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OPTIMIZATION TECHNIQUES FOR DISTRIBUTION GENERATION ALLOCATION AND SIZING – A REVIEW

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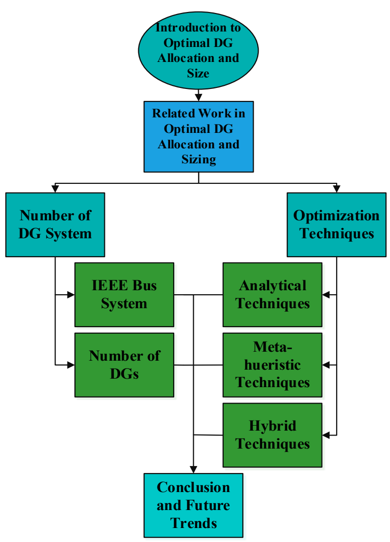
Graphical abstract



Abstract

Optimization techniques (OPT) are important tools to improve electric power quality, dependability, power flow, and cost of power systems. Power systems are complex networks controlled by physical laws, subject to expected occurrences, with increased complexity due to distribution generation (DG) integration capacities from renewable energy sources (RES). RESs are also integrated with conventional DG to enhance the efficiency of DGs. Thus, OPT plays a vital role in modeling optimal system planning through which allocation and sizing factors can be easily carried out. Various OPTs via analytical, meta-heuristic, and hybrid are used in addressing challenges related to the positions and size of units for DG within distribution networks, accepting a range of objectives and constraints. These techniques have also been applied to simple and complex systems. Mostly multi-objective and hybrid OPTs are employed to resolve challenging issues in DG sizing and allocation and give efficient results. In the literature review, generally, researchers took the standardized models of IEEE bus systems used for testing various OPTs. Three DGs have very effectual outputs within the IEEE-33 bus system and seven DGs for the IEEE 69 and IEEE 118 bus gave efficient results. Therefore, this paper is an overview of recent work and a critical analysis of different OPTs, that have been used for optimal DG in power systems.

Keywords: Optimization techniques (OPT), Allocation and Sizing of DG, distribution system (DS), Renewable Energy Resources (RER)

1.0 INTRODUCTION

Traditional power sources can no longer meet the world's growing need for power. Approximately 16% of the worldwide still does not have access to power because of subpar network design [1] For an improved user experience, a power supply system must therefore be able to adapt to these changes. Regretfully, distributed generation (DG), in which power is generated near the load centers, has shown to be a workable alternative solution. DGs present several operational challenges for the distribution system (DS) despite their many environmental, voltage management, and financial benefits[2]. These could comprise, yet, it are not restricted to, voltage rise issues, power quality concerns, and inverse power flow-related power relaying problems [3]. DGs are small-scale plants that are placed near the load and provide electrical power that is produced with the exhaust of renewable energy sources (RES). The DG splits into two types of energy sources, renewable and non-renewable. The term renewable is referred to as main native and clean or endless energy resources [4]. With the growing importance of RES, incorporating DG systems into power distribution networks (DN) has emerged as a critical component of modern power systems [5]. Installing DG devices, like wind turbines (WT), solar photovoltaic (PV) arrays, and biomass generators, presents a viable way to improve the sustainability, dependability, and efficiency of electrical networks. The wise selection of DG system size and suitable placement within the DN the crucial elements in effectively integrating these systems [6]. To optimize the advantages of RES while resolving technical, financial, and environmental challenges, the placement and size units of DG are critical decisions.

Enclosed by current years, notable attention has been organized towards optimal the location and sizing of renewable energy (RE) installations within radial DS [7]. The highest goal is to harness clean energy's full potential while upgrading distribution systems' reliability and efficiency. The integral constraints and complexities of radial configuration require a refined understanding of how to place diplomatically and size RE units. The dynamic relationship between the distribution system's physical design, energy production trends, and changing end-user demands requires a thorough investigation of efficacious approaches [8]. In the context of radial distribution networks (RDN), the ideal sizing of DG systems has attracted a lot of interest lately.

An extensive review of mathematical optimization techniques (OPT), in particular, ant colony optimization (ACO), genetic algorithms (GA), and particle swarm optimization is given in this study [9]. Heuristic algorithms like Simulated Annealing and Tabu Search are also studied. The review delves into the distinct contributions of metaheuristic algorithms like the harmony search (HS) and the firefly algorithm to DG scaling problems. Lastly, a comprehensive grasp of the algorithmic environment in DG sizing is provided by a discussion of hybrid algorithms, which combine the best features of several approaches [10]. In the implementation of DG, there are some challenges to be faced, such as Sensitive electronic equipment may experience operational difficulties due to variations in voltage [11]. Systems with little capacity for generating are more vulnerable to problems with power quality. Adjustments in the levels of short circuits, protection blinding, single-phase, asynchronous reclosing connections, impedance fault changes, reversing the power flow, and mains outage are among the difficulties. Difficulties are associated with a high penetration of variable DG, such as managing DN limits to accommodate DG capacity[12].

Issues include voltage rise, reverse power flow, and coordination difficulties with protection that might arise when DG systems are integrated into already-existing distribution networks. Operational challenges may arise from sizing DG systems without considering these grid integration factors [13]. RES have unpredictable and sporadic generation patterns, including wind and solar power. Accurately scaling DG systems to satisfy different demand patterns is challenging because of the inherent unpredictability of these sources [14].

This review study examines OPTs for DG sizing and allocation, emphasizing the significance of precise unit sizing for robust power systems, especially in RDN. The search used common search engines and articles from journals and conferences over five years. The paper analyzes research on the most suitable places and sizes for DG in radial distribution systems, considering factors like regulatory framework, environmental impact, and economic feasibility. The below-mentioned Figure 2 shows related work on literature breakdown. The key points of this study are as follows:

- This paper highlights recent studies of DG allocation and sizing in power systems considering optimizing techniques, constraints, objective functions, and challenges.
- This paper will help to identify the most suitable sizes and allocation for DG in the radial system. Based on various optimization techniques, suggested by existing authers.
- Such work will assist in identifying gaps in related research that has been conducted and will suggest new methodologies.

This paper is organized into multiple sections starting from problem formulation for DG sizing and allocation and further connects the remainder of paper as Section 2 presents the reviews on DG allocation and sizing, section 3 is about significance of optimal sizing and allocation of DG, Section 4 discusses the optimization techniques and Section 5 provides the conclusions and future trends.

