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Optimal Placement And Sizing Of Distributed Generation For Loss Minimization And Voltage Stability Using Meta-Heuristic Optimization Techniques: A Comphrensive Review

Clement Effiong[1]
Department of Electrical/Electronic Engineering,
University of Uyo, Akwa Ibom, Nigeria.
klems4real@yahoo.com

Nseobong Okpura[2]
Department of Electrical/Electronic Engineering,
University of Uyo, Akwa Ibom, Nigeria.

Akaninyene Obot[3]
Department of Electrical/Electronic Engineering,
University of Uyo, Akwa Ibom, Nigeria.

***Abstract*— Efficient placement and sizing of Distributed Generation (DG) units within power distribution systems play a vital role in minimizing power losses, enhancing voltage profiles, and facilitating the integration of renewable energy sources. This study conducts an extensive literature review on the utilization of meta-heuristic techniques to tackle these challenges. Various meta-heuristic algorithms, such as Genetic Algorithm (GA), Ant Colony Optimization (ACO), Simulated Annealing (SA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Firefly Algorithm (FA), Differential Evolution (DE), Grey Wolf Optimization (GWO), Harmony Search (HS), and Multi-Objective Flower Pollination Algorithm (MOFPA), are examined. The assessment focuses on the strengths and limitations of each algorithm, particularly in managing multi-objective optimization, uncertainties, and network complexities. Furthermore, the review delves into the potential advantages of employing meta-heuristics for DG placement and sizing, including the reduction of power losses, enhancement of voltage profiles, increase in system capacity, strengthening of resilience, and improved integration of renewable energy sources. Additionally, key areas for future research are identified, with an emphasis on developing hybrid algorithms, establishing real-world integration frameworks, standardizing benchmarking procedures, enhancing computational efficiency, and exploring emerging meta-heuristic techniques. This survey serves as a valuable reference for researchers and engineers seeking to optimize DG placement and sizing for the advancement of efficient, reliable, and sustainable power distribution systems.**

Keywords*— *Distributed Generation placement and sizing, Meta-heuristic optimization, Power distribution systems, Optimal power flow

I. INTRODUCTION

The growing demand for clean and reliable energy has spurred the integration of Distributed Generation (DG) units into power distribution systems. These smaller-scale generation sources, typically located closer to end-users, offer various benefits, including reduced reliance on centralized power plants, improved power quality, and enhanced system resilience (Hirth, 2011). However, their effectiveness heavily relies on optimal placement and sizing.

Improper DG placement and sizing can lead to increased power losses within the distribution network, negatively impacting overall system efficiency. Additionally, it can compromise voltage stability, potentially causing voltage fluctuations that can damage sensitive equipment and disrupt power supply (Khodaei et al., 2013). To address these challenges and unlock the full potential of DGs, researchers are exploring the application of meta-heuristic optimization techniques. These techniques, inspired by natural processes like swarm intelligence or biological evolution, offer efficient search algorithms for complex optimization problems such as optimal DG placement and sizing (Barati et al., 2020).

This review delves into the effectiveness of meta-heuristic techniques in minimizing power losses and ensuring voltage stability by optimizing DG placement and sizing within radial distribution systems.

II. BACKGROUND

A. *Loss Minimization in Power Systems*

Power losses are an inherent reality in any electrical power system. As electricity travels through transmission and distribution lines, a portion of the energy is inevitably dissipated as heat due to resistance in the conductors. While these losses are typically a small percentage of the total energy transmitted, they still represent a significant economic and environmental burden. Minimizing these losses becomes crucial for ensuring efficient and sustainable power delivery systems (Acha et al., 2004).

Several strategies can be employed to minimize power losses in power systems. One key approach focuses on system improvements, such as upgrading transmission and distribution lines with conductors that offer lower resistance. Additionally, reactive power management plays a vital role, as strategically placed capacitor banks can help compensate for reactive power demand and improve the overall voltage profile, indirectly reducing losses (Singh & Murthy, 2007). Furthermore, operational optimization techniques, including optimal dispatch of generation units and load shedding during peak demand periods, can also contribute to minimizing losses by ensuring efficient utilization of the existing system infrastructure (Hirst & Kirby, 2011).

DG can also play a role in loss minimization. By injecting power closer to load centers, DGs can reduce the power flow through long-distance transmission lines, thereby minimizing losses associated with these lines. However, optimal placement and sizing of DGs are crucial to maximize their effectiveness in loss reduction (Khodaei et al., 2013).

Loss minimization in power systems is a multifaceted challenge requiring a combination of system improvements, operational strategies, and strategic integration of distributed generation. By implementing these approaches effectively, utilities can ensure efficient and sustainable power delivery while minimizing environmental and economic impacts.

