Nigerian Journal of Technology (NIJOTECH)
Vol. 44, No. 3, September, 2025, pp.471 - 483
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v44i3.11

ASSESSMENT OF THE IMPACT OF DISTRIBUTION GENERATION ON RADIAL DISTRIBUTION NETWORK PROTECTION SYSTEM

AUTHORS:
F. K. Ariyo[1,*], S. O. Ayanlade[2], A. P. Adeagbo[3], A. Jimoh[1] and M. T. Adebayo[1]

AFFILIATIONS:
[1]Department of Electronic and Electrical Engineering, Faculty of Technology, Obafemi Awolowo University, Ile-Ife, NIGERIA
[2]Department of Electrical and Electronics Engineering, College of Engineering and Environmental Studies, Olabisi Onabanjo University, Ago-Iwoye, NIGERIA
[3]Department of Electrical and Electronics Engineering, Faculty of Engineering, Adeleke University, Ede, NIGERIA

***CORRESPONDING AUTHOR:**
Email: ayanlade.oladayo@oouagoiwoye.edu.ng

ARTICLE HISTORY:
Received: September 05, 2024.
Revised: October 06, 2025.
Accepted: October 08, 2025.
Published: October 15, 2025.

KEYWORDS:
Distribution generation, Overcurrent relay, Power losses, Time multiplier setting, Plug multiplier setting, Voltage profile.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract
Distributed generation (DG) entails the integration of small-scale generators into the distribution level of power systems. While DG deployment enhances distribution network performance, it also presents challenges to protection systems. This study analyzes the impact of DG integration on the protection scheme of a radial distribution grid. The Dingo Optimization Algorithm (DOA) was implemented in MATLAB to determine the optimal placement and size of DG units aimed at minimizing active and reactive power losses and improving voltage profiles. The optimized network configuration obtained from MATLAB was then modeled in ETAP for detailed protection analysis to assess the influence of DG on overcurrent relay coordination. The base-case load flow revealed active and reactive power losses of 202.71 kW and 23.56 kVAr, respectively, which were reduced by 61.21 % and 57.6 % after optimal DG integration. The results show that while DG integration enhances voltage stability and minimizes technical losses, it also increases short-circuit current levels, thereby affecting relay operating times. In conclusion, adaptive protection coordination is essential to maintain system reliability in DG-integrated distribution networks.

1.0 INTRODUCTION
Distribution networks, the final subsection of the power system, face numerous challenges that compromise their operational effectiveness [1, 2]. Addressing these challenges is essential for enhancing the overall grid efficiency. Consequently, considerable efforts have been directed towards improving distribution networks through the implementation of various techniques [3, 4]. Technical and line losses constitute major challenges in power networks, particularly within transmission and distribution lines. These losses not only waste significant amounts of generated energy but also lead

HOW TO CITE:
Ariyo1.F. K., Ayanlade. S. O., Adeagbo. A. P., Jimoh. A. and Adebayo. M. T. "Assessment Of The Impact Of Distribution Generation On Radial Distribution Network Protection System", *Nigerian Journal of Technology*, 2025; 44(3), pp. 471 – 483; https://doi.org/10.4314/njt.v44i3.11
© 2025 by the author(s). This article is open access under the CC BY-NC-ND license

to voltage drops, overheating of conductors, and reduced equipment lifespan [5]. In Nigeria and similar developing power systems, technical losses account for a substantial portion of total energy loss, often exceeding 20% of generated power. Such inefficiencies contribute to frequent voltage instability, poor power quality, and reduced system reliability [6]. Addressing these problems is therefore critical to ensuring efficient power delivery and maintaining system performance.

The predominant focus of these techniques lies in diminishing power losses and boosting network's voltage profile. Common approaches include capacitor installations, deployment of Distribution Flexible Alternating Current Transmission System (DFACTS) controllers, and integration of Distribution Generation (DG) units [7, 8, 9]. While capacitor installations are the most cost-effective method, their impact on network performance is primarily limited to reactive power injection [10]. Moreover, in situations of excess reactive power, capacitor installations exacerbate the issue without providing a comprehensive solution.

In addressing the limitations of capacitor installations, DFACTS devices have emerged as a solution, leveraging advancements in power electronics. These controllers can supply and absorb reactive power as needed by the network. However, their effectiveness is hindered in certain scenarios due to their inability to inject active power [11].

Further advancements in the field led to the DG's penetration into distribution networks. Unlike DFACTS devices, DG units have the unique capability to inject active power, offering a more comprehensive solution to network challenges. Integrating them offers multiple advantages, such as lowering power losses, boosting voltage stability, and increasing the overall effectiveness of the distribution grid [12, 13].

Despite the advantages, integrating DG units alters the short-circuit current levels, leading to potential issues with the protection system. The parameter settings of overcurrent relays are compromised, jeopardizing the network's security and integrity [14-16].

In distribution grids, determining the DG placement and size presents an optimization challenge necessitating a robust solution technique. Poorly positioned or sized DG units can significantly reduce network efficiency [17]. Therefore, achieving optimal placement and sizing is essential to enhance network performance. Various optimization techniques have been developed and documented in the literature for this purpose.

Ang and Leeton [18] utilized the Newton Raphson power flow method to reduce total real loss in a distribution grid. They introduced the Fast Voltage Stability Index (FVSI) and Whale Optimization Algorithm (WOA), inspired by humpback whale hunting behavior, to optimize DG placement. Evaluation on 15- and 33-bus grids across varying DG contributions demonstrated the strategy's efficacy. However, the study achieved only near-optimal solutions for DG location and capacity.

Mirsaeidi *et al.* [19] introduced a Genetic Algorithm (GA) to optimize DG placements and capacities, reducing active and reactive losses. Simulation on IEEE 30- and 118-bus networks showed notable loss reductions and voltage improvements. However, the study's evaluation only compared the GA with one other method, raising questions about its broader effectiveness.

Tan *et al.* [20] introduced an objective function that takes into account power losses, voltage profile, and environmental emissions, advocating for the Swarm Moth Flame Optimization algorithm. This algorithm aims to optimize the objective function and meet specified criteria, evaluated using the IEEE 33-bus system. Despite promising results, further enhancements are needed to accurately pinpoint the optimal DG location.

Roy *et al.* [21] utilized Multi Verse Optimization (MVO), a novel bio-inspired technique, to address DG placement challenges. The study implemented the MVO algorithm on a 33-bus distribution system, comparing its findings with existing literature. However, the study identified a convergence issue with MVO, limiting its effectiveness in reaching optimal solutions.

