp. 1-6, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[11] Sreevidya L., S.U. Prabha, and S. Sathiya, "Evaluation of the Reliability of Distribution System with Distributed Generation Using ETAP," *International Journal of Soft Computing and Engineering (IJSCE)*, vol. 8, no. 5, pp. 1-4, 2019. [Google Scholar] [Publisher Link]

[12] Teketay Mulu Beza, Yen-Chih Huang, and Cheng-Chien Kuo, "A Hybrid Optimization Approach for Power Loss Reduction and DG Penetration Level Increment in Electrical Distribution Network," *Energies*, vol. 13, no. 22, pp. 1-17, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Abdurrahman Shuaibu Hassan, Yanxia Sun, and Zenghui Wang, "Optimization Techniques Applied for Optimal Planning and Integration of Renewable Energy Sources Based on Distributed Generation: Recent Trends," *Cogent Engineering*, vol. 7, no. 1, 2020. [CrossRef] [Google Scholar] [Publisher Link]