B. *Voltage Stability in Power Systems*

Voltage stability is a critical aspect of power system operation, ensuring the system's ability to maintain acceptable voltage levels throughout its network even under varying load conditions (Adegoke & Sun 2023). Voltage fluctuations beyond acceptable limits can have detrimental consequences. Undervoltage can lead to equipment malfunction, overheating, and potential blackouts, while overvoltage can damage electrical insulation and lead to equipment failure (Ali, 2019).

Voltage instability in power systems can be influenced by various factors, such as sudden load changes causing strain on voltage levels, transmission line outages disrupting power flow and creating imbalances, and insufficient reactive power support impacting voltage stability. Rapid fluctuations in power demand, critical line failures, and inadequate reactive power provision can all contribute to voltage instability within the system, highlighting the importance of addressing these factors to ensure reliable and stable power distribution (Ramakanta et al. 2021; Ramli et al., 2022).

Maintaining voltage stability requires a proactive approach. System planning and design incorporate voltage stability considerations to ensure adequate capacity and redundancy within the network. Additionally, operational strategies such as reactive power compensation using capacitor banks and strategic dispatch of generation units can help manage voltage fluctuations and maintain system stability (Eladl et al. 2022). Furthermore, (advanced control systems and real-time monitoring techniques play a crucial role in dynamically adjusting system operation and preventing voltage collapse under dynamic load conditions (Biswal et al. 2023).

Maintaining voltage stability in power systems is essential for reliable and safe operation. A combination of system design, operational strategies, and advanced control techniques is crucial to ensure the system's ability to deliver power at consistently acceptable voltage levels.

C.
Limitations of Traditional Optimization Techniques

Traditional optimization techniques face challenges in addressing complex and dynamic issues like optimal DG placement and sizing due to their deterministic nature, limited search capabilities, and computational complexity. These methods, relying on deterministic algorithms, struggle to adapt to the stochastic nature of power systems with uncertainties from fluctuating loads and renewable energy generation (Vijay et al., 2022).

Additionally, gradient-based algorithms may get trapped in local optima, hindering the discovery of globally optimal solutions critical for optimal outcomes. Moreover, as power system problems grow in size and complexity, traditional techniques become computationally burdensome and time-intensive, especially in scenarios with numerous variables and constraints. Addressing these limitations is crucial for enhancing the effectiveness of optimization strategies in power system planning and operation (Moustafa et al., 2023).

These limitations highlight the need for alternative optimization approaches that can effectively address the complexities of power system problems like optimal DG placement and sizing. Meta-heuristic optimization techniques, inspired by natural processes and exhibiting inherent stochasticity and global search capabilities, have emerged as promising alternatives to overcome these limitations and offer more robust and efficient solutions.

III. META-HEURISTIC OPTIMIZATION TECHNIQUES FOR DG PLACEMENT AND SIZING

A. *Overview of Meta-Heuristic Techniques*

Power system optimization presents a complex challenge due to non-linear relationships, uncertainties, and a multitude of variables. Conventional methods often face difficulties in tackling these complexities. However, meta-heuristic optimization techniques have emerged as potent tools for delivering efficient solutions. Drawing inspiration from natural phenomena, these techniques have been effectively utilized in power system optimization, offering benefits such as enhanced voltage profiles, minimized power losses, improved system reliability, and safety (Marouani et al., 2023). Metaheuristic optimization algorithms, grounded in mathematical principles, prove particularly valuable in scenarios with sparse or inaccurate data or limited computational resources. These algorithms have demonstrated successful applications in optimizing power flow, reactive power dispatch, economic and emission dispatch, Volt/Var control, as well as the sizing and placement of distributed generators within power systems (Nassef et al., 2023). The efficacy of these optimization algorithms in addressing power system challenges is well-established, with widespread implementation and documented success in the field (Vijay et al., 2022).

Metaheuristic techniques, such as heuristics and metaheuristics, offer a stochastic approach to optimization problems, incorporating randomness into their search process. This allows them to explore a broader solution space and potentially escape local optima, converging towards the globally optimal solution. These techniques are well-suited for complex problems in power systems, which often involve non-linear relationships and poorly defined objective functions. They do not require strong assumptions about the problem structure, making them flexible and adaptable to various scenarios. The use of metaheuristics in solving optimization problems has gained popularity due to their ability to provide near-optimal solutions in a reasonable amount of time. (Monteiro et al., 2022; Shafiullah et al., 2022; Thippeswamy, 2022).

The diverse landscape of meta-heuristic techniques encompasses various approaches, each offering unique strengths. Popular examples include Ant Colony Optimization (ACO), inspired by the foraging behaviour of ants, Genetic Algorithms (GA), inspired by biological evolution, Particle Swarm Optimization (PSO), mimicking the behavior of swarming insects, and Simulated Annealing (SA), modeled after the physical process of annealing in metallurgy. This variety empowers researchers to select the most appropriate technique based on the specific characteristics and requirements of the problem at hand, further enhancing the effectiveness of the optimization process (Kareem et al., 2022)

Meta-heuristic optimization techniques offer significant advantages for tackling complex problems like optimal DG placement and sizing in power distribution systems. Their inherent stochastic nature, ability to handle intricate problem structures, and iterative improvement approach make them valuable tools for navigating the complexities of power systems and achieving optimal solutions.

