Journal of Renewable Energies ICREPS'24 Naama (2024) 131 – 149

DOI: https://doi.org/10.54966/jreen.v1i3.1298

Journal of Renewable Energies

Revue des Energies Renouvelables

journal home page: https://revue.cder.dz/index.php/rer

Conference paper

A Modified Genetic Algorithm for Optimizing the Placement and Sizing of Distributed Generators in Radial Distribution Systems Including Security Analysis

Nasreddine Bouchikhi [a,*], Fethi Boussadia [a], Riyadh Bouddou [b], Sarra Zaidi [c], Sarra Adiche [d], Abdallah Belabbes [e]

[a] *Department of Electrical Engineering, Laboratory Mechatronics (LMETR), University of Setif 1, Setif, Algeria*
[b] *Department of Electrical Engineering, Institute of Technology, University Centre of Naama, Naama, Algeria*
[c] *Department of Electrical Engineering, Laboratory GIDD, University of Relizane, Relizane , Algeria*
[d] *Department of Electrical Engineering, L2GEGI Laboratory, University of Tiaret, Tairet , Algeria*
[e] *University of Oran 2, Industrial maintenance and safety institute, Oran , Algeria*

ARTICLE INFO

Article history:

Received October 1, 2024
Accepted October 16, 2024

Keywords:

Distribution electrical network,
Modified Genetic Algorithm (MGA),
Distributed Generation (DG),
Optimization,
ETAP.

ABSTRACT

In this paper, a Modified Genetic Algorithm (MGA) combined with ETAP (Electrical Transient Analyzer Program), is proposed to optimize the placement and sizing of Distributed Generation (DG) units while considering multiple objectives, such as improving voltage profiles, reducing line losses, and managing short-circuit levels. These factors are critical for maintaining power quality, system reliability, and overall stability. The MGA approach is validated through simulations using the IEEE 33-bus distribution system, modeled in both MATLAB and ETAP. The results show significant improvements in voltage stability, loss reduction, and short-circuit level management, enhancing energy management and operational efficiency. A comparative analysis with alternative algorithms, including the Bat Algorithm (BA), Bacterial Foraging Optimization Algorithm (BFOA), and Artificial Immune System (AIS), demonstrates that MGA achieves superior convergence speed and accuracy, making it highly effective for DG placement and power system performance optimization.

1. INTRODUCTION

The optimization of power distribution networks is based on a number of approaches aimed at improving energy efficiency while guaranteeing the reliability and quality of supply (Das et al., 2018). Among

* *Corresponding author, E-mail address: bouchikhi.nasreddine@univ-setif.dz*
Tel : + 213 660778539

ISSN: 1112-2242 / EISSN: 2716-8247

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License. Based on a work at http://revue.cder.dz.

these approaches, the integration of decentralized production, particularly via renewable energy sources, is playing an increasingly important role. Today, electricity distribution is facing new challenges, linked to the massive integration of renewable energies, smart grids and growing demands for resilience in the face of disruption. The development of technologies such as smart grids and energy storage systems is enabling more dynamic and optimized management of the distribution network. These technologies offer greater responsiveness to demand fluctuations and incidents, and are also crucial for the effective integration of Distributed Generation (DG) sources (such as solar and wind), which introduce intermittency and variability into the energy supply. One of the main challenges is to reduce technical and non-technical losses, which can be caused by factors such as heat dissipation in cables, incorrectly sized or faulty equipment, and fraud (Henriques et al., 2020; Hoang et al., 2021; Khalid, 2024). The networks must also meet long-term sustainability and energy security criteria, while adapting to future flexibility requirements. This requires rigorous planning, based on in-depth simulations and analyses, to anticipate future energy needs and avoid overloads or prolonged outages. Traditionally, compensating for reactive energy by installing capacitor banks has long been a preferred solution for reducing power losses due to the transit of reactive currents and for improving voltage profiles in distribution networks (Javid et al., 2024). These systems make an effective contribution to energy management, but technological developments and the emergence of renewable energies have fundamentally altered the structure and requirements of electricity networks. Today, DG's, from renewable sources such as solar photovoltaics and wind, has become a key element in this transformation, offering a sustainable alternative to traditional generators and improving flexibility and power quality. Integrating DG units into distribution networks not only enhances the resilience of the system, but also reduces long-term operational costs (Bajaj & Singh, 2020; Mishra et al., 2021). DG facilities, which are often decentralized, offer the advantage of limiting losses associated with transporting energy over long distances, while at the same time providing considerable environmental benefits through reduced greenhouse gas emissions and less dependence on fossil fuels. These developments also enable distribution networks to adapt to fluctuating demand and ensure better management of energy resources. However, the non-optimized integration of DG units, combined with capacitor banks, can generate imbalances and lead to additional losses, offsetting the expected benefits (Ali-Dahmane, 2023; Nadeem et al., 2023). Inappropriate positioning of these units can, for example, cause voltage fluctuations and affect grid stability. It is therefore crucial to develop optimization methods to determine the optimum location and sizing of DG units and capacitors. Indeed, an optimal configuration of reactive energy compensation devices and DG units would enable active and reactive losses to be minimized, while ensuring a balance between investment costs and long-term economic gains (Oladeji et al., 2021). In addition, the environmental and economic profit associated with DG are significant. Renewable energy sources, strategically integrated into the grid, promote a sustainable energy transition and enhance security of electricity supply. In the context of the fight against climate change, this decentralization of energy production represents a major opportunity for distribution companies and grid operators. However, the increasing penetration of DG units is introducing considerable technical challenges, particularly with regard to the optimal operation of large power systems. (Bouddou et al., 2020; Rani et al., 2024) These challenges are intensified by the variability of DG sources, which can be classified into two main categories: intermittent sources (such as solar and wind) and non-intermittent sources (such as biomass and hydro). Each type of source has its own operating characteristics, with intermittent sources requiring dynamic management due to their dependence on climatic conditions, and non-intermittent sources generally being more stable, but imposing other constraints such as the availability of primary resources (Bamisile et al., 2024). Short circuits represent a major challenge in electrical distribution systems, particularly with the integration of DG sources such as solar and wind power. These faults can lead to a significant increase in fault currents, making the coordination of protection systems more complex. Existing protection devices, such as circuit breakers and protective relays, may find it difficult to respond adequately to the increased currents generated not only by the power network, but also by DG sources (Razavi et al., 2019; Zeggai et al., 2021). This inability to trip effectively can lead to delayed tripping and inadequate fault isolation, resulting in costly equipment damage, prolonged power outages and significant economic impacts. In addition, DG sources can destabilize voltage levels during fault events. As these units attempt to maintain their energy output, they can cause voltage fluctuations that reduce the stability of the network. This increases the risk of system collapse, as undesirable oscillations can occur, upsetting the balance between energy production and consumption. The oscillations may persist even after the fault has been rectified, further complicating the management of grid stability. The interaction between conventional generation and DG sources also raises concerns about overall system stability. The presence of DG can introduce unanticipated dynamic behavior into the system, exacerbating resonance and oscillation effects. As a result, the planning and operation of power systems must be rethought to take account of these additional challenges. To address these complex issues, it is crucial to adopt advanced protection schemes that include features such as adaptive fault current detection, dynamic tripping threshold settings and real-time coordination algorithms. In addition, the integration of real-time monitoring and control systems provides greater visibility of network operational conditions, facilitating a rapid and effective response to short-circuit events (Biswal et al., 2023; Nsaif et al., 2021; Salman et al., 2023). The strategic placement of DG units plays a crucial role not only in improving voltage profiles and reducing line losses, but also in managing faults and short-circuit currents. The integration of DGs changes the power flow and affects the short-circuit levels of the network, posing challenges for the coordination of protection devices. This is particularly problematic during large-scale integration, where several small units or large capacity installations can cause a substantial increase in fault currents. As a result, protective devices such as relays and circuit breakers need to be recalibrated to maintain effective coordination, preventing nuisance tripping or un isolated faults. Furthermore, the impact of DG units on fault currents depends on a number of parameters: the production capacity of the units, the distance from fault locations, the line resistance, and the technology used (synchronous or asynchronous) (Idrissi et al., 2021; Meskin et al., 2020). This paper introduces a hybrid approach for optimizing the placement and sizing of DG units using a Modified Genetic Algorithm (MGA), with a focus on assessing the impact of DG integration on protection coordination within electrical distribution networks using ETAP. By utilizing ETAP software, the proposed method simulates the electrical network to comprehensively analyze short-circuit currents both before and after the incorporation of DGs. This dual-layer analysis not only ensures optimal DG placement but also examines the potential challenges posed by increased short-circuit levels on protective device coordination. The optimization process incorporates stringent safety and reliability standards, ensuring compliance with power system operational constraints while enhancing overall network performance. Furthermore, this methodology provides a robust validation of the optimized configurations through ETAP simulations, allowing for detailed assessment of the DGs' influence on fault current profiles and the protective relays' settings. To validate the relevance and effectiveness of the proposed MGA algorithm, its performance is compared with other well-established metaheuristic methods from the literature, such as the Newton-Raphson (NR) method, the Bat Algorithm (BA), the Immune System Algorithm (AIS), and the Bacterial Foraging Optimization Algorithm (BFOA). The comparison is conducted based on key performance metrics, including convergence time, precision, robustness, and result quality. The results indicate that MGA consistently outperforms these alternative techniques. Specifically, MGA demonstrates faster convergence with a higher degree of accuracy, ensuring that the optimization process achieves better-quality solutions in less time. Its robustness is evident across a wide range of test cases, handling both the placement and sizing of DGs simultaneously, with fewer errors and deviations.