1.1 Problem formulation

This section discussed the sizing and allocation of DG problem formulation. Figure 1 presents the single-line diagram of the system. As illustrated in Figure 1, the voltage of the system will be influenced by the integrated DG, as stated in Eq.(1)

$$V_i^{new} = V_i + \Delta V_i^{DG} \tag{1}$$

Where V_i is the voltage *i*th bus and ΔV_i^{DG} as denoted, the voltage difference shows the difference at the *i*th bus before and after the DG installed. The ΔV_i^{DG} as per the difference of the currents in *i*th and *i* + 1th section ($\Delta V_i^{DG}, \Delta V_{i+1}^{DG}$) can be stated as Eq. (2)

$$\Delta V_i^{DG} = \begin{cases} \dfrac{P_i^{load} + Q_i^{load} j}{(I_{i+1}^{section} - \Delta I_i^{section})* - (I_{i+1}^{section} - \Delta I_i^{section})*} - V_i & if\ i \neq m \\ \dfrac{(P_i^{load} - P_{DG}) + (Q_i^{load} - Q_{DG}) j}{(I_{i+1}^{section} - \Delta I_i^{section})* - (I_{i+1}^{section} - \Delta I_i^{section})*} - V_i & if\ i = m \end{cases} \tag{2}$$

Where P_i^{load} and Q_i^{load} are the total actual and reactive loads at *i*th bus, $I_{i+1}^{section}$ is the current of the *i*+1th section. The DG's installation bus number is indicated by m. The total active and reactive powers injected by DG placed at the *i*th bus are denoted by P_{DG} and Q_{DG}. This non-linear equation must be solved using the power flow method to determine each sector's voltage profile and currents. The following equations can be used to determine the system's overall power loss. (3) and also (4) [15]:

$$P_{loss}^{total} = real\left(\sum_{i=1}^{N_{section}} Z_i |I_{i+1}^{section}|^2\right) \tag{3}$$

$$Q_{loss}^{total} = imag\left(\sum_{i=1}^{N_{section}} Z_i |I_{i+1}^{section}|^2\right) \tag{4}$$

Where Z_i, as shown in Figure 1, is the impedance of the *i* + 1-th sector.

Below given Figure 1 is reflating the problem section formulation as discussed above.

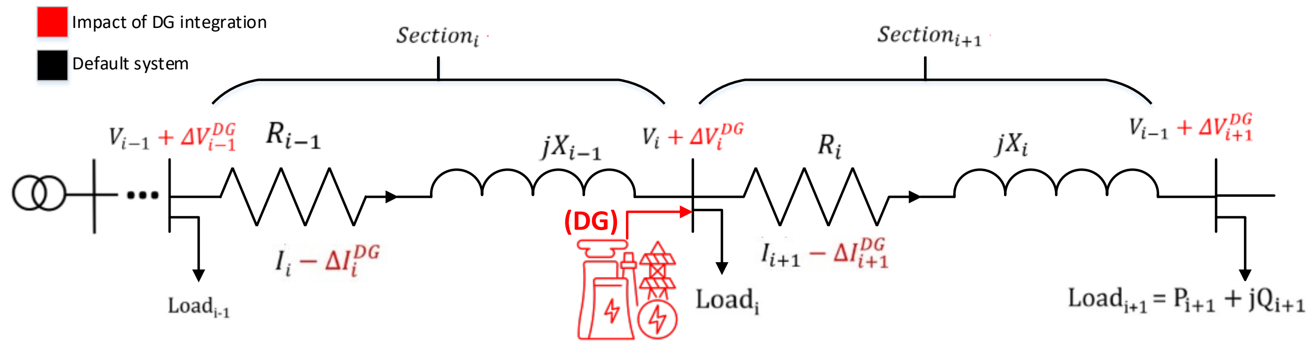


Figure 1 Single-line diagram of integration distribution generation system

2.0 REVIEWS ON DG ALLOCATION AND SIZING

The investigation of demand-based DG allocation and sizing has attracted great interest in the field of power systems. Previous research has looked into several techniques like, meta-heuristic and hybrid for maximizing DG resource sizing and allocation in response to shifting demand trends. Jellyfish search (JS) optimization and a unique meta-heuristic optimization approach to calculate both multi and single-objective functions to improve the voltage profile by reducing voltage deviation (VD), power losses, and enhancing voltage stability index (VSI) were adopted in [16]. The obtained statistics show that the multi-type of DG distribution including DG Type III for overall power loss 94.44%, 98.10%, and 96.07% for IEEE 33, 69, and 94 bus systems, reduction separately was proven.

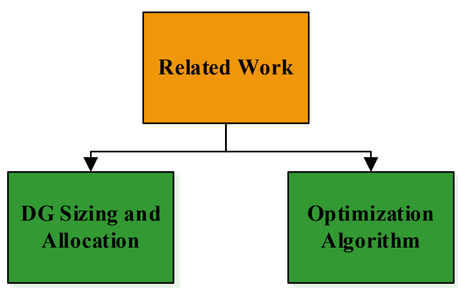


Figure 2 Literature Breakdown

Optimal reconfiguration of DS using multi-criteria optimization algorithms for reconfiguring networks and minimizing the decision criteria along with examination of NR in failures was recommended in [17]. The article was used to keep the system remote or automated switching devices operational and minimize de-energized zones. however, it was proved in IEEE 33 and the 123 bus test system. The worked out fine with the use of a speculative resolution that might enable the optimal outcome being achieved for every criterion, the multi-criteria algorithm seeks to identify an effective solution that is closest to the ideal solution.

Optimized the allocation and size of RE sources using the shark optimization algorithm in a radial system to increase system performance by decreasing power outage and enhancing both power quality and voltage profile using White Shark Optimisation (WSO) with constraints proposed in [18]. The test systems are the most common radial networks, the IEEE 33, 69, and 85 node systems. The developed approach was executed on MATLAB, and when comparing WT installation to PVs, the results are significantly superior. When comparing WSO's power losses to those of other recent research, its notability was guaranteed. The improvement was 27.78%, 70%, and 39.27% for each of the three employed strategies.