B. Popular Meta-Heuristic Techniques for DG Placement and Sizing

1. Genetic Algorithm (GA):

(a) Basic principles: Inspired by natural selection and evolution, GA operates iteratively. It begins with a population of potential solutions (chromosomes) representing different DG configurations. Each solution is evaluated based on a fitness function (e.g., minimizing power loss). Solutions with higher fitness scores are more likely to be selected for reproduction through "crossover" (combining elements) and "mutation" (randomly altering elements). This process iteratively refines the population, converging towards optimal DG placement and sizing (Emiroglu et al., 2021).

(b) **Suitability for DG placement and sizing:** GA's ability to handle complex objective functions, escape local optima, and adapt to diverse scenarios makes it suitable for this application (Madhusudhan et al., 2020)

.2. Ant Colony Optimization (ACO):

(a) Basic principles: Inspired by the foraging behavior of ants, ACO utilizes a population of "artificial ants" traversing the solution space. These ants deposit a virtual pheromone on paths they explore, signifying the "attractiveness" of the path based on the objective function. Subsequent ants are more likely to follow paths with higher pheromone concentrations, guiding the search towards promising regions (Nayar et al., 2021)

(b) Suitability for DG placement and sizing: ACO's ability to efficiently explore the search space and leverage collective learning makes it a promising candidate for further exploration in DG placement and sizing (Ogunsina et al., 2021)

3. Simulated Annealing (SA):

(a) Basic principles: Inspired by the physical process of annealing metals, SA starts with a randomly chosen solution and iteratively explores neighbouring solutions. The acceptance of a new solution depends on a "temperature" parameter that gradually decreases over time. Initially, even worse solutions might be accepted, allowing escape from local optima, while later stages favour improvements (Tsai & Chiang, 2023)

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(b) Suitability for DG placement and sizing: SA's ability to escape local optima is valuable for complex problems, but it can be computationally expensive compared to other techniques (Bagherian et al., 2021)

4. Particle Swarm Optimization (PSO):

(a) Basic principles: Inspired by the behavior of bird swarms, PSO utilizes a population of "particles" representing potential solutions. Each particle explores the search space, influenced by its own experience and the knowledge of the best-performing particle in the swarm. This collaborative search helps the swarm converge towards promising regions (Gad, 2022).

(b) Suitability for DG placement and sizing: PSO's simplicity, fast convergence, and ability to handle continuous variables make it suitable for DG placement and sizing problems (Gad, 2022).

5. Artificial Bee Colony (ABC):

(a) Basic principles: Inspired by the foraging behavior of honey bees, ABC utilizes three types of "bees": employed bees searching near the hive (current solution), onlooker bees selecting food sources based on employed bees' information, and scout bees searching randomly for new food sources. This collaborative search process allows the colony to efficiently explore the solution space (Wang et al., 2020)

(b) Suitability for DG placement and sizing: ABC's ability to balance exploration and exploitation makes it suitable for complex optimization problems, including DG placement and sizing (Valavala, 2021).

6. Firefly Algorithm (FA):

(a) Basic principles: Inspired by the flashing patterns of fireflies, FA utilizes a population of "fireflies" representing potential solutions. Fireflies emit light (brightness) inversely proportional to the objective function value. Fireflies are attracted to brighter fireflies, mimicking the bioluminescent communication of these insects. This attraction mechanism guides fireflies towards solutions with lower objective function values (Kumar & Kumar, 2020).

(b) Suitability for DG placement and sizing: FA's simplicity, ease of implementation, and ability to handle non-linear and discontinuous problems make it a promising option for DG placement and sizing (Jalili & Taheri, 2020)

However, several other meta-heuristic techniques are also being explored for DG placement and sizing, including Differential Evolution (DE), Grey Wolf Optimization (GWO), and Harmony Search (HS).

IV. REVIEW OF EXISTING LITERATURE

In their research, Zakaria et al. (2020) utilized Genetic Algorithm (GA) and Ant Colony Algorithm (ACO) to determine the optimal allocation and sizing of distributed generation in a radial distribution system. The study focused on minimizing active power losses in the distribution network by identifying the most efficient placement and size of distributed generators. By employing these meta-heuristic techniques, the authors aimed to enhance the performance of the power system and improve distribution network efficiency. The results showcased the effectiveness of GA and ACO in reducing active power losses and optimizing the placement of distributed generation units within the network, highlighting the potential of these algorithms in addressing power system optimization challenges.