2. RELATED WORKS

Several research studies have dealt with the optimal placement and sizing of DG units in radial distribution systems, focusing on minimizing power losses and improving voltage profiles. In (Helal et al., 2012), a basic genetic algorithm (GA) is proposed for determining the optimal location and size of DGs. However, this approach has limitations in handling complex multi-objective problems. In (Vita, 2017)a decision-making algorithm for DG placement highlights the need for addressing uncertainty in distributed networks, while (Yuvaraj et al., 2018) employs the bat optimization algorithm to enhance performance, though convergence issues are noted. Other approaches, such as using the artificial immune system (P.S. & Hemamalini, 2017) and bacterial foraging optimization (Mohamed Imran A & Kowsalya M, 2014) offer diverse optimization strategies but face challenges in computation time and scalability. Recent works have introduced neural network-based techniques for adaptive overcurrent protection in the presence of DGs (Uma et al., 2023) showing promise for integrating advanced control mechanisms. Further research has explored various optimization techniques to improve DG placement and sizing. For instance, the grey wolf optimizer is applied in (Lakum & Mahajan, 2019), showing effectiveness in nonlinear DG environments, though it requires careful tuning of algorithm parameters. In(Palanisamy & Muthusamy, 2021), the ant lion optimization algorithm is used, achieving competitive results, but it may suffer from high computational complexity in larger networks. Multi-objective optimization techniques, such as particle swarm optimization (PSO)(Wanjekeche et al., 2023) , and enhanced coyote optimization (Pham et al., 2021) offer robust solutions for balancing conflicting objectives like loss reduction and voltage stability. However, methods like the krill herd algorithm (Sultana & Roy, 2016) and crow search algorithm (Barati & Shahsavari, 2018) are noted for their slower convergence rates in high-dimensional spaces. More recent algorithms, such as the modified spider monkey optimization (Deb et al., 2020) and moth-flame optimization (A. Das & Srivastava, 2017) , have demonstrated improvements in voltage security and loss minimization. Cutting-edge techniques like Harris Hawks optimization (Gogula & Vakula, 2024) and symbiotic organisms search algorithm (B. Das et al., 2016) further optimize DG allocation but require careful parameter adjustments to avoid premature convergence. Hybrid evolutionary algorithms (Jamil Mahfoud et al., 2019) and enhanced search group algorithms (Huy et al., 2023) present innovative solutions for DG planning, yet challenges remain in balancing speed and accuracy. Advanced techniques such as the shark optimization algorithm (Ali et al., 2023) and combined PSO with ETAP simulations (Nasreddine et al., 2024) provide comprehensive strategies for DG placement, incorporating short-circuit analysis and voltage stability considerations. Despite these advancements, the MGA algorithm proposed in our study has significantly outperformed these methods, particularly in terms of convergence precision, computational time, and result quality. We have enhanced the basic GA by modifying it to simultaneously handle both the optimal placement and sizing of DG units with greater accuracy and fewer errors compared to the standard GA. This modification improves its performance by reducing errors in achieving optimal solutions, ensuring faster convergence, and more reliable results. Furthermore, our study includes a comprehensive analysis of the protection scheme for distribution power systems, incorporating fault scenarios such as three-phase faults, phase-to-phase faults, double phase-to-ground faults, and phase-to-ground faults. The IEEE 33-bus test system is modeled in ETAP to calculate short-circuit current values, and the results are compared across different fault conditions. This dual focus on voltage control and system protection highlights the robustness and effectiveness of our proposed method in managing modern power distribution networks.

3. PROBLEM FORMULATION

This paper's installation strategy for distributed generation seeks to improve the voltage profile of the distribution network and concurrently minimise power losses. Reducing power losses in the distribution system is essential for the proper functioning of the entire power system, since excessive losses can result in increased operational costs and diminished system reliability. To do this, power losses can be precisely evaluated using Formula (1), which takes into account the system's individual operational characteristics. The suggested method aims to reduce overall power losses and the voltage profile gradient, consequently enhancing service quality for consumers. The objective function can be mathematically formulated to accurately represent these goals. (Meddeb et al., 2018)

$$Minimize\ P_L = \sum_{i=1}^{N} |I_i|^2 R_i \tag{1}$$

Within the constraints of the balance of power:

$$\sum\nolimits_{i=1}^{N} P_{DGi} = \sum\nolimits_{i=1}^{N} P_{Di} + P_L \tag{2}$$

Voltage constraints:

$$|V_i|^{min} \leq |V_i| \leq |V_i|^{max} \tag{3}$$

Current limits:

$$\left|I_{ij}\right| |I_{ij}|^{max} \tag{4}$$

Where i is the number of buses, N is the total number of buses, P_l is the actual power loss in the system, P_{DGi} is the actual power generated by DG in bus i, P_{Di} is the required power in bus i, I_{iJ} is current, and R_i is the resistance between buses i and J. Newton Raphson is used to determine current I_i from load flow. In single-source networks, the power is all supplied by the source but the power loss of a properly installed DG is reduced. This reduction in power loss is expressed as the difference in power loss with and without DG. Therefore, the additional capacity loss in the network of the DG is:

$$P_{L\_new} = \sum\nolimits_{i=1}^{N} |I_i^{new}|^2 R_i \tag{5}$$

$$P_{L\_new} = \sum\nolimits_{i=1}^{N} I^2{}_i R_i - 2J I_i I_{DG} R_i - J I_i I^2{}_{DG} R_i \tag{6}$$