With the equality constraints to find optimal distribution system sizing and allotment using thevenin-based impedance stability index (ISI) in [19] using hybrid optimization to improve bus voltage levels and ISI (index with proposed Zth). The test systems are IEEE 69 and 118 bus systems. Here the suggested algorithm was implemented in MATLAB, and power flow was carried out using MATPOWER. The proposed techniques decrease the power loss of the DS. The quantity of DGs was chosen in terms of economy and power.

The methodology was based on an improved salp swarm algorithm (ISSA) done in MATLAB to solve the placement of renewable sources using a reconfigured radial distribution network in [20] using a proposed technique with equality and inequality constraints. This work illustrated an allocating PV and WT with networks optimally and simultaneously reconfigured of RDS to cut expenses of power outages and enhance stability and the presented problem was implemented in a conventional IEEE 33 and 69 radial bus systems. Proposed ISSA, an enhanced SSA method, in this work. The system performs better when using ISSA than when using other algorithms and the overall result shows that the whole expense of the system in scenarios 5 and 3 for the 33 and 69 bus networks using the ISSA method was 17978.18 and 77278.81 respectively.

The allocations of distribution generators and changing with time in distribution networks, A new hybrid approach based on Salp Swarm Algorithm (SSA) and Particle Swarm Optimization (PSO) initiated in [10], to ascertain the appropriate placement and site of four units of DG in the distributed system with TVVD loads to reduce power losses, voltage variation and reactive power losses, and presents a hybrid strategy with power and voltage index constraints. The test system was the IEEE 69 bus system. To address convergence problems and outperform conventional approaches, this work introduces the hybrid SSA-PSO methodology for distribution generation unit allocation in distribution systems. Its multimodal and system efficiency was demonstrated by the validation of 17 benchmark functions.

Particle swarm optimization (PSO) algorithm proposed in [21], systems were taken with IEEE 34- and IEEE 69-buses for power balance and inequality constraints. It was suggested to use the PSO algorithm to select the best site for renewable distributed generation (DG) units based on their ideal power rating, after which the new voltage stability index (VSI) would be used. This journal presents a unique method for optimizing the placement and dimensions of wind power turbine and solar photovoltaic generating systems using the proposed voltage stability index (VSI) with the PSO technique. And IEEE 34-bus system shows a significant reduction in real power loss under 10 years of load growth, and 59.42% and 76.03% after 15 years of assignment of WTG-DG and SPV-DG.

The allocation of distribution generations (DGs) in RDS using two metaheuristic techniques was used number one was adaptive particle swarm (APSO) and another was an improved gravitational search algorithm (MGSA) for suitable allocation of DGs to lower the power outages in RDS with all constraints. The test system IEEE 69 and the 85 bus test system are pre-owned. Upon further examination in [22], it can be observed that power losses with two or three DGs are almost constant. Therefore, enhancing the number of DGs in the system won't help to lower system losses.

Optimization of distribution generation size and placement found by using particle swarm optimization (PSO) based on a graphical user interface (GUI) system. Examine the constraints to create the network system for power distribution. This article aimed to optimal capacity and placement of the DG, to lower power loss and enhance the system's voltage profile. For determining location using GUI system interface. This researcher used a feeder known as the Basuki Rahmat feeder and adjusted the two and three DGs according to the needs, which decreased the losses. The installation was successful in raising higher voltage values' voltage profile and lowering the overall system power losses from 25.38 kW to 1.56 kW. He took the 9.5MVA DG limit [23].

In the recent work presented, the OPT obstruction coefficient particle swarm optimization (CPSO) was used to lessen the overall power loss, which was limited by disparity and equality. This paper[24], to ascertain the position and size of the gravity energy storage (GES) and RES units in DN. Reducing the amount of active energy lost was the goal. The IEEE 33 TEST distribution network had been taken to be located near Kandla, India. important actual power loss weakening and an intensified voltage profile are demonstrated by the CPSO and SGA research of the best size and placement of RES and storage segments. The bus experienced a 63.90% reduction in losses, with a low voltage of 0.984 pu.

As suggested in [6], a hybrid meta-heuristic algorithm (A blend of the gravitational search method and the phasor particle swarm optimization.) was applied to look into via two angles, specifically the simultaneous minimization of a distribution network's overall energy loss and the enhancement of revenue for RDS owner with including constraints. The IEEE 69 bus test system was used for the sizing and placement of DGs. In this research, to calculate the OPS of RDG problem, a hybrid algorithm was suggested and successfully deployed, to abate the overall energy loss in DNs and enrich the profit for RDG proprietors.

The multileader particle swarm optimization (MLPSO) has been applied in [25] to optimally place and size distribution generation s (DGs) in the distribution network (DN) to mitigate active power losses while overcoming the shortcomings of earlier algorithms and the subjected constraints. The active radial bus system and the typical IEEE 33 bus test system have been built in the Malaysian context. The results show that bring together three DGs at one power factor reduces losses in two systems by 67.40% and 80.32%, respectively. The efficacy of the suggested MLPSO algorithm was shown by contrasting the outcomes with those from other optimization methods.

In this piece of writing [26], a variety of objective functions was formed by utilizing the voltage stability index in conjunction with the power both, active and reactive extracted from the substation. To calculate the ideal location, sizes, and power factor of distributed generation (DG), this function was minimized using PSO and CPSO. By strategically positioning DGs, the objective was to diminish power while boosting voltage stability extracted through the substation. The short circuit analysis on the DS with optimized DGs revealed that later the installation of the DG, the short circuit current differences were greater than 12 p.u.

Using selective particle swarm optimization (SPSO) in [27], to solve the best network reconfiguration for distribution systems to improve voltage profiles (VP) and shorten actual power losses. The IEEE 33 bus RDS was used to test the SPSO technique, which was programmed in MATLAB R2016b software. Considering equality and inequality constraints. Overall, the results demonstrate how effective the favored algorithm was at lowering the system's reactive and actual power outages. In light of the test outcomes, actual power was significantly increased for thin, average, and thick load circumstances in that order 99.341%, 97.289%, and 95.385%.