Prakash *et al.* [22] developed a strategy to optimally allocate DGs considering various load levels, including peak demand. Their aim was to reduce network total loss by determining the optimal DG allocations based on peak loss-saving criteria. Unlike alternative methods, this approach simplified computational demands, requiring only a base-case power flow solution. Evaluation on IEEE 33- and 69-bus grids demonstrated its effectiveness in reducing overall system energy losses, albeit with some limitations due to approximations in size and location optimization.

Wankhede *et al.* [23] introduced a genetic algorithm (GA) method to optimize DG location and capacity in distribution grids, aiming to reduce active losses and boost voltage magnitudes. Their approach simultaneously determines optimal locations and capacities for DGs, offering a comprehensive solution. However, its applicability is limited to 12-

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

bus distribution networks due to concerns about premature convergence when applied to larger systems.
Nageswari *et al*. [24] introduced the Chaotic Artificial Flora Optimization based on Optimal Placement and Sizing of DGs algorithm, integrating chaos theory into the AFO algorithm to enhance global optimization. The algorithm's fitness function addresses voltage regulation, loss reduction, and penalty costs. Experimental findings on IEEE 33- and 69-bus grids demonstrate the model's potential in reducing loss and improving voltage profiles, albeit its complexity and iteration requirements.
Radosavljević *et al*. [25] tackled the challenge of strategic location and sizing of renewable DG (RDG) using a hybrid metaheuristic algorithm combining phasor PSO and GSA. The aim was to minimize energy loss while maximizing RDG owner profit, considering RDG's stochastic nature through probabilistic models. Tested on an IEEE 69-bus system, the algorithm outperformed other metaheuristics but exhibited complexity, slow convergence, and time-consuming processes.
The existing literature reveals shortcomings in current methods for optimally placing and sizing DG units. Many of these methods lack efficiency and overlook the crucial aspect of assessing the detrimental impact on the protection scheme of radial distribution systems. Neglecting this aspect is concerning, given the protection system's essential role in the power system. Therefore, this study aims to address these gaps by utilizing a novel approach—the Dingo Optimization Algorithm (DOA)—to optimize the placement and capacity of DG units in a distribution grid. Furthermore, it seeks to analyze and assess the adverse effects of optimized DG units on the protection scheme, specifically focusing on the impact on fault currents, time multiplier settings (TMSs) of relays, and relay operating times. The DOA implementation was carried out utilizing MATLAB and validated on the IEEE 33-bus, a standard test grid. For the protection studies, the test network was modeled and simulated using ETAP 19.
The contributions of this research include:

- Providing a novel approach using the DOA for the strategic position and sizing of DG units in distribution grids.
- Conducting a comprehensive analysis of the adverse effects of optimized DG units on the protection scheme, considering TMSs, PMSs of relays, and relay operating times.
- Utilizing industry-standard tools (MATLAB and ETAP) for simulation and analysis, ensuring the validity and applicability of the findings.

The DOA was selected for this study because of its fast convergence rate and balanced exploration–exploitation characteristics, which make it effective for nonlinear optimization problems such as DG allocation. MATLAB was used to perform the load flow analysis and to implement the DOA for determining the optimal DG locations and capacities that minimize active and reactive power losses while improving the voltage profile. The IEEE 33-bus test network was used as a benchmark to validate the accuracy of the proposed optimization framework.

To analyze the impact of DG integration on protection coordination, the optimized DG configuration obtained from MATLAB was exported to ETAP, where fault and relay coordination studies were carried out. Thus, MATLAB handled the optimization and load flow analysis, while ETAP was used solely for the protection study. This sequential approach ensured methodological consistency and avoided duplication of power flow results.

2.0 METHODOLOGY

2.1 Problem Formulation

The integration of DG units into distribution grids primarily aims to reduce total active power losses and enhance voltage profiles. Accordingly, the optimization problem formulated in this study seeks to minimize the overall active power loss across all branches of the system, expressed as the objective function (OF) in Eq. (1) [18, 19].

$$OF_{\min} = \sum_{i}^{n_b} |I_i|^2 R_i \quad (1)$$

where, n_b = total branch, R_i = i^{th} branch resistance and $|I_i|$ = magnitude of the current in the i^{th} branch.
The objective function was subject to the equality and inequality constraints as follows:

2.1.1 Power flow balance and generation

Eqs. (2) and (3) depict the fundamental elements governing the grid's active and reactive power flows. Eq. (2) describes the dynamic aspect of active power flow, while Eq. (3) quantifies reactive power flow.

$$P_{Gi} = P_{Di} + \sum_{j=1}^{n_b} |V_i||V_j| \left[G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right] \quad (2)$$

$$Q_{Gi} = Q_{Di} + \sum_{j=1}^{n_b} |V_i||V_j| \left[G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right] \quad (3)$$

where V_i and V_j = bus voltages, P_{Gi} and P_{Di} = active power generated and demanded, Q_{Gi} and Q_{Di} = reactive power generated and demanded, and G_{ij} and

© 2025 by the author(s). Licensee NIJOTECH. This article is open access under the CC BY-NC-ND license.

https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

B_{ij} = branch conductance and susceptance, respectively.

2.1.2 Parameter Limitations

Voltage limits: Eq. (4) delineates the voltage thresholds, specifying the precise range for voltage operation.

$$V_{\min} \le V_i \le V_{\max} \tag{4}$$

where V_{min} and V_{max} = minimum and maximum voltage magnitudes

Distributed generation limits: For DG units to work best, they need to stay within certain operational limits outlined in Eq. (5).

$$DG_{(\min)} \le DG \le DG_{(\max)} \tag{5}$$

2.2 Dingo Optimization Algorithm

The DOA algorithm is inspired by the cleverness and social structure of dingoes, known for living in packs led by an Alpha. Scouts monitor surroundings, and the pack hunts with coordinated actions. DOA mimics this to optimize resource allocation, showing adaptability in solving optimization problems like power systems. This approach introduces a unique dimension to optimization algorithms [26].

2.3 Dingo Optimization Algorithm Mathematical Model

The DOA algorithm is based on a mathematical model that mimics the circling, hunting, attacking, and searching behaviors exhibited by animals such as dingoes. This approach enables the algorithm to emulate the flexible and effective hunting strategies exhibited by dingoes Incorporating these behaviors enhances the DOA algorithm's capability and efficiency in addressing optimization challenges across various domains.