Therefore, the power losses minimization for bus i with distributed generation is obtained by a subtraction of (5) from (6) as follows:

$$PLR = P_{L_{new}} - P_L \tag{7}$$

$$PRL_i = -\sum\nolimits_{i}^{N} (2J I_i I_{DG} R_i + J I_i I^2{}_{DG}) R_i \tag{8}$$

The bus providing the highest PLR value is selected as the optimal position of the DG. Instead of DG, the emphasis is on maximizing losses. to get the DG current that minimizes loss, differentiate Equation (8) about I_{DG} and set it equal to zero, yielding the current as shown in Equation (9) below.

$$I_{DG} = -\frac{\sum_{i=1}^{n} I_{ai} R_i}{\sum_{i=1}^{n} R_i} \tag{9}$$

The process is done for all the bus units. The highest power loss reduction value is obtained because the DG units are autonomous and expressed as follows,

$$P_{DGi} = I_{DG} V_i \tag{10}$$

The best size for the DG is calculated by equation (10) for bus i, denoted V. The optimal placement for the DG to achieve a significative decrease in power losses is bus i.

4. PROPOSED OPTIMIZATION ALGORITHM

4.1 Genetic Algorithm Overview

Genetic algorithms (GAs) are optimisation methods derived on the concepts of natural selection and genetics. These strategies address intricate problems by emulating the evolutionary process, wherein optimal solutions are progressively chosen and amalgamated to generate new candidate solutions. A genetic algorithm generally commences with a population of prospective solutions depicted as chromosomes. Each chromosome experiences selection, crossover, and mutation processes that emulate the natural evolutionary process. Selection prioritises the most fit individuals, whereas crossover facilitates the flow of genetic information between solution pairs. Mutation, conversely, adds arbitrary modifications to preserve diversity throughout the population. (Katoch et al., 2021)This iterative method persists until a stopping criterion is attained, such as a predetermined number of generations or an acceptable quality level. Genetic algorithms are characterised by their capacity to effectively navigate intricate search spaces, rendering them appropriate for many applications, including engineering, finance, and biology. GAs can be tailored to particular optimisation issues, regardless of whether they are limited or unconstrained, owing to their robustness and flexibility. Moreover, they can be integrated with additional optimisation methods to enhance their efficacy, especially in scenarios where precise solutions are challenging to ascertain. This capacity to traverse intricate optimisation terrains renders it a formidable instrument for operations research and the advancement of intelligent systems (Katoch et al., 2021).

4.2 MGA Implementation

The MGA algorithm for the optimal placement and sizing of DG units is a robust method that enhances the efficacy of conventional genetic algorithms by integrating tactics to augment convergence and solution quality. The procedure commences with the formulation of the objective function, primarily aimed at minimising operational expenses, voltage fluctuations, and line losses, while maintaining system reliability. The algorithm employs a population of candidate solutions, with each individual denoting a particular arrangement of PD units, encompassing their positions and capacities. MGA enhances the population across subsequent generations through a sequence of evolutionary processes: selection, crossover, and mutation. The integration of adaptive mutation rates and elite preservation methods sustains population variety, enabling the algorithm to investigate a broader solution space while converging on optimal designs. The results are corroborated through simulations employing recognised distribution system models, such as the IEEE 33-bus system, guaranteeing real applicability and dependability.

4.3 Steps for Implementing the Modified Genetic Algorithm

1. **Define the Problem:**
   - Identify the objective functions to be minimized, such as total power losses, voltage deviations and PD installation cost.
   - Specify constraints, including voltage limits, generation capacity limits and operational limits of the existing network.
2. **Initialization:**
   - Generate an initial population of solutions, where each individual represents a potential configuration for DP placement and sizing. Each solution should include:
     - The locations of the DG units in the network.
     - The sizes (capacities) of each DP unit.
3. **Relevance Assessment:**
   - Calculate the relevance of each individual in the population based on the objective functions and constraints defined. This may include:
     - Calculations of total power losses.
     - Evaluations of voltage profiles at various points in the network.
4. **Selection:**
   - Selecting individuals for breeding based on their suitability values using techniques such as tournament selection or roulette selection to ensure that more suitable individuals have a greater chance of being selected.
5. **Crossover:**
   - Applying crossover operations to pairs of selected individuals to create offspring. This may involve exchanging PD configuration segments to produce new solutions. Use methods such as:
     - One-point crossover.
     - Two-point crossover.
     - Uniform crossover.
6. **Mutation:**
   - Introduce random mutations into offspring to maintain diversity within the population. This could involve:
     - Changing the size of a DG unit.
     - Changing the location of a DG unit within certain limits.
     - Using adaptive mutation rates that adjust as the population converges.
7. **Elitism:**
   - Preserve a certain number of the best individuals from the current generation for the next generation to ensure that the best solutions are not lost during iterations.
8. **Stop criteria:**
   - Establish stopping criteria for the algorithm, such as:
     - A maximum number of generations.
     - Relevance threshold reached.
     - Convergence of solutions over a predefined number of generations.
9. **Results analysis:**
   - Once the stopping criteria have been reached, analyses the best solution found:

- Evaluate its efficacy in diminishing power losses and enhancing voltage profiles.
- Validate the results using simulation software ETAP against the original distribution network model.

10. **Results Report:**

- Document the results, including optimal DG placements, sizes and improved system performance indicators.
- Discuss the implications of the results and potential areas for future research or practical application.

The process involves implementing and evaluating the most efficient dimensions of DG to reduce energy loss in the distribution system is summarized and presented in Figure 1.