Utilizing the Artificial Hummingbird Algorithm (AHA) amidst uncertain conditions, this study employs a Monte Carlo simulation approach coupled along a backward reduction algorithm to optimize the allocation of renewable Distributed Generations (DGs). A key innovation in this research [28] lies in presenting an efficient and cutting-edge methodology for the ideal size and positioning of radial DGs in systems with radial distribution assuming uncertainty into account in loading and RDG output powers. The AHA, recognized as the most contemporary and effective optimizer, was introduced to facilitate the identification of optimal locations and sizes for RDGs in the radial distribution network (RDN). Proposed multi-objective function aims to minimize overall voltage deviations, emissions, and expenses while enhancing system stability. Comparative analysis between scenarios with and without these considerations reveals substantial improvements in the IEEE 33-bus network, showcasing enhancements of 38.91%, 62.43%, 70.48%, and 12.12%. Similarly, for the 94-bus network, the improvements stand at 39.6%, 62.59%, 78.52%, and 23.24%.

To achieve the ideal positioning of distribution generating in the distribution system and a capacitor, the Artificial Bee colony (ABC) algorithm is proposed in [29] with constraints. This is crucial for obtaining ideal placement and sizes of DG and capacitor, reduction of the major objective function was power outages. The test system used in this study was a public hospital's RDS. Using the ABC approach, the capacitor's dimensions and placement and DG in the DS were determined simultaneously in this investigation. The setting of the capacitor and DG simultaneously significantly, reduced in power system from 648kW to 56kW resulting in a 91% reduction in power loss.

In this work [30], the ideal size and location of distribution generations have been completed with a novel idea to concurrently lessen overall power loss, average voltage drop, and total energy expenses by using an artificial bee colony (ABC) implemented on IEEE 69-bus radial networks, IEEE 33-bus networks, and CIGRE medium voltage Benchmark grid for (MV), considering multiple objectives with all power constraints. to abate average voltage, drop, total power loss, and overall energy costs all at once. We have created and examined two test cases. The outcomes demonstrate that while GA reduces total power loss to 30.17%, the suggested ABC algorithm dramatically reduces it to 48.5%.

With the inequality constraints to find optimal capacitor banks and distribution generation placement and sizing at double voltage stages, preferred in [31]. A modified genetic algorithm is used to overcome losses and refine the voltage profile in low voltage (LV) nodes without the enlarge in the price of investments. This suggested method has been used on the radial distribution system of the IEEE 33 bus. the article suggests a technique for the best placement and sizing of CBs and two kinds of distributed generation (DG): intermittent (solar PV) and no intermittent (biomass) DG for minimizing actual power losses and voltage deviations except increasing capital spending. Significant reduction in power losses through 1062.72 to 1034.34 kW, voltage deviation from 185.91V2 to 170.45V2, and lower investment expenses from 5333.23 to 5324.34 $/day.

The optimal allotment of several types and DG unit value was determined using an unbalanced power distribution network (PDN) with three-phase 123 buses. included paper, the Equilibrium optimizer (EO) algorithm was present to decode the DG allocation problem in 123-bus unbalanced multiphase PDN. For this problem solution has been performed by openDSS, IEEE-PES data, and MATLAB/Simulink. The thorough and in-depth investigations showed that, when applied to an imbalanced 123-buse PDN, the suggested method exhibits a greater voltage profile and the least amount of power loss augmentation, and the EO algorithm's superiority could be found in [32]. EO algorithm outperform due to its high global optimum point number (63%), least average power loss and lowest error rates.

For the installation of DG units, weak and sensitive buses were found with the use of the loss sensitivity factor (LSF). The ideal placement and capacity of the DG items are ascertained using the Golden Jackal Optimization (GJO) method. To define a novel technique for location and sizing distribution generation (DG) units, in radial distribution network (RDN) to lower overall line losses with different constraints and the test system was 33 bus test system. The achieved outcomes display that the system's voltage profile can be improved, and total reduction in actual power could be lowered by integrating DGs into RDN preference in [33]. The objective value for sizing 3DGs in the RDNe was determined through iterations.

The ideal location and dimensions of DGs proposed in [34], the swarm moth flame optimization algorithm (SMFO), and an objective function taking into account voltage profile and included power losses, and pollutant emissions are utilized to solve the power balance and DG sizing constraints. The IEEE 33 bus system was applied for implementation. In this paper, the algorithm's effectiveness was effectively verified when the distribution network optimized using SMFO had a 50.37% drop in power losses and a 45.37% decrease in power losses while using GA. Additionally, the voltage profile has greatly improved.

The Moth Flame Optimization (MFO) algorithm was employed in [35] for the constraction of the total power cutoffs employing an integrated method to determine where solar distribution generation units should be placed in three different IEEE Standard radial distribution systems consisting of 33, 69, and 118-bus systems, in different sizes. The suggested algorithm outperformed previous ones in performance, accurately predicting ideal PV-DG unit locations and sizes and ensuring maximum power loss reduction. At IEEE-33 two PV DGs, 58.687% loss minimization, At IEEE-69 three PV DGs, 69.149% loss minimization and At IEEE-118 two PV DGs, 55.687% loss minimization.

Solution of ideal sizes and location of DG for increasing voltage and decreasing power loss in the DS using the Improved Harmony Search Algorithm (IHSA). Primery goal of this paper was to solve an affordable and reliable network possessing the least power loss, the best bus voltage profile, and good branch current limitations. An IEEE-33 bus test system and a realistic Indian 52-node system. It was concluded that, in comparison to the HSA and GA methods, the suggested improved harmony search approach efficiently reduces total power loss. Performance was better with active and reactive power insertion systems than with real power booster for loss. Enhancement and reduction of voltage systems by percentage loss decrease were found to be 50.63% and 74.65%, respectively, when one DG and three DGs were placed in [36].

In [37], the optimal allocation of DG in DS is solved using an improved firefly algorithm (IFA) for Lowest Possible Active Power Losses. This work presented a unique technique to optimize power flow distribution, voltage stability, and active power loss in the distribution system. A new, improved firefly method was offered to calculate the best location and capacity of DGs. With the implementation of equality and inequality constraints and test system bus IEEE 33 and 69. Compared with the normal firefly method, the suggested IFA has batter convergence speed and can obtain a lesser active power loss. actual network loss change rate was 81.2%.

An improved flower pollination algorithm (IFPA) was used to calculate the optimal placement and sizing of DG, performed on a practical Indian 52 bus system. Considering power balance and inequality constraints to minimization of power loss. A revised and improved Flower Pollination Algorithm for DG sizing and allocation was suggested in this study [38]. An immediate system, like the useful Indian 52 bus system, was used to assess this research, it was determined that the voltage profile factor has been increased, and the 82% decline in power outages has occurred.