2.3.1 Encircling

Dingoes' encircling behavior, which includes pack members' strategic positioning and coordination, is represented by mathematical Equations (6)–(10) proposed by [26].

$$\vec{D}_c = \left|\vec{A}\cdot\vec{P}_p(x) - \vec{P}(x)\right| \tag{6}$$

$$\vec{P}(i+1) = \vec{P}_p(i) - \vec{B}\cdot\vec{D}(d) \tag{7}$$

where, $\vec{A} = 2\cdot\vec{a}_1$ (8)

$$\vec{B} = 2\vec{b}\cdot\vec{a}_2 - \vec{b} \tag{9}$$

where,

$$\vec{b} = 3 - \left(I * \left(\frac{3}{I_{\max}}\right)\right) \tag{10}$$

where, $\vec{D}_c$ = distance between the dingo and prey, $\vec{P}_p$, $\vec{P}$ = prey and dingo position vectors, $\vec{A}$ and $\vec{B}$ = coefficient vectors, $\vec{a}_1$ and $\vec{a}_2$ = random vectors in [0, 1], $\vec{b}$ = variable that decreases linearly from 3 – 0, I = 1,2,3,..., I_{max}.

These equations model how dingoes encircle prey and cooperate. They help simulate and analyze the efficiency of this behavior within optimization algorithms [27].

2.3.2 Hunting

In optimization, agents in DOA mimic dingoes' hunting, with all knowing potential prey locations. Alpha leads; others may join. Top agents' positions guide updates using equations (11)–(16) [26, 27].

$$\vec{D}_\alpha = \left|\vec{A}_1\cdot\vec{P}_\alpha - \vec{P}\right| \tag{11}$$

$$\vec{D}_\beta = \left|\vec{A}_2\cdot\vec{P}_\beta - \vec{P}\right| \tag{12}$$

$$\vec{D}_o = \left|\vec{A}_3\cdot\vec{P}_o - \vec{P}\right| \tag{13}$$

$$\vec{P}_1 = \left|\vec{P}_\alpha - \vec{B}\cdot\vec{D}_\alpha\right| \tag{14}$$

$$\vec{P}_2 = \left|\vec{P}_\beta - \vec{B}\cdot\vec{D}_\beta\right| \tag{15}$$

$$\vec{P}_3 = \left|\vec{P}_o - \vec{B}\cdot\vec{D}_o\right| \tag{16}$$

These equations embody the hunting strategy in the DOA algorithm, reflecting how dingoes coordinate their actions based on the alpha's lead and information from the group. This modeling introduces a distinct approach to optimizing search, mirroring the teamwork seen in dingo packs. Equation (17)-(19) determine each dingo's intensity [26, 27].

$$\vec{I}_a = \log\left(\left(F_\alpha - (1E-100)\right)^{-1} + 1\right) \tag{17}$$

$$\vec{I}_\beta = \log\left(\left(F_\beta - (1E-100)\right)^{-1} + 1\right) \tag{18}$$

$$\vec{I}_o = \log\left(\left(F_o - (1E-100)\right)^{-1} + 1\right) \tag{19}$$

where, F_α and F_β = α and β-dingo fitness values, and F_o = other dingo fitness value.

These equations represent the mathematical processes used to assess dingo intensities in the DOA algorithm.

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

2.3.3 Attacking prey

Once the hunt is complete, the dingo launches an attack on its prey if there is no requirement for a location adjustment. Mathematically, the variable $\vec{b}$ decreases linearly, reducing the range of $\vec{D}_{\alpha}$. As $\vec{b}$ reduces from 3 to 0, $\vec{D}_{\alpha}$'s random values range narrows. This narrowing range models the dingo's decision-making, gradually restricting movement options. The DOA algorithm integrates these adjustments, improving search agent efficiency in finding optimal solutions.

2.3.4 Searching

Dingoes hunt using group dynamics, assessing prey movement relative to the pack. In the DOA model, "pack" represents the group of search agents (dingoes) that explore the solution space together. In this model, $\vec{B}$ indicates prey approach or retreat, while $\vec{A}$ promotes exploration with random values. Eq. (8) accommodates varying prey behaviors. Values ≤ 1 signify prey moving away, ≥ 1 signify approach. This setup analyzes the gap's impact (Eq. 7).

2.4 Optimal DG Allocation Utilizing the DOA

Step 1: Initialize dingo agents randomly within the search area.

Step 2: Assess fitness using a function considering network performance post-DG allocation.

Step 3: Select agent with highest fitness as global best solution.

Step 4: Update agents' positions and velocities based on individual and global knowledge.

Step 5: Apply boundary constraints to keep agents within feasible region.

Step 6: Assess fitness of adjusted agents.

Step 7: Adjust personal best solutions for each agent based on fitness comparison.

Step 8: Update the global best solution if a superior alternative is identified.

Step 9: Continue executing steps 4 through 8 iteratively until termination criteria is reached.

Step 10: Select the optimal dingo agent as the final solution and assign DGs to the distribution network according to their designated positions.

The DOA was implemented in the MATLAB environment to determine the optimal placement and sizing of DG units. The optimization process utilized the IEEE 33-bus test network as the study case. The objective function was formulated to minimize active power losses and enhance the voltage profile. The simulation was executed with a population size of 1000 and a maximum of 100 iterations to ensure convergence. The DOA algorithm evaluated the performance of each candidate DG configuration by running a Newton-Raphson load flow analysis at every iteration until the optimal solution was obtained. The IEEE 33-bus distribution network used in this study was divided into four protection zones to facilitate relay coordination and fault studies. The network topology and zone segmentation are illustrated in Figure 1, which provides a schematic overview of the system layout and bus numbering adopted for the analysis.

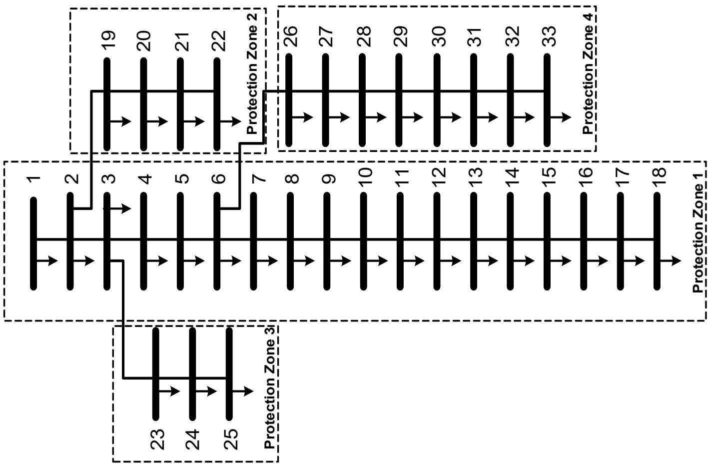


Figure 1: IEEE 33-bus network divided into four zones

2.5 Determination of Relay Parameter Settings

The operational relay time was determined through the following procedure.

$$I_R = I_f / I_{CT} \tag{20}$$

I_f = expected fault current while I_{CT} = transformer ratio.