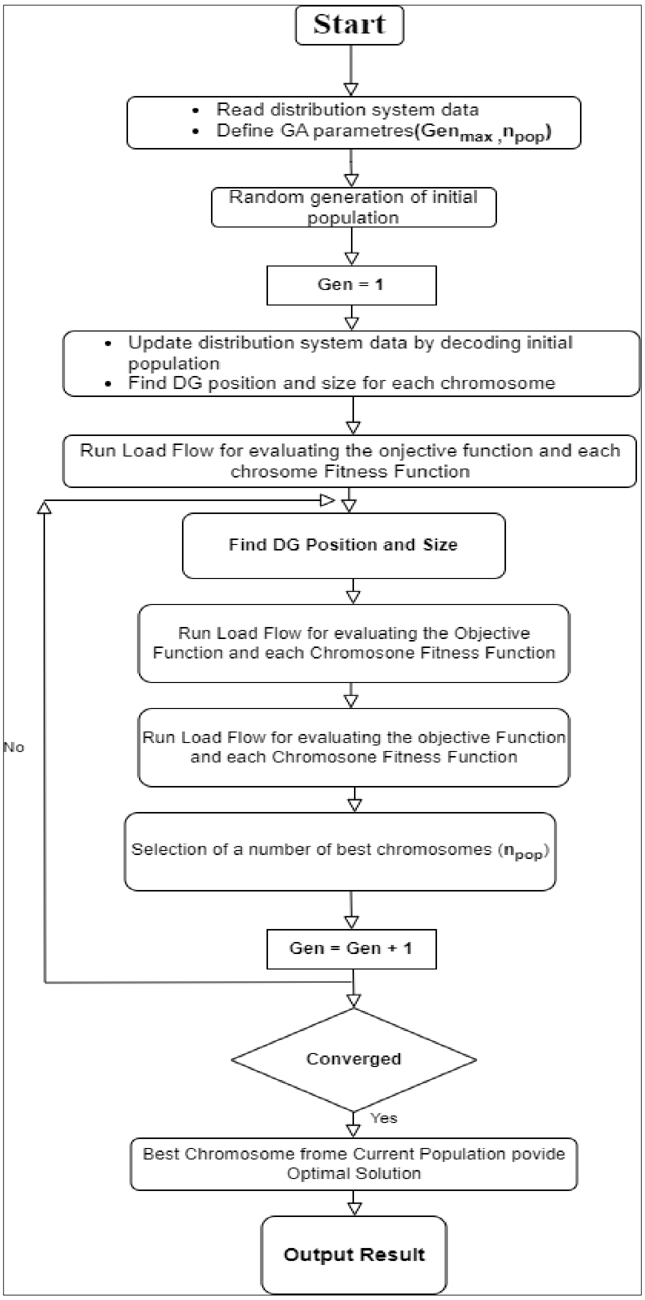

Figure 1. Flowchart of the proposed MGA Algorithm

5. SIMULATION RESULTS AND DISCUSSION

This study was segmented into two separate sections. The preliminary phase concentrated on identifying the ideal position and dimensions of the distributed generator (DG) through the application of the suggested MGA technique, executed within the MATLAB environment. This step entailed the analysis of multiple characteristics, including load profiles, line losses, and voltage profiles, to determine the optimal designs for distributed generation installation. During the second step, a short circuit analysis was performed utilising the ETAP (Electrical Transient Analyser Program) program. This investigation sought to assess the system's performance and dependability in fault scenarios. By simulating potential short circuit events, we can evaluate the influence of the DG on system stability and safety, hence offering essential insights into the requisite protection schemes and fault management procedures. This holistic strategy guarantees that the incorporation of distributed generation enhances operational efficiency while preserving the overall integrity and security of the electrical distribution system.

5.1 The optimal sizing and placement of distributed generation

The IEEE 33-bus test system is employed to validate the suggested technique. The system comprises 33 buses and 32 branches, with a total active power load of 3.72 MW and a reactive power load of 2.3 MVAR. The system functions at a nominal voltage of 11 kilovolts (kV), use aluminium conductors for the transmission lines. The line impedance is defined by a resistance of 0.55 ohms per kilometre and a reactance of 0.35 ohms per kilometre. The system's base power is established at 100 MVA, assuring alignment with conventional power system calculations. The branch and load data for the IEEE 33-bus test system are sourced from reference (Kothari, D. P, 2012). The IEEE 33-bus system is first executed in MATLAB for load flow analysis, followed by simulation in ETAP for additional examination. In ETAP, the configuration state is adjusted to its standard operational condition in edit mode. The single-line diagram of the power system in ETAP is depicted as a balanced three-phase system, illustrated by a singular black line. The graphical interface of ETAP enables straightforward connections between components and buses, employing the equipment characteristics editor to adjust parameters. Furthermore, the load flow analyses in ETAP confirm the system's power distribution and substantiate the efficacy of the suggested control technique across various operational situations (Tahir et al., 2019). The simulation configuration guarantees that all elements are accurately specified, and the graphical representations within ETAP provide real-time observation and evaluation of the system's performance under diverse load and fault scenarios. The developed MGA technique was utilised to identify an optimal location for the Type 2 Distributed Generator (DG) to improve system performance. The outcomes of this optimisation process illustrate the efficacy of the MGA in determining the appropriate placement and sizing of DG units, resulting in improved voltage profiles, diminished line losses, and increased power system stability. The results are comprehensively displayed in Table 1, which enumerates the numerical results of the optimisation, while Figures 2 and 3 visually depict the effects of the optimal DG placement on the system's voltage profile and loss reduction, respectively. The results validate the MGA's efficacy in managing intricate distribution network configurations and optimising distributed generation deployment to enhance system reliability and efficiency.

Installing distributed generation units at strategically advantageous locations and with suitable dimensions markedly improves the voltage attributes of the electrical distribution system. These units enhance voltage magnitude, especially in areas experiencing voltage degradation, therefore fostering improved voltage stability throughout the network. This results in an enhancement in the quality of electricity provided to clients, guaranteeing a more reliable and consistent service. Comprehensive study of the three scenarios depicted in Table 1 and the associated figures revealed that augmenting the capacity of distributed generation at the ideal site significantly lowers power losses along the transmission line.

Table 1.Global results after optimum DG's placement

Parameters	Case 1 (Without DG)	With 1DG	With 2DG	With 3DG
$P_{Loss}(kw)$	202.677	125.80	102.10	49.02
$Q_{Loss}(kvar)$	135.141	93.50	75.50	32.62
Optimal DG Location (Bus)	/	31	16 20	30 22 18
$P_{DG}(kw)$	/	605	412 442	507 657 445
$Q_{DG}(kvar)$	/	202.24	170.52 198.32	221 178.03 252.19