The optimal positions and size of RE acquired in [39] by using the grasshopper optimization (GOA) technique, to improve reliability, a multi-objective function concerning voltage profile and economic benefits have been implemented with constraints. The test system was a 94-bus distribution system. When both renewable DG are provided at the same time, the maximum benefits are seen. After comparing the outcomes of the work that was provided with those of other approaches, it was determined that the suggested approach produced superior results. Research has shown that when wind and solar DGs are placed simultaneously, the system's reliability was at its highest and there was no penalty factor.

In this work [40], IEEE 16 and 33 buses were the test networks, used to find distribution generator (DG) positioning by using an exhaustive search approach to achieve strategic placement of multiple DGs of several kinds to select the ideal DG size and location to lower the distribution network's overall actual power loss with the power constraints. The DLF methodology was presented in this research to examine the effects of DG placement because of their size and sitting. The results accurately pinpoint the ideal size for several DG locations and demonstrate how DG placement affects the decrease of DS loss. The first DG injection at the eighth bus reduces loss by 12%, the second at the twenty-fourth bus increases it to 14.75%, and the third at the fourth bus has the least reduction by 14.95%.

These researchers in [41], applied the fuzzy logic technique for the distribution generation placement to preserve a healthy voltage profile while mitigating the network's power outages while considering effective local energy resource harvesting. Fuzzy logic applied to large distribution networks to solve a good position and sizing for many DG devices to mitigate power losses as well as enhance the system's voltage profile. The power loss reduction resulted in an approximately 84% reduction.

The technique of analytical least squares extrapolation was used to better the voltage profile and mitigate losses. A practical Yirgalem-I distribution network in Ethiopia was used with constraints and This paper focuses on demand forecasting and improving Yirgalem DS performance by optimizing SPV DG integration, and analyzing cost across multiple locations without size increments [42]. Result compared to SPV DG at a single location6610.3 US dollars were saved yearly by using the identiical SPV DG size intwo places.

Through the use of the multi-objective whale optimization (MOWOA) algorithm and its techno-economic analysis, the best distribution network for DG unit placement was provided. To reduce annual economic loss, decrease active power losses, and boost voltage profile to maximize savings. They were considered IEEE 33 and 69 radial bus systems. By placing ideally sized DGs in optimal places, the author provides an advanced multi-objective technique known as the Whale Optimisation strategy for lowering annual economic loss [43]. The above-summarised literature's Table 1 suitably gives the data for analysis of the literature.

A hybrid optimization technique was a grasshopper optimization algorithm (GOA) and cuckoo search technique proposed to reduce losses and augment the voltage stability of DG's placement by taking IEEE 33 and 69 bus test systems. This hybrid technique can find the distribution network's good, refined determination. In this paper [44], researchers mention the future scope of the analysis of the effect on power loss, with conducting both lagging and leading power factors during DG sizing.

The review finds that hybrid techniques are mostly used for optimizing distribution generation sizing and allocation, to enhance efficiency, reliability, and sustainability, with further refinement potentially leading to more resilient and eco-friendly energy infrastructure.

3.0 SIGNIFICANCE OF OPTIMAL SIZING AND ALLOCATION OF DG

The ideal size and allotment of DG play a crucial part in enhancing the efficiency and accuracy of power distribution networks. DG units, when strategically placed and appropriately sized, contribute to minimizing power losses, improving system security, and optimizing overall network performance [45], [46]. Non-optimal places or sizes of DG units could result in technical issues, including increased power losses, compromised protection coordination schemes, and adverse effects on voltage profile [47]. Therefore, the significance lies in ensuring that DG systems are allocated in optimal locations within the DN and are sized appropriately to match the demand and characteristics of the specific grid.

The overarching goal of ideal DG allotment and size is to achieve a balanced and resilient power distribution system. By utilizing advanced optimization methodologies, such as those considering uncertainties and employing mixed-objective optimization techniques, power engineers can make informed decisions about the placement and size of DG units [48]. This approach contributes to the overall sustainability of the electrical grid, fostering improved energy efficiency, reduced environmental impact, and increased system robustness against fluctuations in demand or unforeseen disruptions. As a result, the significance of optimal DG allotment and sizing lies in its ability to address technical challenges, enhance system reliability, and clear the path for an extra enduring and robust energy shell [49].

There are multiple sources that point to the benefits of distributed generation (DG) integration. According to the research, DG contributes to faster recovery from disruptions by decentralizing power generation, which increases grid resilience. Generating electricity closer to consumption sites also improves the power quality, increases power flow, and lowers transmission losses. Combining renewable DG resources, such as wind and solar, promotes sustainability while minimizing the environmental effects presented in [50]. Furthermore, DG systems help the grid by controlling reactive power, maintaining frequency, and supporting voltage, all promoting stability. Rewards and possible cost savings on energy bills also provide financial advantages for customers. This extensive list of benefits highlights the importance of DG integration in changing energy systems to become more resilient, sustainable, and efficient [51].

There are several mathametical techqiues are utilized for the optimal allocation and sizing of DG in power system. These include deterministic approaches, such as linear programming, mixed-integer linear programming and nonlinear programming, which provide precise solutions under specific constrainst. Analytical techniques, such as the loss Sensitivity factor (LSF) and Power Flow Sensitivity (PSF) analysis, ofer simplifies yet eefective ways to determine optimal DG placement by evaluating system performance metrics. Additionally, hueristic and hybrid that combine traditional algorithms with modern optimization techniques are increasingly popular for handling complex and large scale integration challenges. A brief discussion of these techniques and their application in power systems follows below