The relay pickup current I_P was calculated using Eq. (21).

$$I_p = P_{setting} \times I_{SCT} \tag{21}$$

$P_{setting}$ = plug setting while I_{SCT} = rated secondary current of CT

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.

https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

The plug setting multiplier PSM was computed using Eq. (22)

$$PMS = I_R / I_P \quad (22)$$

The relay operating time was computed using Eq. (23).

$$T = TMS\left[\mathrm{A} / \left(PSM^{\infty} + \mathrm{B} \right) \right] \quad (23)$$

A is constant, B is constant (-1), while ∞ is a constant that varies 0.02 and 2. TMS is a time-setting multiplier.

The procedural steps for determining relay operating time are summarized in Figure 2 which illustrates the sequence from current measurement to relay time calculation.

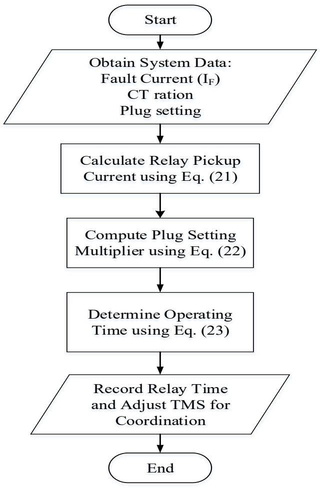


Figure 2: Flowchart for Determination of Relay Operating Time

2.6 Modeling of the IEEE 33-Bus on ETAP

Prior to protection analysis, the IEEE 33-bus network was characterized through a load flow study using Newton-Raphson method on MATLAB. This enabled the identification of the network's voltage levels, current distribution, and total system losses under base conditions. The load flow results served as a benchmark for comparing the system's performance after DG integration, helping to quantify the technical losses and determine buses with the lowest voltages and highest losses. These buses later guided the optimal DG placement during the optimization process. The network was divided into four zones because of its radial nature. Each zone operates independently of the others. Zone 1 spans buses 1–18, housing 17 overcurrent relays. Zone 2 covers buses 2-19 to 22 with four relays, while Zone 3 extends from bus 3 through 23 to 25, equipped with three relays. Zone 4 encompasses buses 6 through 26 to 33, containing eight relays as depicted in the system's single-line diagram. Current is measured using 200/5A-rated current transformers (CTs), and voltage at each bus is measured using 12660/100V-rated capacitor voltage transformers (CVTs). The integration of DGs into the grid negatively impacts traditional overcurrent protection relay coordination. The ETAP 19 model, shown in Fig. 3, incorporates protection system components such as CTs, overcurrent relays, and circuit breakers (CBs). Fault simulations were conducted at the zone boundaries, both with and without DGs, to assess relay operational characteristics. Following simulations, fault currents, TMSs, and relay operational times were determined.

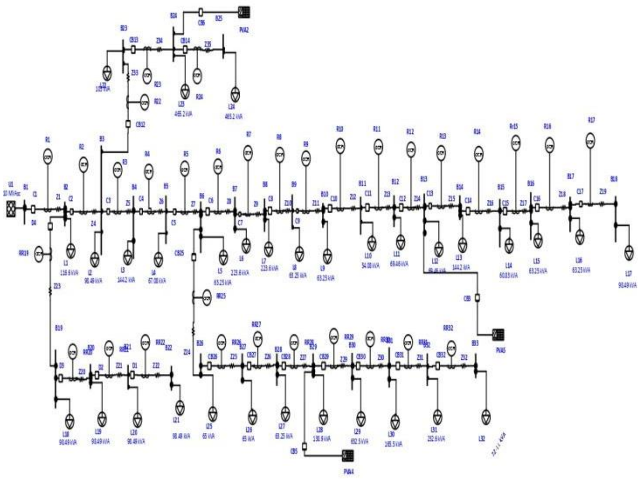


Figure 3: IEEE 33-Bus Network Model on ETAP

The overall methodological framework of this study, which links the MATLAB-based DOA optimization process with the ETAP-based protection analysis, is presented in Figure 4. This framework demonstrates how load flow and optimization results obtained from MATLAB are transferred into ETAP for fault simulation and relay coordination assessment.

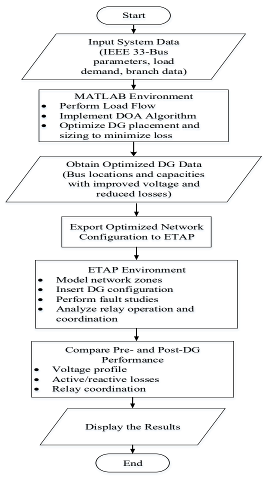


Figure 4: Interconnection Between DOA Optimization, Load Flow, and Protection Analysis

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

3.0 RESULTS AND DISCUSSION

The DOA methodology, implemented in MATLAB and applied to the IEEE 33-bus distribution grid, demonstrated strong optimization performance. As shown in Figure 5, the algorithm achieved rapid convergence, reaching the minimum total active power loss within approximately 40 iterations out of the 100-iteration limit. This confirms the DOA's efficiency and robustness in solving non-linear, multi-variable optimization problems associated with DG allocation.

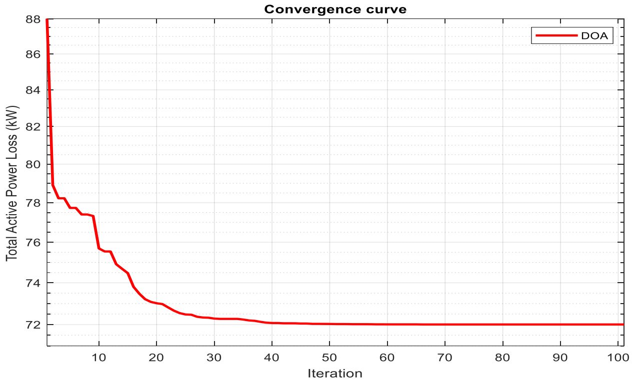


Figure 5: Convergence curve of DOA for the IEEE 33-bus grid

Following the optimization of DG allocation, buses 24, 29, and 13 were identified as the most suitable locations for DG deployment. The respective sizes of DG units, determined to be 978.00 kW, 1101.00 kW, and 786.00 kW for buses 24, 29, and 13, are presented in Table 1.