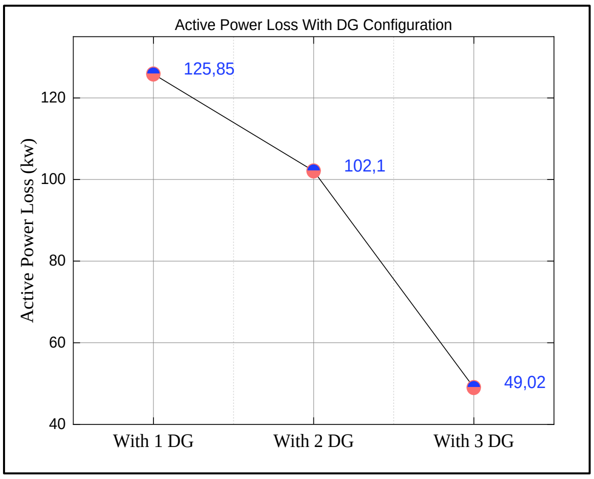

Figure 2. Active power losses After the DG placement

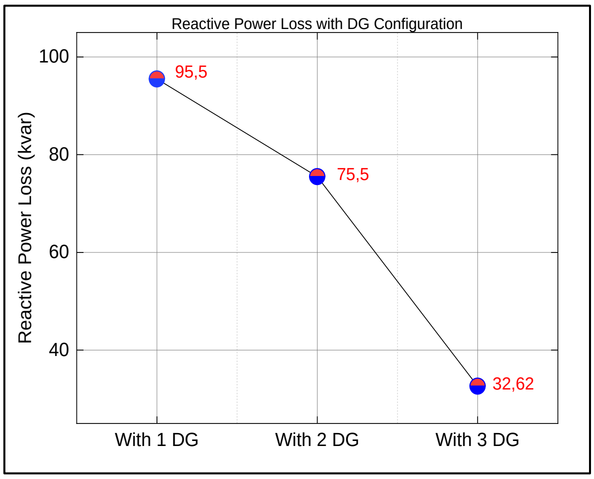

Figure 3. Reactive power losses After the DG placement

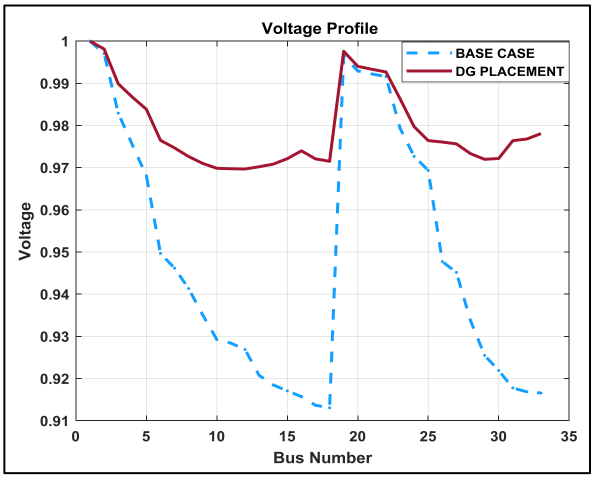

Figure 4. Voltage profile before and after DG placement

Table 2. Comparison of proposed algorithms with MGA

Parameters	Case 1	NR	MGA	BA (Yuvaraj et al., 2018)	AIS (P.S. et al 2017)	BFOA (Kowsalya M et al, 2014)
$P_{Loss}(kw)$	202.67	97.4	49.02	73.41	73.62	89.9
$Q_{Loss}(kvar)$	135.14	65.6	32.62	/	/	/
Number of DG	/	3	3	3	3	3
Optimal DG Location	/	31 33 16	32 22 18	13 24 30	31 14 3	14 18 32
$P_{DG}(kw)$	/	507 657 445	507 657 445	720 1020 980	750 750 1500	652.1 198.4 1067.2
$Q_{DG}(kvar)$	/	221 178.03 252.19	221 178.03 252.19	/	/	/

This decrease in losses enhances the system's efficiency and facilitates more effective power distribution. Moreover, voltage fluctuations were reduced, resulting in improved system efficiency. A comparative investigation was done to validate the effectiveness, robustness, and correctness of the findings generated from the MGA algorithm for optimal DG placement and sizing versus competing optimisation techniques. The comparison, detailed in Table 2 and depicted in Figure 5, encompasses assessments utilising the BA, BFOA, and AIS algorithms. The MGA-based method regularly shown enhanced performance, especially in reducing line losses and enhancing voltage stability, underscoring its efficacy in optimising distributed generation integration within the distribution network.electricity distribution network

In this study, three distinct scenarios were considered to evaluate the impact of DG allocation on the power system's performance. The scenarios are as follow:

1. **Scenario 1: Power Flow Without DG Allocation**

   This scenario represents the base case where the power flow analysis is performed without any DG integration. It simulates the conventional operation of the distribution network, relying entirely on central generation and traditional transmission systems. The objective is to establish a baseline for comparison in terms of voltage profiles, power losses, and system performance metrics. This scenario highlights the typical challenges faced in radial distribution systems, such as voltage drops and high-power losses, which DG allocation aims to mitigate.

2. **Scenario 2: Power Flow with DG Allocation Using the Classical Newton-Raphson Method**

   In this scenario, DG units are integrated into the power system, and a power flow analysis is conducted using the classical Newton-Raphson method. The Newton-Raphson technique, known for its iterative approach, is widely used in solving power flow problems due to its fast convergence and accuracy for well-behaved systems. This scenario explores how the allocation of DGs affects the power network when solved through a traditional approach, providing insights into voltage improvements and loss reductions. However, the effectiveness of this method may be limited by its sensitivity to initial conditions and the complexity of DG placement.

3. **Scenario 3: Power Flow with DG Allocation Using the Proposed MGA Algorithm**

   In this scenario, the power flow is executed with distributed generation allocation optimised by the suggested MGA Algorithm. The MGA is a robust optimisation method derived from the concepts of natural selection and genetics, particularly effective for managing non-linear, intricate systems like distribution networks containing many DG units. This methodology seeks to determine the ideal positioning and dimensions of distributed generators to reduce power losses, boost voltage profiles, and bolster system stability. The comparison of this scenario's findings with the preceding two clearly illustrates the advantages of the MGA regarding computational efficiency, optimality, and robustness, establishing it as a superior alternative to classical approaches.

Figure 5 illustrates a comparison of the proposed MGA Algorithm with alternative optimisation techniques. The efficacy of the MGA method has been evaluated against the BA method, BFOA Algorithm, and AIS Algorithm. MGA consistently exhibits exceptional efficacy in minimising transmission power losses by determining the appropriate location and sizing of distributed generation units inside the distribution network. The advantage is apparent in the comparison analysis, where MGA surpasses competing algorithms in minimising power loss, hence enhancing the efficiency and dependability of the network.

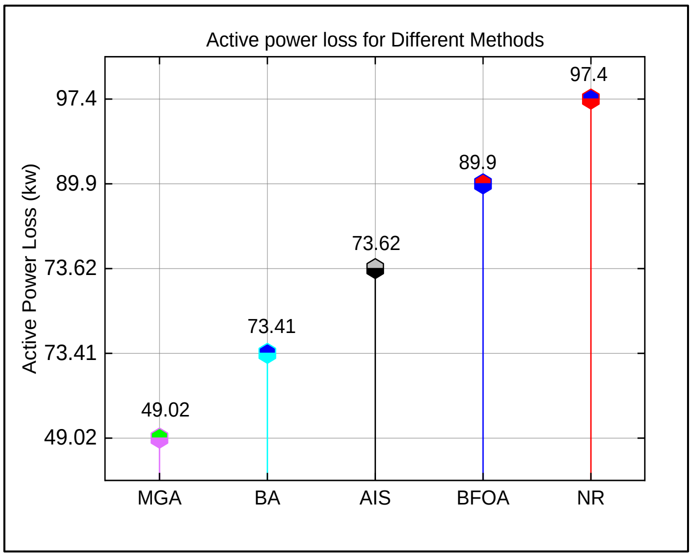

Figure 5. Active power losses comparison with different methods.

5.2 The Short-Circuit Analysis

This study performed a short-circuit analysis utilising ETAP software to assess the influence of distributed generation location on the protection system of the radial IEEE 33-bus test system. The DG units were classified as Type 2, proficient at injecting both active and reactive power. ETAP software was employed to simulate power flow and analyse short-circuit problems in the context of distributed generation integration, as seen in Figure 6. The power flow analysis utilised the Newton-Raphson (NR) approach to model the system with optimally positioned distributed generators (DGs). The objective of the investigation was to examine the influence of Distributed Generators (DGs) on fault levels, evaluate their effect on the efficacy of protection systems, and investigate potential methods to alleviate these consequences. Table 3 displays the results achieved after the optimal distribution generator position. The strategic positioning of Type 2 DG units at bus 32, bus 22, and bus 18 has resulted in considerable fluctuations in short-circuit current levels throughout the distribution network.

Table 3. The obtained results after the optimal DG location.

Configuration	Type of DG	Location (Bus)	P_{DG} (kw)	Q_{DG} $(kvar)$
		32	507	221
IEEE 33-Bus system	2	22	657	178.03
		18	445	252.19

Figure 6 illustrates the graphical modeling of the IEEE 33-bus system, highlighting the optimal placement of three Distributed Generators (DGs) using ETAP. In the first case, a short-circuit was simulated at bus 31 and bus 33, where the integration of one DG at bus 32 was implemented. Subsequently, the fault was analyzed at bus 21 with one DG placed at bus 22, followed by another fault scenario at bus 17 with the integration of one DG at bus 18. A comprehensive fault analysis was then conducted to evaluate the impact of these configurations on the network's performance. In this part of the study, four types of faults were examined:

- **Three-phase fault:** This fault occurs when all three phases are shorted together, leading to maximum fault current and significant impacts on the system.
- **Phase-to-phase fault:** In this scenario, two phases are shorted, which can cause imbalances and operational challenges in the network.
- **Double phase-to-ground fault:** This fault involves two phases being shorted to ground, posing serious risks to equipment and requiring specific protection strategies.
- **Phase-to-ground fault:** This is one of the most common fault types, affecting a single phase and leading to unbalanced currents in the system.