In a recent study by Omar et al. (2021), a real radial distribution network in a rural area of Malaysia was investigated. The study focused on addressing objective functions such as loss minimization and voltage stability improvement. By employing the ACO algorithm, the research aimed to reduce power losses in the network and improve voltage stability through the strategic allocation of DG sources. This approach underscored a dedicated effort to enhance the efficiency and performance of the distribution system by carefully situating DG assets, resulting in improved operational effectiveness and decreased energy losses.

The study by Prakash (2021) utilized a Particle Swarm Optimization (PSO) meta-heuristic technique to optimize the sizing and placement of distributed generation (DG) units in a distribution network. The research focused on a radial distribution system, where DG units capable of injecting active and reactive power were strategically positioned to achieve objectives of reducing system losses and enhancing bus voltage levels. By addressing loss minimization and voltage stability improvement as primary objective functions, the study highlighted the critical role of optimal DG placement in mitigating power losses and ensuring network stability. Through the application of the PSO-based optimization approach on an 85-bus network and utilizing the Forward and Backward Sweep (FBS) method for implementation, the research demonstrated the effectiveness of PSO in efficiently determining the optimal capacity and siting of DG units in distribution systems, emphasizing the significance of meta-heuristic techniques in enhancing the operational efficiency and performance of power distribution networks.

In addressing the environmental and economic challenges faced by modern power systems, Anbuchandran et al. (2022), proposed a multi-objective optimization approach using the Firefly Algorithm for the placement of DGs. The research focused on addressing various objective functions, including the minimization of power losses, improvement of voltage profile, enhancement of Voltage Stability Index, reduction of pollutant emissions, and elimination of average voltage Total Harmonic Distortion. The study considered both a standard IEEE 33-bus system and a practical 62-bus Indian Utility System, representing a real-world distribution network scenario. By utilizing the Firefly Algorithm and incorporating fuzzy decision-making methodology to select the Best Compromise Solution from the Pareto-optimal solutions, the research aimed to optimize the siting and sizing of DGs to mitigate power system volatility and losses. The outcomes of the study were compared with previous research efforts, demonstrating significant improvements in addressing the environmental and economic challenges faced by modern power systems.

In the study by an Improved Artificial Bee Colony Algorithm (IABC) was developed to determine Khetrapal et al.,(2020) the optimal siting and sizing of Distributed Generation (DG) units for minimizing total power losses in distribution systems. The research focused on addressing the objective of power loss minimization while ensuring compliance with equality and inequality constraints. The proposed algorithm was implemented and validated using MATLAB on IEEE 33-bus and IEEE 69-bus radial distribution systems. Comparative analysis with other algorithms demonstrated the superior efficiency of the IABC in terms of simulation results for power loss and convergence properties. The study concluded that the solution obtained through the IABC algorithm represented a global optimum, highlighting its effectiveness in optimizing the placement and size of DG units for power loss reduction in distribution networks.

B. Analysis of Reviewed Studies

Review of some related studies are presented in the table 1.

Table 1: Analysis of Recent Research on Optimal DG Placement and Sizing Using Meta- heuristic Techniques

Study	Meta-Heuristic Technique	Objective Function	Performance Metric	Key Findings	Limitations
Zakaria et al. (2020)	Genetic Algorithm (GA) and Ant Colony Algorithm (ACO)	Minimization of total real power loss in the grid with DG	Reduction in active power losses and improvement in voltage profile	Effective in reducing total losses of power and improving voltage profile	Requires further exploration for broader applicability
Omar et al. (2021)	Ant Colony Optimization (ACO)	Minimize power loss and improve voltage profile	Power loss reduction, voltage stability improvement	ACO implementation in rural network system minimized power loss, improved voltage profile, and achieved optimal DG position	Limited to a specific rural network system in Malaysia
Prakash (2021)	Particle Swarm Optimization (PSO)	Optimize sizing and position of DG	System loss reduction, bus voltage enhancement	PSO-based optimization approach applied to optimize DG sizing and position in distribution network	Limited to a specific 85-bus network
Sanam (2020)	Differential Evolution Algorithm.	Minimize power loss, improve voltage profile, minimize energy loss cost, and maximize net profit/savings	Total planning cost, energy loss cost, net profit/savings percentage.	The proposed approach with DSTATCOM allocation leads to significant improvements in power loss reduction and net profit/savings.	The study did not consider the maintenance and operational costs of DSTATCOM for the total planning horizon. It also assumes steady-state conditions for voltage and current constraints.
Anbuchandran et al. (2022)	Multi-objective firefly algorithm (MOFA) is used for the optimization process.	Minimize power losses, voltage deviation, and pollutant emission, while enhancing the Voltage Stability Index (VSI) and reducing Total Harmonic Distortion (THDv).	The effectiveness of MOFA is measured by its ability to reduce power losses, energy cost, and pollutant emission, as well as improve voltage profile and VSI5.	The implementation of MOFA demonstrates significant improvements in power loss reduction, voltage profile enhancement, and pollutant emission decrease.	There is a potential of MOFA to get stuck in local optima, as it is a local search algorithm
Khetrapal et al. (2020)	Improved Artificial Bee Colony (IABC) algorithm, integrating features of the Artificial Bee Colony (ABC) and Differential Evolution (DE) algorithms .	Minimize total power losses	Reduction in power loss	The IABC algorithm exhibits better results in terms of real power loss reduction and convergence speed compared to other methods.	Requires further investigation for the scalability of the algorithm or its applicability to different types of distribution systems.