Table 1. Strategic DG allocations on IEEE 33-bus grid

DG size (kW)	Location
978.00	24
1101.00	29
786.00	13

3.1 Voltage Profile

The voltage profiles were obtained from two power flow analyses–one conducted before DG integration (base case) and another after DG allocation using the DOA results–to highlight the improvement in voltage profile Figure 6 depicts the grid voltage profile, contrasting scenarios pre- and post-DG units' integration. Prior to the DG deployment, the voltage profile showed significant deficiencies, with multiple bus voltages falling below acceptable thresholds. Voltage magnitudes for buses 7 through 18 fell short of the minimum threshold of 0.95 p.u., with bus 18 showing the least reading at 0.91312 p.u. After the DG units were installed, notable improvements in the voltage levels at these buses were observed. Specifically, the voltage at bus 30 was recorded at 0.966 p.u., which played a key role in enhancing the grid voltage profile. Integrating the DOA for optimizing DG, was crucial for improving the performance of the test grid.

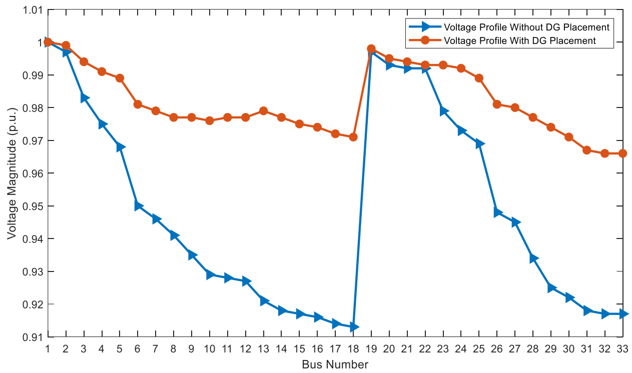


Figure 6: Voltage profiles pre- and post-DG integration

3.2 Active Power Loss

Prior to the installation of DGs, the grid had an active power loss totaling 202.71 kW. However, by employing the DOA optimization algorithm for DG allocation, a substantial decrease of 61.21%, totaling 78.62 kW, was achieved in total active power loss. Figure 7 depicts the distribution of active power losses throughout the grid branches. Reviewing the data reveals that the highest active power loss in branch 2–3, which was 52 kW before the integration of DGs, was substantially diminished to 14.95 kW after their strategic placement, representing a 71.25% decrease. These decreases in individual branch losses contribute to a total minimization in active losses throughout the entire grid.

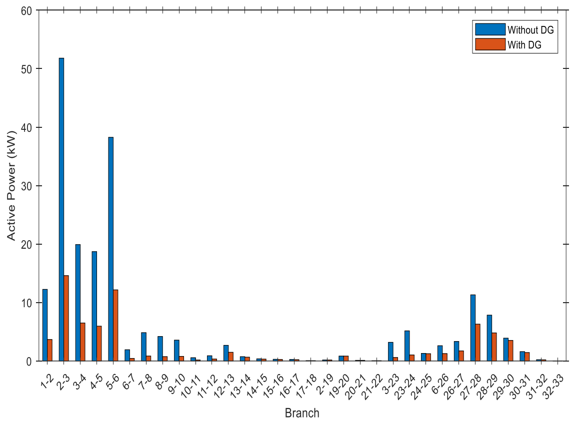


Figure 7: Active power losses pre- and post-DG integration

© 2025 by the author(s). Licensee NIJOTECH. This article is open access under the CC BY-NC-ND license. http://creativecommons.org/licenses/by-nc-nd/4.0/

https://doi.org/10.4314/njt.v44i2.11

3.3 Reactive Power Loss

Figure 8 illustrates a comparison of reactive losses in the distribution network branches both prior to and following the integration of DGs. At the outset, the branches 2–3 and 5–6 were identified as having the largest reactive power losses, measuring 26.0 and 34.0 kVAr, respectively. Nevertheless, with the strategic placement of DGs, these losses were greatly diminished to 7.0 and 11.0 kVAr. This highlights the substantial impact of optimally positioned DGs in reducing reactive power losses in the distribution grid. Figure 6 shows a significant reduction in reactive power losses across the network. The total loss decreased from 23.561 kVAr to 10.0 kVAr, a 57.6% reduction. This demonstrates the DOA's effectiveness in optimizing DG allocation and enhancing network performance.

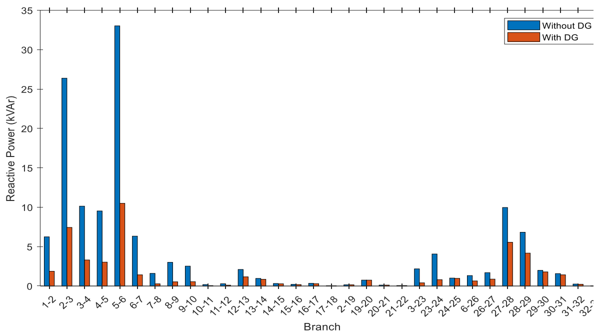


Figure 8: Reactive power losses pre- and post-DG integration.

3.2 Over-current Protection Relays

The IEEE 33-bus model was implemented in ETAP, as discussed in the previous section. Short-circuit faults were simulated at each end of the protection zone, both without and with DG unit deployment. For zone 1, a short-circuit current was introduced at bus 18; for zone 2, at bus 22; for zone 3, at bus 25; and for zone 4, at bus 33.

The relay parameters, including the TMS, fault current, and relay operating time, were determined and summarized in Tables 2–5 for each zone. Upon examining Tables 5–10, which compare the relay parameter settings without and with DG unit integration, it becomes evident that the TMS, fault current, and relay operating times underwent significant changes with the penetration of DGs into the grid. These alterations in relay parameters stem from variations in short-circuit current levels due to DG unit integration, ultimately affecting the values of TMS, PMS, and relay operating times. Consequently, the protection scheme of the network is compromised, as relay coordination is disrupted due to changes in relay parameters within the protection system. The relay characteristic curves without and with DG placements for each zone are illustrated in Figures 9–12.