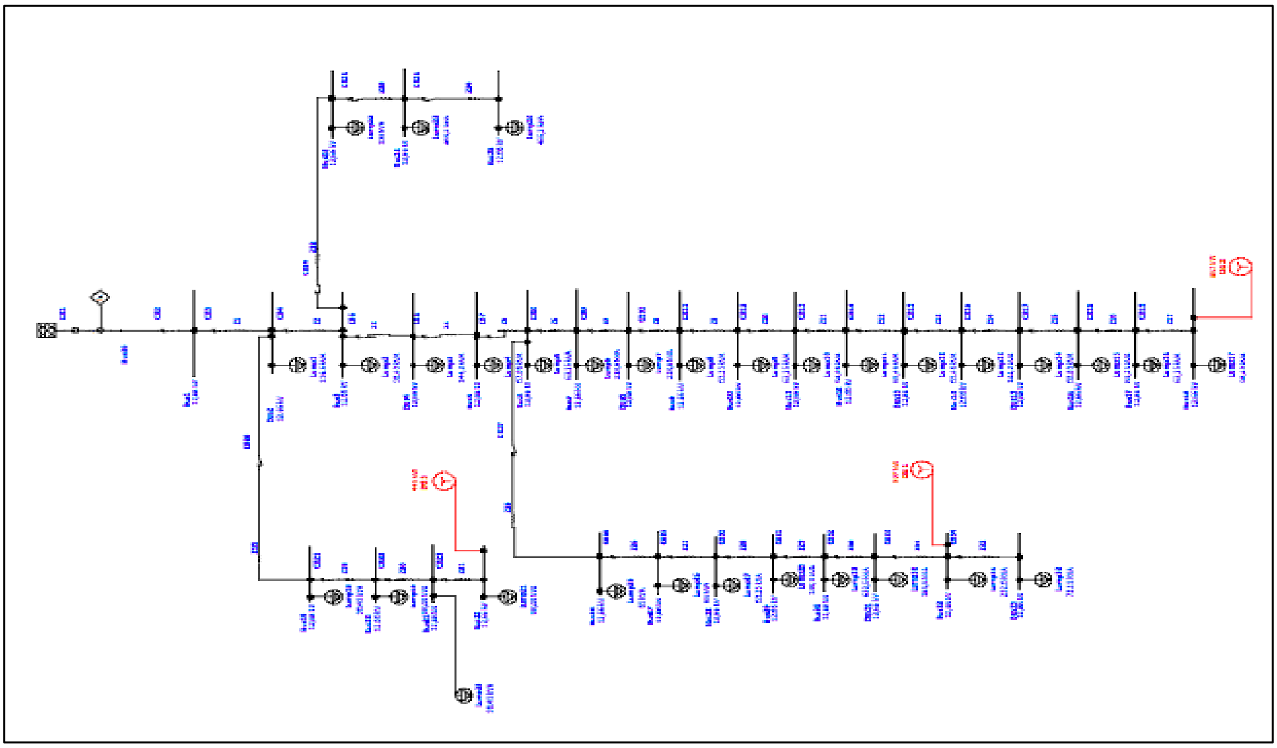

Figure 6. Modelling of the IEEE 33 bus with 3 DG's in ETAP

Figure 7 and Figure 8 present the results from the first study case, illustrating the network's response to the aforementioned fault conditions. Additionally, Figure 9 and Figure 10 present the results of the second study case following the short-circuit analysis, providing insights into the effectiveness of the DG placements in mitigating fault impacts and enhancing system stability.

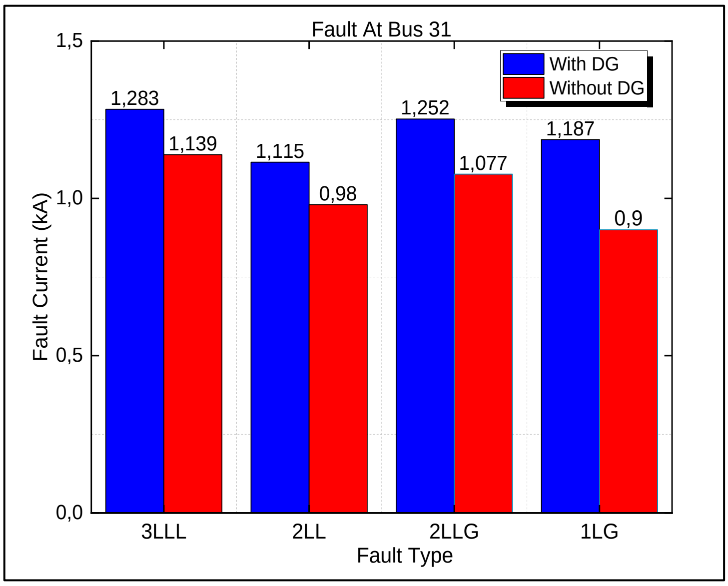

Figure 7. Fault current without and with DG at bus 31

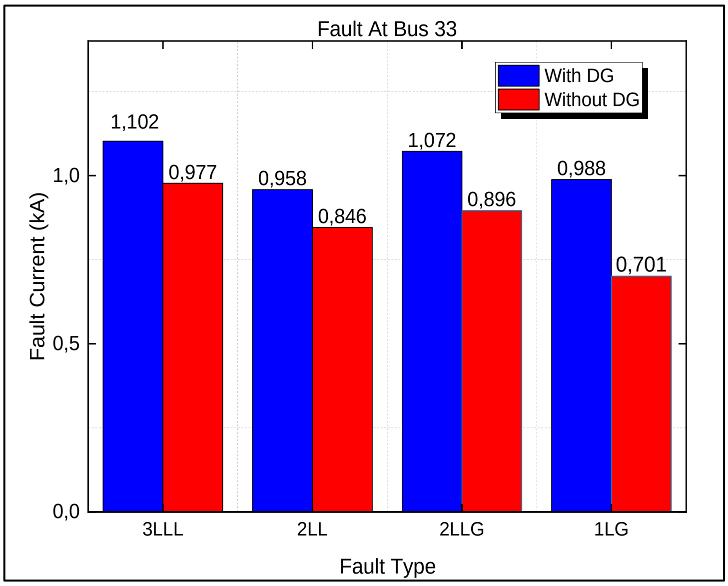

Figure 8. Fault current without and with DG at bus 33

From Figures 7 and 8, it is shown that the short-circuit current measured at bus 31 is higher than that at bus 33. This observation can be attributed to the principle that short-circuit currents are typically more significant closer to the power generation plant. Notably, after the integration of DG at bus 32, an increase in short-circuit current is observed at both bus 32 and bus 33 across all types of fault currents applied. The DG units usually possess lower impedance compared to traditional grid configurations, which reduces the overall impedance of the system and consequently raises the short-circuit current levels. Furthermore, this increase in fault current can enhance the system's capacity to manage disturbances, leading to improved stability and resilience during fault conditions. However, it is essential to recognize that while integrating DG may bolster short-circuit currents, it also requires careful planning and protection coordination to ensure the system can effectively manage these increased levels without compromising safety or reliability.