(Karunarathne et al. 2020)	Multileader Particle Swarm Optimization (MLPSO)	Minimization of system's active power loss	Loss reduction percentage and voltage profile enhancement.	The MLPSO algorithm significantly reduced power losses by 67.40% and 80.32% in the two systems, respectively, and improved voltage profiles compared to other PSO variants.	Premature convergence and less uniformity of results.
Haider et al. (2021)	PSO	Minimize Power loss	Power loss reduction and voltage profile improvement	Significant improvements in power loss reduction (32% and 68.05% before and after network reconfiguration, respectively) and voltage profile enhancement were observed.	Requires further investigation for handling uncertainties and real-world complexities
Almabsout et al. (2020)	Enhanced Genetic Algorithm (EGA).	Minimize total real power losses and total voltage deviation.	Reduction in power losses and improvement in voltage profiles.	The EGA outperforms other algorithms in terms of technical and economic improvements, showing significant reductions in power losses and enhancements in voltage profiles across various test systems.	Requires further research on convergence speed
Elattar & Elsayed (2020)	Modified Moth Flame Optimization (MMFO)	Minimize the total operating cost, which includes reducing active power loss, voltage deviation, DG unit costs, and emissions.	Total operating cost reduction and improvement in voltage profiles.	The MMFO algorithm showed effectiveness and superiority over other published algorithms when applied to the IEEE 69-bus test distribution system.	Requires further investigation for handling uncertainties and real-world complexities
El-Ela et al. (2021)	Coyote Optimization Algorithm (COA)	Minimize power losses, reduce fault currents, and economize the installed Fault Current Limiters (FCLs) sizes	Significant power loss and fault level reduction	The single-stage approach for DGs and FCLs allocation proved effective compared to the two-stage approach.	Computationally intensive
Selim et al. (2020)	Sine Cosine Algorithm (SCA) and chaos map theory.	Minimize power loss and improve voltage profiles	Convergence rate and power loss reduction	The proposed Chaotic SCA (CSCA) outperforms the original SCA and other competitive techniques, showing efficiency in solving	Requires further exploration for broader applicability

				the optimal multiple DGs allocation problem.	
Salau et al. (2020)	Selective Particle Swarm Optimization (SPSO)	Minimize real power loss, reactive power loss, and cumulative voltage deviation.	Percentage reduction of power losses and voltage deviation.	Achieved significant reduction of power losses and voltage deviation under different load levels.	The proposed method was only applied to a single test system and may not generalize to other systems with different characteristics and constraints.
Iftikhar et al. (2024)	Gazelle Optimization Algorithm (GOA) and Mountain Gazelle Optimization Algorithm (MGOA)	Minimization of active power losses, voltage stability, voltage deviation, greenhouse gas emissions, and total electricity purchase cost	Reduction in power losses and improvement in voltage profiles.	The MGOA outperformed the GOA and other algorithms in terms of solution quality and convergence speed.	The proposed algorithms are only tested on one test system and may not generalize to other systems
Mehroliya & Arya (2024)	Whale Optimization Technique (WOT).	Minimize the total active and reactive power losses and improve the voltage stability	Voltage profile improvement, power loss reduction, less execution time, and fast convergence rate.	Achieved significant reductions in power losses and enhancements in voltage profiles	Requires further investigation for handling uncertainties and real-world complexities
Chakraborty & Ray (2024).	Slime mold algorithm (SMA) combined with weighted sum technique (WST) and fuzzy clustering	Minimize average daily active power loss, improve average daily voltage profile, and reduce daily operational cost of distributed generators	Reduction in average daily power loss, improvement of Voltage Profile and Cost reduction	SMA achieved significant reduction in power loss, voltage deviation, and operational cost, as well as improvement in voltage stability index.	Requires further exploration for broader applicability
Sharma & Naick (2024).	Artificial Rabbits Optimization (ARO)	Minimize real power loss, total voltage deviation, and maximizing the voltage stability index.	Reduction in power losses and improvement in voltage profiles.	ARO algorithm demonstrated promising results, showed power loss reduction, voltage profile improvement, and voltage stability enhancement.	Requires further exploration for broader applicability
Pamuk & Uzun (2024)	Arithmetic Optimization Algorithm (AOA)	Minimization of total power loss and voltage deviation	Reduction of power loss and improvement of voltage profile compared to other optimization methods and scenarios	The best results were obtained when only DGs were placed and the optimal power factor of each DG was determined in addition to the optimal location and capacity	The study did not perform real-time operations or field tests to validate the results
Poshtyafteh et al. (2024)	Modified Harris Hawk optimization (MHHO)	Minimize cost, emissions, and losses	generation cost, the Reduction of power exchange cost, the demand response cost, and the power	MHHO algorithm Outperformed the other algorithms mentioned in the study in terms of cost reduction, emission reduction,	Requires further exploration for broader applicability