Table 1 Related Work on DG Allocation and Sizing

Ref.	Year	Objective	Method	Test System	Constraints
[16]	2023	To maximize voltage stability index, to mitigate power outage, and to refine voltage profile.	Jellyfish Search Optimizer (JS),	94 Portuguese bus systems, IEEE 33 and 69	This paper's researchers do not mention the constraints
[17]	2023	To reduce de-energized zones and maintain system reliability through remote or automatic switching devices.	Multi-criteria optimization algorithm.	IEEE 33 and 123 bus test system.	This paper's researchers do not mention the constraints
[18]	2023	Reducing power outages and enhancing power quality and voltage profile through WSO.	White Shark Optimization (WSO).	IEEE 33, 69, and 85 node systems.	**Equality Restriction** – Power-conservation restrictions. **Inequality Restrictions** – Voltage restriction – DG limit restrictions. – Line Capacity Restriction.
[19]	2023	Increasing the levels of bus voltage, enhancement of ISI index with suggested Zth, diminished actual power outages	Grey Wolf Optimization (GWO) And (GA) Genetic Algorithm	IEEE 69 and 118-bus test system	**Equality Constraints** – Power balance **Inequality constraints** – Voltage limits – The penetration level of DGs
[20]	2023	Allocating the solar panel PV and WT simultaneously while changing the radial distribution	Improved salp swarm algorithm (ISSA)	IEEE 33 and 69 bus radial networks.	**Equality constraints** – Power Balance **Inequality constraints** – Voltage constraint, – DG production range – Line power
[28]	2023	To decrease total expense, emissions, and voltage deviation while enhancing voltage stability, considering uncertainties	Artificial hummingbird algorithm (AHA), Monte-Carlo simulation approach alongside backward reduction algorithm.	IEEE 33 and Portugal 94-bus	**Equality constraints** – Power losses **Inequality constraints** – Voltage limits
[42]	2023	To refine the voltage profile and abate losses.	Analytical least squares extrapolation technique	Ethiopia's useful Yirgalem-I Distribution Network	**Equality constraints** – Not mentioned **Inequality Constraints** – Bus voltage constraints – DG power rating constraint – Reactive and real power loss – Line loading constraint
[43]	2023	To reduce annual economic loss, minimize real power loss, and enhance voltage profile to maximize savings.	Multi-objective whale optimization (MOWOA) algorithm	Radial bus systems IEEE-33 and IEEE-69	**Equality constraints** – Power balancing **Inequality Constraints** – Bus voltage limit – Line power flow – Generator capacity
[10]	2023	The study put forward a hybrid technique as bettering the placement and size of four DG units in distribution networks that have TVVD loads to reduce power losses and voltage deviation.	The latest hybrid technique pounded, Particle Swarm Optimization (PSO) Salp Swarm Algorithm (SSA) and	69-bus system	This paper's researchers do not mention the constraints

Ref.	Year	Objective	Method	Test System	Constraints
[31]	2023	To mitigate outages and refine the voltage profile in LV nodes avoid raising the price if the asset	Modified Genetic Algorithm	IEEE 33 bus radial distribution system	**Equality constraints** – Not mentioned **Inequality constraints** – Current Magnitudes – Voltage Magnitudes – Power Magnitudes – Positions of New DG – Installed power of new DGs – Installed Power and Positions of New CBs
[32]	2023	To identify 3 different forms of 3 phase, 123 bus unstable PDN with numerous DGs, including their location, size, type and power factor.	Equilibrium Optimizer (EO) algorithm	unbalanced PDN Three-phase 123-bus.	**Equality constraints** – Power balance limit **Inequality constraints:** – Voltage Limits – Current Limits – Voltage Regulator Tap Position Limits – Power Limits
[33]	2022	To minimize the radial distribution networks' total line losses	Loss sensitivity factor (LSF) Golden Jackal Optimization (GJO) algorithm	33 buses test system.	**Equality constraints** – Power flow **Inequality constraints** – Not Mentioned
[34]	2021	SMFO is utilized to address voltage profiles, power outages, and pollution emissions.	Swarm moth flame optimization algorithm (SMFO)	IEEE-33 bus	**Equality constraints** – Power balance **Inequality constraints** – DG Sizing
[36]	2021	To find a cost-effective yet stable network with minimal power loss, optimal bus voltage profile, and superior branch current limits.	Improved Harmony Search Algorithm (IHSA).	A realistic Indian 52-node and an IEEE 33-bus RDS	**Equality constraints** – Total power loss **Inequality constraints** – Not Mentioned
[37]	2021	To improve power flow distribution, voltage stability, and lower real power loss in the distribution system, the placement and capacity of DGs must be optimized.	Improved firefly Algorithm (IFA)	IEEE-33 and IEEE-69	**Equality constraints** – Power flow formulation **Inequality constraints** – Voltage limits – Current limits – The real power limit of DG unit – The reactive power limit DG unit – DG power factor limit
[24]	2021	Minimizing active power losses in DN can be defined using an equation that determines the position and size of GES and RES units.	Coefficient Particle Swarm Optimization (CPSO)	33-bus test system	**Equality constraints** – Power flow **Inequality constraints** – Number of RES and GES units – RES and Storage unit's capacity – load supplied by RES and storage unit using penetration level. – Voltage magnitude at buses – Storage unit parameter
[38]	2021	Limitations are taken into consideration to minimize power loss.	Improved flower pollination algorithm (IFPA).	Indian 52-bus system that is practical	**Equality constraints** – Power balance

Ref.	Year	Objective	Method	Test System	Constraints
					Inequality constraints – Voltage limit – DG sizing Limits – Thermal limits
[52]	2021	An analysis of sensitivity has been carried out, employing PLF to track how different DGs with different pfs and load SDs affect the relevant goals	Adaptive modified whale optimization algorithm (AMWOA)	Conventional IEEE 33 and 69 bus DNs have been employed	**Equality constraints** – Not Mentioned **Inequality constraints** – Voltage limit – Line loading. – DG capacity
[30]	2020	To simultaneously reduce typical voltage reduction, total power loss, and overall energy costs.	Artificial bee colony (ABC)	CIGRE medium voltage (MV) benchmark grid, IEEE 33, and 69-bus radial networks .	**Equality constraints** – Active power loss – Voltage drops. – Total energy cost – Power balance **Inequality constraints** – Voltage limitation of buses – Capacity limitations of DGs – Limitations of branch currents
[23]	2020	To shorten power losses and enrich the voltage profile on the system by optimizing the DG's placement and capacity.	Particle Swarm Optimization (PSO).	BASUKI RAHMAT SURABAYA FEEDER	**Equality constraints** – Actual and reactive power loss **Inequality constraints** – Voltage limits
[22]	2020	There are two metaheuristic methods applied. To lower the Radial Distribution Systems' (RDS) power losses.	The modified Gravitational Search Algorithm (MGSA) and adaptive Particle Swarm Optimization (APSO).	The test RDSs for the IEEE 69-bus and 85-bus	**Equality constraints** – Power balance constraints **Inequality constraints** – Voltage amplitude – DG capacity
[27]	2020	To lower actual power outages, enhance the voltage profile of the distribution system	Particle swarm optimization with selectivity (SPSO)	Radial distributed system (RDS) for IEEE 33-bus	**Equality constraints** – Not Mentioned **Inequality constraints** – Voltage Limit – Reactive power limit – Line loading
[39]	2020	To improve reliability, economic benefit, and voltage profile, a multi-objective function (MOF) has been implemented.	Using the grasshopper optimization (GOA) method	94-bus Portuguese	**Equality constraints** – Not Mentioned **Inequality constraints** – Voltage magnitude limits constraint – DG Capacity Constraints
[25]	2020	Resolving the shortcomings of earlier algorithm while minimizing actual power loss	Multileader particle swarm optimization (MLPSO)	In the Malaysian context, an actual radial bus system and the standard IEEE 33 bus sequence.	**Equality constraints** – Nodal power balance – Active power loss **Inequality constraints** – Voltage – Thermal – DG capacity