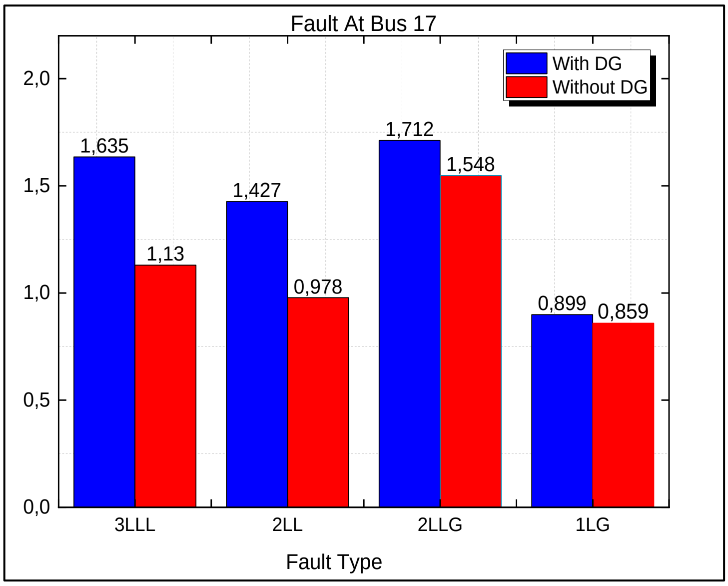

Figure 9. Fault current without and with DG at bus 17

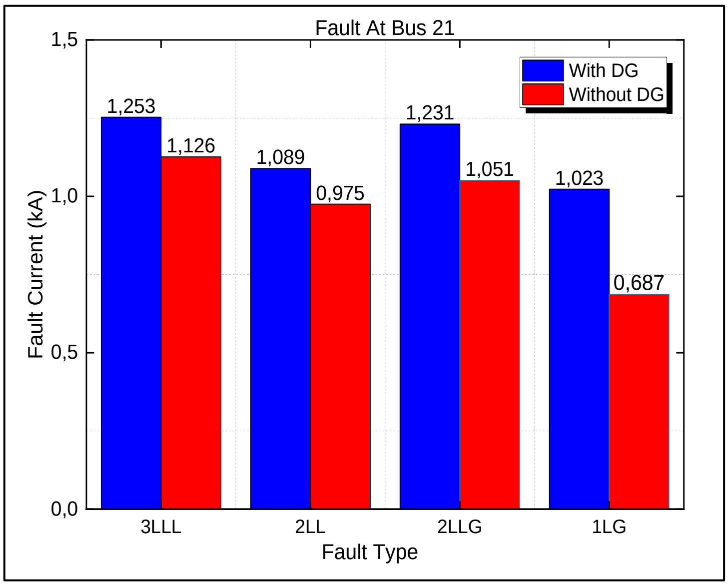

Figure 10. Fault current without and with DG at bus 21

From Figures 9 and 10, it is clear that the short-circuit current for buses 17 and 21 has increased considerably following the integration of DG units into the electrical network. The primary reason for this significant rise in short-circuits current is that DG units function as additional sources during fault conditions, contributing to the overall current alongside the main utility supply. Consequently, this increase necessitates careful consideration in the design of protection schemes to prevent potential damage within the electrical system. It is essential to revise protection settings to account for the presence of DGs, ensuring safety and optimal operation of the network. Adjusting these settings will help mitigate risks associated with elevated fault currents and enhance the reliability of the electrical infrastructure.

6. CONCLUSION

This paper thoroughly examines the integration of DG into radial distribution power systems, addressing both its opportunities and challenges. An MGA algorithm is proposed to optimize the placement and sizing of DG units using ETAP software, enhancing system efficiency, reliability, and security. The analysis shows that strategic DG integration improves voltage stability, reduces line losses, and manages short-circuit levels, contributing to a more resilient power system. However, the inclusion of DG units increases short-circuit currents, impacting network operation and protection systems. The elevated energy flow near DG locations raises fault levels due to the additional generation capacity, leading to altered power flow patterns and uneven load distribution, which heighten the risk of short-circuit events. This necessitates a reevaluation of network infrastructure and potential upgrades to protection systems, as traditional schemes may not sufficiently handle the increased fault levels. A comparative evaluation indicates that the MGA outperforms alternative algorithms, such as the Bat Optimization Algorithm and Bacterial Foraging Optimization Algorithm, in terms of convergence speed and solution accuracy. The study highlights the importance of advanced optimization techniques in managing the complexities of DG integration, recommending future research to refine these methodologies and enhance the resilience and efficiency of electrical distribution networks amid changing energy landscapes.

REFERENCES

Ali, E. S., Abd Elazim, S. M., Hakmi, S. H., & Mosaad, M. I. (2023). Optimal allocation and size of renewable energy sources as distributed generations using shark optimization algorithm in radial distribution systems. Energies, 16(10), 3983.

Ali-Dahmane, M., Benhamida, F., Bouddou, R., & Zeggai, A. (2023). Combined Optimal Capacitor Placement and Network Reconfiguration in A Distribution Power System for Load Flow Analysis Using ETAP. Przeglad Elektrotechniczny, 2023(9).

Bajaj, M., & Singh, A. K. (2020). Grid integrated renewable DG systems: A review of power quality challenges and state-of-the-art mitigation techniques. International Journal of Energy Research, 44(1), 26-69.

Bamisile, O., Cai, D., Adun, H., Dagbasi, M., Ukwuoma, C. C., Huang, Q., & Johnson, N. (2024). Towards Renewables Development: Review of Optimization Techniques for Energy Storage and Hybrid Renewable Energy Systems. Heliyon.

Barati, H., & Shahsavari, M. (2018). Simultaneous Optimal placement and sizing of distributed generation resources and shunt capacitors in radial distribution systems using Crow Search Algorithm. International Journal of Industrial Electronics Control and Optimization, 1(1), 27-40.

Biswal, C., Sahu, B. K., Mishra, M., & Rout, P. K. (2023). Real-time grid monitoring and protection: A comprehensive survey on the advantages of phasor measurement units. Energies, 16(10), 4054.

Bouddou, R., Benhamida, F., Zeggai, A., Belgacem, M., & Khatir, M. (2020). Integration of wind power generation into a double-sided competitive electricity market for profit and social welfare maximization. In 2020 International Conference on Electrical and Information Technologies (ICEIT) (pp. 1-6). IEEE.

Das, A., & Srivastava, L. (2017, July). Optimal placement and sizing of distributed generation units for power loss reduction using moth-flame optimization algorithm. In 2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT) (pp. 1576-1581). IEEE.

Das, B., Mukherjee, V., & Das, D. (2016). DG placement in radial distribution network by symbiotic organisms search algorithm for real power loss minimization. Applied Soft Computing, 49, 920-936.

Das, C. K., Bass, O., Kothapalli, G., Mahmoud, T. S., & Habibi, D. (2018). Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality. Renewable and Sustainable Energy Reviews, 91, 1205-1230.

Deb, G., Chakraborty, K., & Deb, S. (2020). Modified spider monkey optimization-based optimal placement of distributed generators in radial distribution system for voltage security improvement. Electric Power Components and Systems, 48(9-10), 1006-1020.