			loss cost	and loss reduction	
Jayabarathi et al. (2024)	Grey wolf optimizer (GWO)	Minimization of total power loss	Power loss reduction and voltage profile improvement in distribution systems	Effective for minimizing power losses, achieved comparable results to other techniques	Requires fine-tuning of parameters and initial population size for different problems
Gautam et al. (2024)	Bat Algorithm (BA)	Minimise power loss and improve voltage profile	Power loss reduction, voltage deviation, uncertainty quantification	Achieved significant reductions in power loss and also highlighted the importance of considering uncertainties in Distributed Generation Systems (DGS) placement strategies for achieving optimal outcomes.	Requires further exploration for broader applicability
Yumbla et al. (2024)	Neighborhood-based Matheuristic Algorithm (NMA)	Minimize power losses, operational cost, and Greenhouse Gas (GHG) Emissions	Reduction of operational cost, power losses, greenhouse gas emissions, computational time, optimality gap	Effectively reduced the operational cost, power losses, and also yielded economic and environmental benefits.	Computationally intensive
Tolba et al. (2024)	Modified Capuchin Search Algorithm (mCapSA)	Minimize power losses, voltage deviation, voltage stability	Reduction in power loss, Voltage deviation reduction	The proposed mCapSA algorithm outperforms the other algorithms in terms of accuracy, convergence speed, and robustness.	Requires further exploration for broader applicability
Sadeghi et al. (2023)	Cultural Algorithm (CA) and Cuckoo Search Algorithm (CSA)	Minimize power loss and voltage deviation	Loss reduction, voltage profile improvement, and computational efficiency	CA outperformed CSA in terms of loss reduction and voltage profile improvement, while CSA has a faster convergence speed and less computational time.	Requires further exploration for handling uncertainties and complex network topologies
Moses et al. (2023)	Particle Swarm Optimization (PSO)	Minimize total real and reactive power losses and maximize voltage profile	Total power loss reduction, average bus voltage improvement, and optimal location and size of DG units	The integration of DG units at predetermined buses significantly decreased the total real and reactive power losses and enhanced the voltage profile.	Requires further exploration for broader applicability
Bai et al. (2024)	A combined Differential Evolution and Particle Swarm Optimization (DE-PSO) algorithm	Minimize power loss and improve voltage levels	Reduction in power loss and improvement in voltage levels across all buses in the system	The DE-PSO algorithm effectively combined the global optimization capabilities of DE with the fast convergence rate of	The study only tested two modified IEEE test feeders and did not generalize to other distribution networks.

				PSO.	
Subbaramai& Sujatha (2023)	Multi-Objective Whale Optimization Algorithm (MOWOA)	Minimize power loss, annual economic loss, and voltage deviation	Reduction in power loss, annual economic loss, and voltage deviation	MOWOA achieved better results than other methods in terms of power loss reduction, annual economic loss reduction, and voltage profile improvement	The did not consider the impact of DG units on harmonic distortion and power quality.
ML (2023)	A combined Differential Evolution (DE) and particle swarm Optimization (PSO) algorithm	Minimize the total power loss and improve the voltage profile	The percentage reduction in power loss and the voltage deviation index (VDI) of the system.	Very effective in terms of the convergence rate, power loss reduction and voltage level improvement across all the buses	Requires further investigation for handling uncertainties and real-world complexities
Amroune et al. (2023)	Grey Wolf Optimizer and Cuckoo search (GWOCS), Bald Eagle Search (BES), Marine Predators Algorithm (MPA), Artificial Ecosystem Optimization (AEO), and Slime Mould Algorithm (SMA)	Minimization of the real power loss, voltage deviation, and voltage stability index of distribution networks with multiple distributed generators.	Quality of algorithm output, convergence speed, reliability, efficiency.	AEO showed the highest success rate percentage (82.5%) compared to other algorithms. GWOCS showed the lowest success rate percentage (37.5%).	The study did not consider the environmental, economic, or social impacts of DG integration or the uncertainties and variability of renewable energy sources.
Aarif & Sudabattula (2023)	Particle Swarm Optimization with Perturbed Velocities (PSODE) and Gorilla Troops Optimizer (GTO).	Minimize the active and reactive power losses and the voltage deviation.	The percentage reduction of Power Loss Index (PLI)	The GTO outperformed the PSODE and other existing techniques in terms of PLI reduction, convergence speed, and robustness.	The effects of load variations, network reconfiguration, and power quality issues are not considered.
Alyu et al. (2023).	A hybrid approach combining Grey wolf Optimizer (GWO) and Particle swarm optimization (PSO)	Minimizing power loss and enhancing the voltage profile.	Active Power Loss Reduction (APLR), Reactive Power Loss Reduction (RPLR), Maximum Voltage Deviation Index (MVDI), and Runtime (processing time).	The hybrid GWO-PSO algorithm demonstrated superior performance compared to other techniques in achieving multi-objective optimization	Requires further exploration for broader applicability
Alizadeh et al. (2023).	Non-dominated Sorting Genetic Algorithm (NSGA-II).	Minimize total energy cost, energy loss, average voltage drop, and improve voltage profile.	Reduction in system losses, improved voltage profile, and increased active to reactive power lines.	The study demonstrated that inappropriate DG placement can increase system losses and costs, while optimal placement and sizing can	Computational complexity, accuracy of modeling assumptions, and scalability to larger power systems.