Ref.	Year	Objective	Method	Test System	Constraints
[6]	2020	To analyze the concurrent minimization of a distribution network's overall energy loss and the owner of the RDG's profit maximization.	Hybrid Meta-Heuristic Algorithm (Combination of the phasor particle swarm optimization and the gravitational search algorithm.)	IEEE 69-bus system	**Equality constraints** – Power Flow Constraints – Power balance (active and reactive power) **Inequality constraints** – Bus Voltage and Branch Load Constraints – RDG Capacity Constraints
[40]	2019	To pare down active power loss in the distribution network by strategically placing multiple different types of distributed generators at the optimal size and location.	Exhaustive search approach	IEEE 16- and 33-bus standard test systems	**Inequality constraints** – Bus Voltage – Real Power and Reactive Power injection
[35]	2019	To reduce overall power losses by employing an integrated strategy to determine where PV-DG units should be placed in RDSs.	Moth Flame Optimization (MFO) algorithm,	33, 69, and 118-bus systems.	**Equality constraints** – Power conservation constraint **Inequality constraints** – Bus voltage limits – Voltage drop limit: – Line capacity constraint. **PV DG constraints** – PV-DG capacity limits – Number of PV-DG units – Location of PV-DG units
[26]	2019	To overall the amount of power taken from the substation and increase voltage stability.	The Chaotic Particle Swarm Optimization (CPSO) and Particle Swarm Optimization (PSO)	Mesh and radial distribution networks with 33 nodes.	**Equality constraints** – Power losses **Inequality constraints** – Voltage limit

4.0 OPTIMIZATION TECHNIQUES

It is important that the allocation of DG units at the optimal place with the perfect size reduces the complete power system's loss, running, and care costs and improves power quality, voltage profile, stability, and reliability. The major techniques are analytical, meta-heuristic, and hybrid techniques for DG allocation and sizing as defined below and an analysis of techniques has been given in [53],[54] Table 2.

4.1 Analytical Technique

The most suitable size and placement of DG units within distribution networks are mostly calculated using analytical optimization approaches. These techniques use efficient ways to determine related best sites and mathematical analysis to create expressions for optimal DG sizing as shown in [55]. These techniques offer the convergence of the solution as well as simplicity in computation and use. By contrasting the analytical methods of optimization criteria, the appropriateness of distribution renewable generation (DRG) planning is evaluated [56]. The optimal voltage increases, or power loss solution is determined by looking at the capacity and placement of potential DGs linked to DN. Thus, technical limitations determine the most appropriate DG capacity. Depending on the kind of issue, an analytical analysis employs both linear and nonlinear programming techniques. An optimization technique called linear programming (LP) uses the linearized power flow form to find a solution. Nonlinear functions or incidents are modeled similarly to linear functions in this approach[57]. For example, DG's operation plan, which aims to consume the least amount of energy possible throughout the year, was optimized using mixed-integer linear programming (MILPP) [58]

4.2 Meta-heuristic Technique

Metaheuristic approaches are commonly utilized to optimize the placement of DG units inside DNs. These methods provide effective solutions for the challenging problem of DG allocation, guaranteeing enhanced dependability and efficiency of the network [59]. The following are a few important metaheuristic techniques used in DG allocation. Over many epochs, a bundle of research has been done on heuristic strategies to choose the best placement for DG. Widely used as heuristic methods are particle swarm optimization, genetic algorithms techniques dissimilar evolution, and others as mentioned in [60]. A summary of standard heuristic optimization techniques is summarized below.

4.2.1 Genetic Algorithm (GA)

In 1960, John Holland introduced GA, which was later expanded upon in 1989 by his student David E. Goldberg [4], [46]. The search technique known as a genetic algorithm (GA) is situated on concepts of natural selection and genetics, including choice, crossover, mutation, and inheritance [61]. GA operates a team of individuals who represent a unique answer. The number of

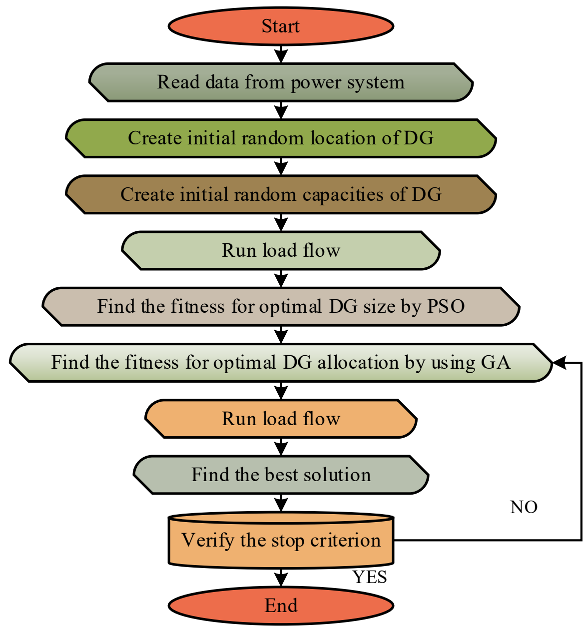


Figure 3 The method for allocation and sizing of DG using GA-PSO

variables in the fitness function is considered while creating a random candidate solution set or population. Through the application of genetic operators like mutation and crossing, it is guided toward an improved answer. By reducing the bad solutions, the right response will be discovered. The applicability of newly created and genetically enhanced solutions that use the objective function is assessed[56]. The best placement of DGs for networks having distribution loads, loads with concentrated power that are both constant and variable, can be solved using genetic algorithms [62],[63],[64].