Table 2: Zone 1 relay parameters comparison with and without DGs

	Without DG			With DG		
Relay	TMS	Fault Current (kA)	Operation Time (ms)	TMS	Fault Current (kA)	Operation Time (ms)
R17	0.1214	0.495	213	0.1268	0.534	180
R16	0.1668	0.479	353	0.1745	0.519	294
R15	0.2353	0.466	594	0.2456	0.506	487
R14	0.2870	0.454	866	0.3007	0.495	697
R13	0.3389	0.427	1350	0.3552	0.470	1040
R12	0.3941	0.415	1930	0.4141	0.414	1950
R11	0.4849	0.405	3170	0.5033	0.405	3180
R10	0.5271	0.397	3870	0.5473	0.398	3860
R9	0.5620	0.388	5200	0.5827	0.390	5120
R8	0.6993	0.380	8280	0.7195	0.383	8040
R7	0.7927	0.355	16000	0.8116	0.361	15000
R6	0.9436	0.355	>32200	0.9712	0.345	28600
R5	1.0276	0.232	-	1.0585	0.219	x
R4	1.1067	0.227	-	1.1340	0.215	x
R3	1.1504	0.216	-	1.1745	0.207	x
R2	1.1910	0.141	-	1.2146	0.109	x
R1	1.2199	0.106	-	1.2397	0.0825	x

Table 3: Zone 2 Relay Parameters Comparison with and without DGs

Relay	Without DG	With DG

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

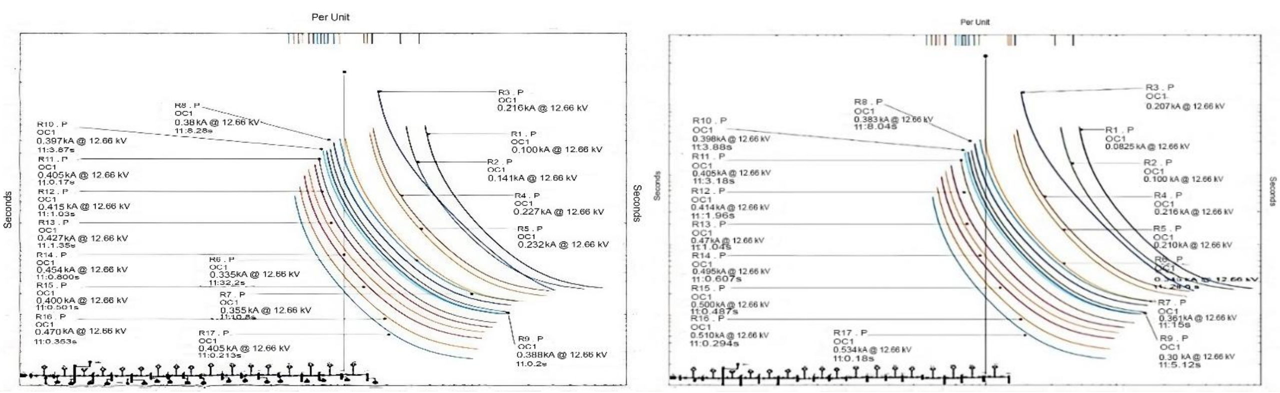
	TMS	Fault Current (kA)	Operation Time (ms)	TMS	Fault Current (kA)	Operation Time (ms)
RR22	0.0588	0.864	627	0.2128	0.917	535
RR21	0.1005	0.840	1230	0.3069	0.894	1040
RR20	0.1380	0.817	1940	0.3942	0.872	1610
RR19	0.2241	0.800	3570	0.5298	0.856	2920

Table 4: Zone 3 relay parameters comparison with and without DGs

	Without DG			With DG		
Relay	**TMS**	**Fault Current (kA)**	**Operation Time (ms)**	**TMS**	**Fault Current (kA)**	**Operation Time (ms)**
R24	0.0681	1.011	183	0.2404	1.108	147
R23	0.1098	0.897	430	0.3419	0.937	381
R22	0.1580	0.874	703	0.4458	0.915	616

Table 5: Zone 4 relay parameters comparison with and without DGs

	Without DG			With DG		
Relay	**TMS**	**Fault Current (kA)**	**Operation Time (ms)**	**TMS**	**Fault Current (kA)**	**Operation Time (ms)**
RR32	0.0736	0.823	166	0.1935	0.895	137
RR31	0.1070	0.795	278	0.2675	0.868	226
RR30	0.1388	0.755	441	0.3380	0.828	348
RR29	0.1970	0.624	634	0.4329	0.703	476
RR28	0.2341	0.596	1800	0.5038	0.613	1630
RR27	0.2896	0.585	3010	0.5887	0.602	2680
RR26	0.3656	0.575	5730	0.6974	0.593	5020
RR25	0.4037	0.566	10100	0.7625	0.585	8610

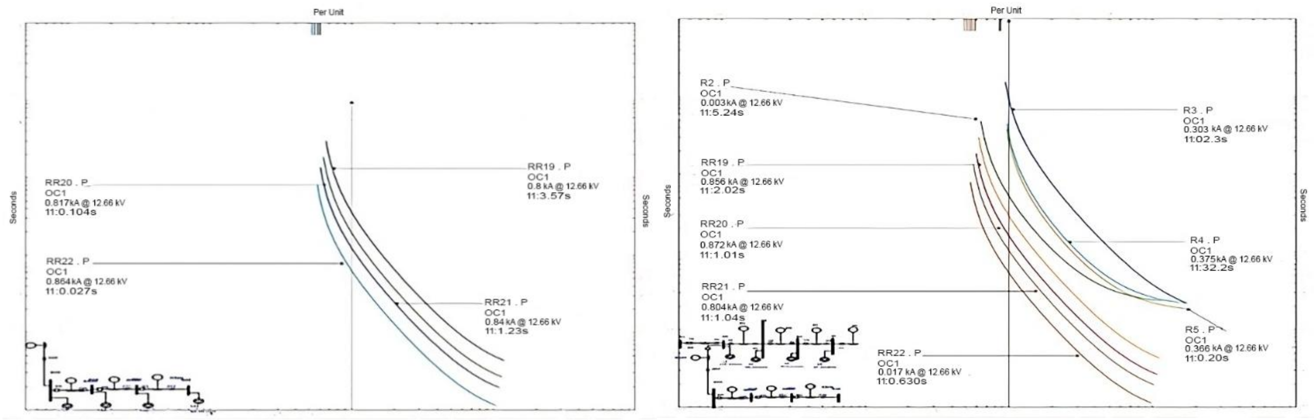


a) b)