				significantly reduce losses and improve voltage profiles	
Huy et al. (2023).	Enhanced Search Group Algorithm (ESGA)	Minimize active power losses, enhance voltage stability, and improve the voltage profile	Superior solution quality and convergence speed, especially for large-scale systems	Effectively reduced power loss and increased voltage stability	Requires further investigation for handling uncertainties and real-world complexities
Ali Raza et al. (2023).	Ant Colony Optimization Algorithm (ACOA)	Minimize Active power loss (APL), reduce Doltage Drop (VD) on buses, enhance system stability (SS), and improve overall reliability	Active power loss reduction and voltage profile improvement	Achieved significant reductions in active power loss and improvements in voltage profiles	The study did not consider the potential challenges in practical implementation within Radial Distribution Networks (RDNs).
Manthri & Datta (2023)	Ant Lion Optimization (ALO) algorithm	Minimization of power loss	Reduction in power loss, Voltage deviation reduction	ALO algorithm outperformed Light Search Algorithm (LSA) in all cases evaluated on an IEEE 33-bus system with varying load conditions.	Scalability to larger systems, computational complexity, and the generalizability of results to different network configurations.
Souheyla & Omar (2023)	Golden Jackal Optimization (GJO) algorithm	To minimize the system's total power loss	Power loss reduction percentage and voltage profile improvement.	Effectively determined the ideal location and sizing of DGs, leading to improved system performance.	Requires further exploration for broader applicability
Pandey et al. (2023).	JAYA algorithm	To minimize active power loss reduction, voltage deviation reduction, and voltage stability index maximization	Reduction in active power loss and voltage profile improvement	Provided simple, feasible, and applicable method for optimal DG calculation.	Scalability of the algorithm or its applicability to different types of distribution networks
Imran et al. (2023)	Gazelle Optimization Algorithm (GOA) and Mountain Gazelle Optimizer (MGO) are utilized.	To minimize active power losses, voltage stability, and voltage deviation, while also considering non-technical objectives like minimizing emissions and electricity purchase costs	Reduction in active power loss, improvement in voltage profiles, reduction in energy purchase costs, and minimizing environmentally problematic Green House Gas (GHG) emissions	MGO showed remarkable efficiency in reducing active power loss, while GOA is less efficient when allocating DGs in parallel with Capacitor Banks.	Requires further investigation for handling uncertainties and real-world complexities
Ajewole et al. (2023).	Genetic Algorithm (GA)	Minimize real power loss and voltage profile improvement	Reduction in real power loss and improvement in voltage profiles, with a focus on energy cost reduction	The approach resulted in a 52.3% decrease in real power loss on the Nigerian feeder and an energy cost reduction from N658,789.12 to N314,227.381.	Requires further investigation for the scalability of the algorithm or its applicability to different types of distribution systems.