4.2.2 Particle Swarm Optimization (PSO)

PSO is a population-based optimization technique (OPT) that Kennedy and Eberhart created in 1995 to optimize multi-dimensional problems. They were motivated by fish training, and wisp social behavior was proposed in [22], [23]. This is an approach for field searches where particles, which are randomly created individuals, change places. PSO serves to tackle complex non-linear optimization issues on a big scale. The optimal DG allocation and sizing issue utilizes an extensive bulk of hybrids and enhanced and modified PSO algorithm types. In time-varying load systems, this well-known optimization technique is employed [5], [65], [53],[54].

4.2.3 Other Meta-Heuristic Optimizations

Metaheuristic approaches represent a category of optimization algorithms inspired by natural events and social behaviors. Demonstrating significant efficacy, these techniques address intricate problems, including optimization challenges in diverse fields. Drawing on concepts from social structures, and nature, these algorithms systematically explore solution spaces to discover optimal configurations. Outstanding examples include Ant Colony optimization (ACO) [66], Harmony Search Algorithm (HSA) [67], Firefly Algorithm (FA) [37], [48], Grey Wolf Optimizer (GWO) [72], and many other meta-heuristic algorithms used for

DG allocation [1], [5], [73]. Metaheuristic approaches are widely recognized for their adaptability and versatility, and they are essential in solving challenging optimization problems. They provide a range of approaches to finding the best answer in complex and changing contexts [74].

Table 2 Strengths and weakness of optimization techniques.

Techniques	Strength	Weakness	Ref.no
Analytical Technique	Quick computation speed, simple to use, non-iterative, and free of convergence problems	Potential for error when dealing with complex issues and a lack of robustness	[68]
Mixed Integer Linear Programming	Simple to use, appropriate for challenging issues, and somewhat adaptable	Potential for erroneous outcomes because of linearization	[58]
Mixed Integer Nonlinear Programming	incredibly precise and computationally effective	Implementation is difficult and requires several choice factors.	[57]
Genetic Algorithm	Suitable for complex problems, with parameters that are both discrete and continuous	Large problem computationally inefficient, potential for early convergence, and potential for becoming stuck in local optima	[69]
Particle Swarm Optimization	Simple to operate, fewer parameters to adjust, and rapid convergence	Having trouble articulating the original design criteria, running the risk of premature convergence, and becoming stuck in local optima	[46], [68], [70]
Hybrid Optimization Technique	Combining algorithms, to improve efficiency in optimal findings. Provide efficient and reliable solutions for complex multi-objectives	Multimodal, fixed dimension multimodal. Require advanced computational sources. Parameters can be challenging	[71]

4.3 Hybrid Optimization Technique

In this technique, more than two optimization techniques are combined and involved to reach the ideal outcome. By completing the gaps in one optimization method with another, hybrid optimization (HO) attempts to maximize efficiency. HO is commonly used and generates good outcomes while managing numerous Optimal DG problems [6]. In [6], HO was used to minimize overall energy losses. In [22], HO was used to mitigate the RDSs' power losses. Another HO was utilized to reduce power losses and voltage deviation [10]. Integrated methods are indicated in Table 1 which includes several HO experiments. Furthermore, many algorithms have been used separately in many ODGA experiments. Figure 3 shows the hybrid method or allocation and sizing of DG.

5.0 CONCLUSION AND FUTURE TRENDS

Distribution generation (DG) demands an optimization technique (OPT) that could balance the safety and power quality of the distribution system within the distribution network (DN). The effective integration and planning of DG can achieve many advantages, in the same way improving power quality, power supply, accuracy, voltage stability, and loss reduction, unsuitable DG planning can hurt the power quality and distribution networks' reliability. This review article performs different OPTs for suitable size and allocation of DG in distribution systems. To figure out the best location and size of DG units in distribution systems, a review of literature addressing the past five years is presented. The literature survey table as mentioned above shows the objectives, techniques, and test systems that researchers conduct. The valuable variables are OPTs and comparisons, the algorithms, which have been valeted in multiple distribution systems and with many different types of loads.

Furthermore, it has been noted that the analytical techniques are producing reliable findings for small systems. However, new and hybrid OPTs must be used for large and complicated systems to find efficient and dependable solutions.

Based on the critical analysis and literature review, the following areas need to be investigated in the future to address the DG's optimal location and sizing problem:

- It was found that subsequent future work for the optimal sizing and installation of the distribution generation must be investigated. Much research has already been conducted to create tools for optimal DG assimilation inside the distribution system.
- Among the optimization technique types, the analytical techniques are one of the techniques used for planning DG in distribution systems, they are limited by their inability to handle the complicate, non-linear features, potentially resulting in simplistic and erroneous solutions. It can disregard crucial variables and have processing demands, which could lead to less than ideal outcomes. Conversely, the researchers look towards meta-heuristic optimization algorithms, which give efficient and reliable solutions. Given the nature of the issue, it is possible to conclude that recommendations for more effective optimization algorithms with high capabilities in the discovery of the global optimum still have room for development

- Here, hybrid optimization algorithms are highly recommended, as they give optimal, reliable, and efficient solutions for large and complex systems.
- Research on renewable distribution energy resources (DER) like micro-turbines and biomass is limited, requiring investigation for long-term planning and integration in distribution systems.

Abbreviation	
OPT	Optimization Techniques
DG	Distribution Generation
RES	Renewable Energy Sources
RER	Renewable Energy Resources
DN	Distribution Networks
WT	Wind Turbines
PV	Solar Photovoltaic
RE	Renewable Energy
RDN	Radial Distribution Networks
VD	Voltage Deviation
VSI	Voltage Stability Index
ISI	Impedance Stability Index
DS	Distribution System
GUI	Graphical User Interface
HO	Hybrid Optimization
DER	Distribution Energy Resources
MILPP	Mixed-integer linear programming
TVVD	Time varying voltage dependent
PLF	probabilistic load flow
pfs	Power factors
SDs	Standard deviations

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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