Figure 9: Zone 1 relay curve characteristics (a) Pre-DG penetration (b) Post-DG penetration

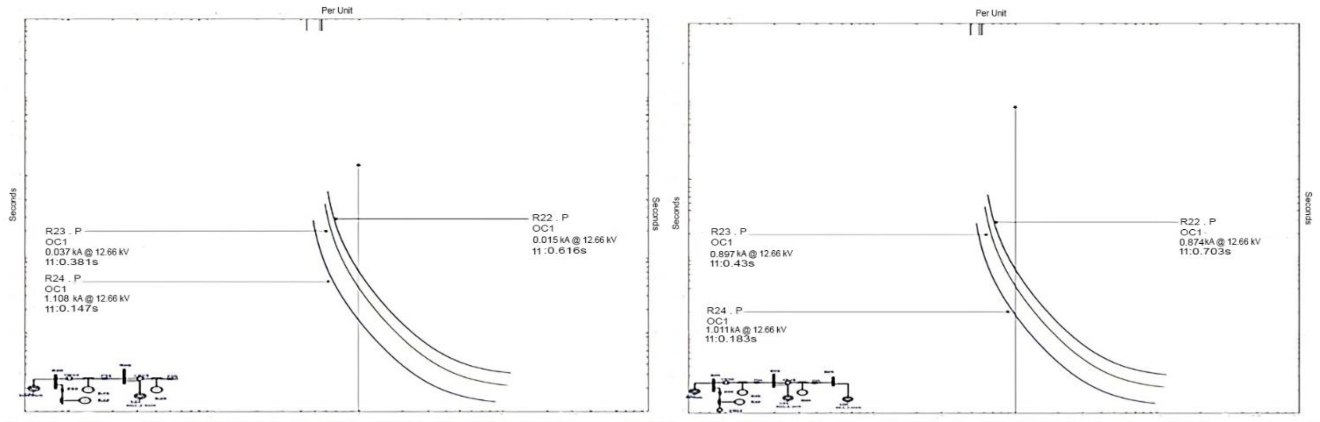
© 2025 by the author(s). Licensee NIJOTECH. This article is open access under the CC BY-NC-ND license. http://creativecommons.org/licenses/by-nc-nd/4.0/

https://doi.org/10.4314/njt.v44i2.11



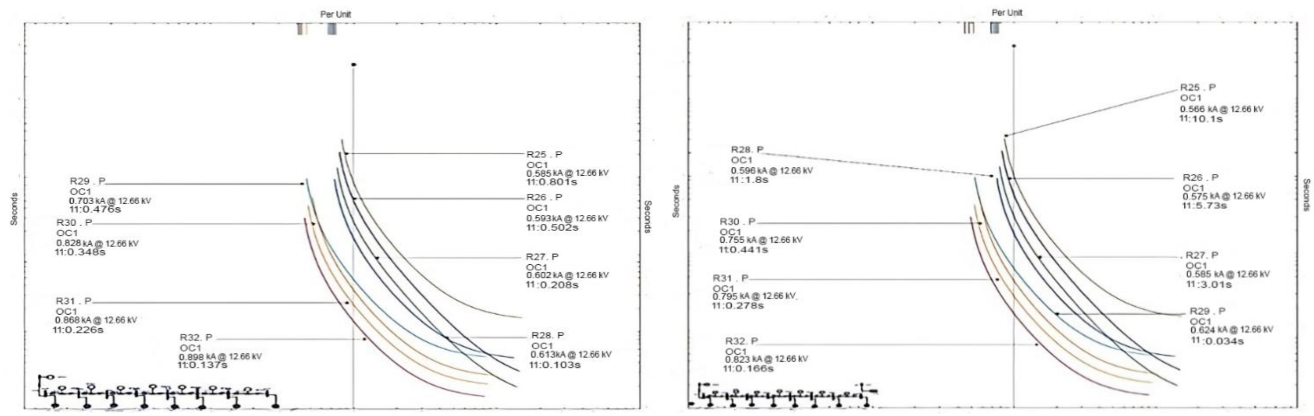
(a) (b)

Figure 10: Zone 2 relay curve characteristics (a) Pre-DG penetration (b) Post-DG penetration



(a) (b)

Figure 11: Zone 3 relay curve characteristics (a) Pre-DG penetration (b) Post-DG penetration



(a) (b)

Figure 12: Zone 4 relay curve characteristics (a) Pre-DG penetration (b) Post-DG penetration

Analysis of the relay characteristics curves presented in Figures 9–12 reveals a significant impact on relay operating times resulting from the incorporation of DG units. A comparison between the relay characteristics curves without and with DG integrations indicates notable changes. These alterations in relay operating times stem from variations in short-circuit currents induced by DG integration. The introduction of DG units into the network leads to fluctuations in short-circuit currents,

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

consequently affecting the TMS of the relays. These changes in TMS, in turn, influence the relay operating times.

Furthermore, it is crucial to note that the observed changes in relay operating times have implications for the overall performance and coordination of the protection scheme. The ability of relays to respond swiftly and accurately to faults is paramount to ensuring the reliability and stability of the network. Any deviations in relay operating times can potentially impact system protection, leading to delayed fault detection and clearance.

Moreover, the findings underscore the intricate relationship between DG integration and relay performance within the distribution network. As DG penetration increases, the network experiences dynamic changes in fault current levels, necessitating adjustments in relay settings for optimal protection coordination.

When protection devices are numerous, DG penetration increases coordination complexity as multiple relays respond to the same fault due to higher short-circuit currents. Conversely, in systems with inadequate protection, DGs can cause delayed or missed relay operation, risking equipment damage. Although this study did not directly compute the optimal number of relays, the observed variations in fault current and TMS across the four zones indicate the need for adaptive protection coordination when integrating DGs.

5.0 CONCLUSION

This study has demonstrated the DOA efficacy in optimizing the DGs deployment within the IEEE 33-bus grid, with MATLAB serving as the simulation platform to bolster network performance. The strategic sizing and positioning of DG units, guided by DOA and validated by empirical evidence, underscore their potential to enhance system efficiency and reliability.

Furthermore, the investigation into the adverse DG integration effects on the network's protection system, conducted using ETAP 19, has unveiled significant challenges. The observed disruptions to TMS, fault currents, and relay operational times underscore the pressing need for innovative solutions to mitigate these negative impacts. Looking ahead, future research endeavors should prioritize the development of advanced relay coordination algorithms tailored to accommodate the dynamic operating conditions induced by DG integration.