Raj & Saravanan, (2023)	Dwarf Mongoose Optimization (DMO)	To minimize power loss, improve voltage profile, and reduce operation costs	Reduction in real power loss and improvement in voltage profiles and cost reduction	DMO effectively determined optimal placement and size of Distribution Static Compensator (DSTATCOM) and DG	Requires further exploration for broader applicability

V. Comparative Analysis and Discussion

A. Comparative Analysis of Meta-heuristic Techniques

Based on the reviewed studies, various meta-heuristic techniques hold promise in optimizing the placement and sizing of distributed generation in power distribution systems.. Presented below is a comparative analysis highlighting their key features, strengths, and limitations:

Table 2: Comparative Analysis of Meta-heuristic Techniques for Optimizing DG Placement and Sizing in Power Distribution Systems

Technique	**Strengths**	**Limitations**	**Suitability**
Genetic Algorithm (GA)	Effective for multiobjective optimization	Computationally intensive	Microgrids with complex objectives (power loss, voltage profile)
Particle Swarm Optimization (PSO)	Handles uncertainties effectively	Sensitive to parameter selection	Microgrids with fluctuating power generation
Firefly Algorithm (FA)	Simple to implement	Limited exploration capabilities	Radial systems for initial exploration, may need hybridization for complex scenarios
Simulated Annealing (SA)	Applicable to complex network topologies	Inherently slow convergence	Meshed systems for initial study, may not be efficient for large scale systems
Differential Evolution (DE)	Suitable for multiobjective optimization	Requires careful parameter tuning	Radial systems with multiple objectives (power loss, voltage stability)
Grey Wolf Optimization (GWO)	Effective for power loss minimization	Requires further research on parameter selection and convergence speed	Radial systems for power loss reduction, needs further exploration for multiobjective scenarios
Artificial Bee Colony (ABC)	Effective for multiobjective problems	Requires investigation for handling realworld complexities	Radial systems with multiple objectives, needs adaptation for uncertainties
Harmony Search (HS)	Good balance between exploration and exploitation	Requires research on parameter tuning and practical constraints	Radial systems for multiobjective optimization, needs further development for realworld application
MultiObjective Flower Pollination Algorithm (MOFPA)	Suitable for economic considerations	Limited applicability for complex network topologies	Radial systems with cost optimization alongside power loss reduction, needs exploration for uncertainties in complex systems
Ant Colony Optimization	Effective for combinatorial optimization problems.	May converge slowly in largescale problems.	Suitable for optimization tasks inspired by the foraging behavior of ants.

The selection of the most suitable optimization technique depends on the specific characteristics of the system and the objectives at hand. Genetic Algorithms (GA), Differential Evolution (DE), Artificial Bee Colony (ABC), Ant Colony Optimization (ACO), and Multi-Objective Flower Pollination Algorithm (MOFPA) show promise for multi-objective optimization tasks. Particle Swarm Optimization (PSO) and Firefly Algorithm (FA) demonstrate proficiency in managing uncertainties, particularly crucial in dynamic power generation environments. Simulated Annealing (SA) is suitable for intricate network structures but may lack efficiency in large-scale systems. Despite the advantages offered by these techniques, challenges such as computational complexity, parameter sensitivity, exploration capabilities, and practical implementation constraints are recognized.

B. Trends and Future Directions

The dynamic field of meta-heuristic techniques for DG placement and sizing is continuously advancing, presenting several key trends and promising future directions. Hybrid approaches, such as the integration of GA and PSO, are gaining traction for their ability to combine strengths and enhance exploration and exploitation capabilities. Ongoing research focuses on developing effective hybrid algorithms to further optimize DG solutions. Real-world Integration is a significant focus, transitioning from theoretical concepts to practical applications by addressing cost optimization, real-time data integration for dynamic adjustments, and managing uncertainties in power generation fluctuations. Benchmarking efforts involve the development of standardized frameworks for objective comparisons, enabling a data-driven selection of the most suitable technique for specific DG placement and sizing challenges. With the increasing complexity of power systems, enhancing computational efficiency is paramount, leading researchers to explore algorithms that can swiftly find near-optimal solutions. Overall, the future outlook for meta-heuristic techniques in DG placement and sizing is promising, offering opportunities for researchers and engineers to contribute to the development of more efficient, reliable, and sustainable power distribution systems with optimized DG integration.

VI. CONCLUSION

In conclusion, this study has comprehensively examined the application of meta-heuristic techniques for optimal DG placement and sizing in power distribution systems. The reviewed studies demonstrate the effectiveness of these techniques in achieving significant improvements in system performance and also in addressing challenges in power system optimization. These methods offer advantages such as optimization capability to find near-optimal solutions, multi-objective optimization for handling competing priorities, flexibility across different system types, and the ability to manage uncertainties like fluctuating power generation. While challenges like computational complexity exist, ongoing research focuses on hybrid approaches and improved algorithms to overcome these limitations. The successful application of meta-heuristics in DG placement and sizing can lead to reduced power losses, enhanced voltage profiles, increased system capacity, improved resilience, and the integration of renewable energy sources. Recommendations for further research include exploring hybrid algorithm development, creating real-world integration frameworks, establishing standardized benchmarking frameworks, improving computational efficiency, and investigating emerging techniques like the Bat Algorithm and Biogeography-Based Optimization. By advancing research in these areas, researchers and engineers can contribute to the development of more efficient, reliable, and sustainable power distribution systems with optimized distributed generation integration.

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