Gogula, S., & Vakula, V. S. (2024). Multi-Objective Harris Hawks Optimization Algorithm for Selecting Best Location and Size of Distributed Generation in Radial Distribution System. International Journal of Cognitive Computing in Engineering.

Helal, A., Amer, M., & Eldosouki, H. (2012, December). Optimal location and sizing of distributed generation based on gentic algorithm. In CCCA12 (pp. 1-6). IEEE.

Henriques, H. O., Corrêa, R. L. S., Fortes, M. Z., Borba, B. S. M. C., & Ferreira, V. H. (2020). Monitoring technical losses to improve non-technical losses estimation and detection in LV distribution systems. Measurement, 161, 107840.

Hoang, A. T., & Nguyen, X. P. (2021). Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process. Journal of Cleaner Production, 305, 127161.

Huy, T. H. B., Vo, D. N., Truong, K. H., & Van Tran, T. (2023). Optimal Distributed Generation Placement in Radial Distribution Networks using Enhanced Search Group Algorithm. IEEE Access.

Idrissi, Z. E., El Mariami, F., Belfqih, A., & Haidi, T. (2021). Impact of distributed power generation on protection coordination in distribution network. Indonesian Journal of Electrical Engineering and Computer Science, 23(3), 1271-1280.

Jamil Mahfoud, R., Sun, Y., Faisal Alkayem, N., Haes Alhelou, H., Siano, P., & Shafie-Khah, M. (2019). A novel combined evolutionary algorithm for optimal planning of distributed generators in radial distribution systems. Applied Sciences, 9(16), 3394.

Javid, Z., Kocar, I., Holderbaum, W., & Karaagac, U. (2024). Future Distribution Networks: A Review. Energies, 17(8), 1822.

Katoch, S., Chauhan, S. S., & Kumar, V. (2021). A review on genetic algorithm: past, present, and future. Multimedia tools and applications, 80, 8091-8126.

Khalid, M. (2024). Smart grids and renewable energy systems: Perspectives and grid integration challenges. Energy Strategy Reviews, 51, 101299.

Kothari, D. P. (2012, March). Power system optimization. In 2012 2nd National conference on computational intelligence and signal processing (CISP) (pp. 18-21). IEEE.

Kowsalya, M. (2014). Optimal size and siting of multiple distributed generators in distribution system using bacterial foraging optimization. Swarm and Evolutionary computation, 15, 58-65.

Lakum, A., & Mahajan, V. (2019). Optimal placement and sizing of multiple active power filters in radial distribution system using grey wolf optimizer in presence of nonlinear distributed generation. Electric Power Systems Research, 173, 281-290.

Meddeb, A., Sahbeni, N., Jmii, H., & Chebbi, S. (2018, March). Impact of distributed generation on the protection system in Tunisian distribution network. In 2018 15th International Multi-Conference on Systems, Signals & Devices (SSD) (pp. 514-520). IEEE.

Meera, P. S., & Hemamalini, S. (2017). Optimal siting of distributed generators in a distribution network using artificial immune system. International Journal of Electrical and Computer Engineering, 7(2), 641.

Meskin, M., Domijan, A., & Grinberg, I. (2020). Impact of distributed generation on the protection systems of distribution networks: analysis and remedies–review paper. IET Generation, Transmission & Distribution, 14(24), 5944-5960.

Mirjalili, S., & Mirjalili, S. (2019). Genetic algorithm. Evolutionary algorithms and neural networks: theory and applications, 43-55.

Mishra, D. K., Ghadi, M. J., Azizivahed, A., Li, L., & Zhang, J. (2021). A review on resilience studies in active distribution systems. Renewable and Sustainable Energy Reviews, 135, 110201.

Nadeem, T. B., Siddiqui, M., Khalid, M., & Asif, M. (2023). Distributed energy systems: A review of classification, technologies, applications, and policies. Energy Strategy Reviews, 48, 101096.

Nasreddine, B., Fethi, B., Yassine, H., Imane, H., & Riyadh, B. (2024, May). Optimal Sizing and Placement of Distributed Generation with Short-Circuit Analysis Using a Combined Technique Based on Modified PSO and ETAP. In 2024 2nd International Conference on Electrical Engineering and Automatic Control (ICEEAC) (pp. 1-6). IEEE.

Nsaif, Y. M., Lipu, M. H., Ayob, A., Yusof, Y., & Hussain, A. (2021). Fault detection and protection schemes for distributed generation integrated to distribution network: Challenges and suggestions. IEEE Access, 9, 142693-142717.

Oladeji, I., Makolo, P., Abdillah, M., Shi, J., & Zamora, R. (2021). Security impacts assessment of active distribution network on the modern grid operation—a review. Electronics, 10(16), 2040.

Palanisamy, R., & Muthusamy, S. K. (2021). Optimal siting and sizing of multiple distributed generation units in radial distribution system using ant lion optimization algorithm. Journal of Electrical Engineering & Technology, 16, 79-89.

Pham, T. D., Nguyen, T. T., & Dinh, B. H. (2021). Find optimal capacity and location of distributed generation units in radial distribution networks by using enhanced coyote optimization algorithm. Neural Computing and Applications, 33(9), 4343-4371.

Rani, P., Parkash, V., & Sharma, N. K. (2024). Technological aspects, utilization and impact on power system for distributed generation: A comprehensive survey. Renewable and Sustainable Energy Reviews, 192, 114257.

Razavi, S. E., Rahimi, E., Javadi, M. S., Nezhad, A. E., Lotfi, M., Shafie-khah, M., & Catalão, J. P. (2019). Impact of distributed generation on protection and voltage regulation of distribution systems: A review. Renewable and Sustainable Energy Reviews, 105, 157-167.

Salman, H. M., Pasupuleti, J., & Sabry, A. H. (2023). Review on Causes of Power Outages and Their Occurrence: Mitigation Strategies. Sustainability, 15(20), 15001.

Sultana, S., & Roy, P. K. (2016). Krill herd algorithm for optimal location of distributed generator in radial distribution system. Applied Soft Computing, 40, 391-404.

Tahir, M. J., Bakar, B. A., Alam, M., & Mazlihum, M. S. (2019). Optimal capacitor placement in a distribution system using ETAP software. Indones. J. Electr. Eng. Comput. Sci, 15(2), 650-660.

Uma, U. U., Nmadu, D., Ugwuanyi, N., Ogah, O. E., Eli-Chukwu, N., Eheduru, M., & Ekwue, A. (2023). Adaptive overcurrent protection scheme coordination in presence of distributed generation using radial basis neural network. Protection and Control of Modern Power Systems, 8(4), 1-19.

Vita, V. (2017). Development of a decision-making algorithm for the optimum size and placement of distributed generation units in distribution networks. Energies, 10(9), 1433.

Wanjekeche, T., Ndapuka, A. A., & Mukena, L. N. (2023). Strategic Sizing and Placement of Distributed Generation in Radial Distributed Networks Using Multiobjective PSO. Journal of Energy, 2023(1), 6678491.

Yuvaraj, T., Devabalaji, K. R., & Ravi, K. (2018). Optimal allocation of DG in the radial distribution network using bat optimization algorithm. Advances in Power Systems and Energy Management: ETAEERE-2016, 563-569.

Zeggai, A., Benhamida, F., & Bouddou, R. (2021). Power System Analysis of Seawater Desalination Plant in Algeria with Different Load Scenarios. Journal Européen des Systèmes Automatisés, 54(3).