Additionally, exploring novel approaches for real-time monitoring and control of relay settings can bolster the adaptability and resilience of the protection system in the face of evolving grid configurations. In light of the pivotal role played by DG unit integration in ensuring the efficient operation of radial distribution networks, continued investigation and collaboration across interdisciplinary domains are imperative. Addressing the complexities and challenges associated with DG integration can pave the way towards a more sustainable, resilient, and responsive energy infrastructure for the future. Overall, the coordinated application of DOA optimization and ETAP-based protection modeling provides a reliable framework for managing the technical and protective challenges associated with DG integration in distribution networks.

REFERENCES

[1] Ayanlade, S. O., Ariyo, F. K., Jimoh, A., Akindeji, K. T., Adetunji, A. O., Ogunwole, E. I. and Owolabi, D. E. “Optimal Allocation of Photovoltaic Distributed Generations in Radial Distribution Networks”, *Sustainability*, 15(18): 13933, 2023. https://doi.org/10.3390/su151813933

[2] Obi, P. I., Okonkwo, I. I. and Ogba, C. O. “Power Supply Enhancement in Onitsha Distribution Network Using Distribution Generations”, *Nigerian Journal of Technology*, 41(2): pp. 318–329, 2022. https://doi.org/10.4314/njt.v41i2.14

[3] Mohamed, E. A., Hegazy, Y. G. and Othman, M. M. “A Novel Probabilistic Technique for Optimal Allocation of Photovoltaic Based Distributed Generators to Decrease System Losses”, *Periodica Polytechnica Electrical Engineering and Computer Science*, 60(4): pp. 247–253, 2016. https://doi.org/10.3311/PPee.10018

[4] Ayanlade, S. O., Jimoh, A., Ezekiel, S. O. and Babatunde, A. A. “Voltage Profile Improvement and Active Power Loss Reduction Through Network Reconfiguration Using Dingo Optimizer”, *International Conference of Advanced Computing and Informatics*, Springer International Publishing, 2022, pp. 29–39. https://doi.org/10.1007/978-3-031-36258-3_3

[5] Olanite, O. O., Nwohu, M. N., Adegboye, B. A. and Tola, O. J. “Large Scale Penetration Impact of PMS-WTGS on Voltage Profile and Power Loss for 5-Bus, 330 kV System of the Nigerian Grid”, *Nigerian Journal of Technology*, 43(1): pp. 115–122, 2024. https://doi.org/10.4314/njt.v43i1.13

© 2025 by the author(s). Licensee NIJOTECH. This article is open access under the CC BY-NC-ND license. https://doi.org/10.4314/njt.v44i2.11 http://creativecommons.org/licenses/by-nc-nd/4.0/

[6] Onah, J. Omeje, C., Onyishi, D., and Oluwadurotimi, J. "Single topology neural network-based voltage collapse prediction of developing power systems", *Nigerian Journal of Technology*, 43(2): pp. 309–16, 2024. https://doi.org/10.4314/njt.v43i2.14

[7] Iqbal, F., Khan, M. T. and Siddiqui, A. S. "Optimal Placement of DG and DSTATCOM for Loss Reduction and Voltage Profile Improvement", *Alexandria Engineering Journal*, 57(2) pp. 755–765, 2018. https://doi.org/10.1016/j.aej.2017.03.002

[8] Bidyanath, K., Singh, S. D. and Adhikari, S. "Implementation of Genetic and Particle Swarm Optimization Algorithm for Voltage Profile Improvement and Loss Reduction Using Capacitors in 132 kV Manipur Transmission System", *Energy Reports*, 9: pp. 738–746, 2023. https://doi.org/10.1016/j.egyr.2022.11.098

[9] Anyalebechi A. E. and Anyaka, B. O. "Overcurrent protective relays for electric distribution systems", *Nigerian Journal of Technology*, 43(4): pp. 772–778, 2024. https://doi.org/10.4314/njt.v43i4.17

[10] Sarkar, M. N. I., Meegahapola, L. G. and Datta, M. "Reactive Power Management in Renewable Rich Power Grids: A Review of Grid Codes, Renewable Generators, Support Devices, Control Strategies and Optimization Algorithms", *IEEE Access*, 6: pp. 41458–41489, 2018. https://doi.org/10.1109/ACCESS.2018.2838563

[11] Alvarado-Reyes, S., Villar-Yacila, P. and Fiestas, H. "Imperialist Competitive Algorithm Applied to the Optimal Integration of Photovoltaic Distributed Generation Units into a Microgrid", *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, 2: 100086, 2022. https://doi.org/10.1016/j.prime.2022.100086

[12] Ehsan, A. and Yang, Q. "Optimal Integration and Planning of Renewable Distributed Generation in the Power Distribution Networks: A Review of Analytical Techniques", *Applied Energy*, 210: pp. 44–59, 2018. https://doi.org/10.1016/j.apenergy.2017.10.106

[13] Bajaj, M. and Singh, A. K. "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): pp. 26–69, 2020. https://doi.org/10.1002/er.4847

[14] Zellagui, M., Belbachir, N., Amroune, M. and El-Bayeh, C. Z. "Investigating the Performance of Non-standard Overcurrent Relay with Integration of Photovoltaic Distributed Generation in Power Distribution System", *Periodica Polytechnica Electrical Engineering and Computer Science*, 68(1): pp. 27–36, 2024. https://doi.org/10.3311/PPee.21780

[15] Beheshtaein, S., Cuzner, R., Savaghebi, M. and Guerrero, J. M. "Review on Microgrids Protection", *IET Generation, Transmission & Distribution*, 13(6): pp. 743–759, 2019. https://doi.org/10.1049/iet-gtd.2018.5212

[16] Oluseyi, P. O., Tinuoye, O. O., Akinbulire, T. O., Awosope, C. O. A. and Babatunde, O. M. "Analysis of Akangba Transmission Substation Protection System", *Nigerian Journal of Technology*, 41(2): pp. 339–358, 2022. https://doi.org/10.4314/njt.v41i2.16

[17] M'hamdi, B., Teguar, M. and Tahar, B. "Optimal DG Unit Placement and Sizing in Radial Distribution Network for Power Loss Minimization and Voltage Stability Enhancement", *Periodica Polytechnica Electrical Engineering and Computer Science*, 64(2): pp. 157–169, 2020. https://doi.org/10.3311/PPee.15057

[18] Ang, S. and Leeton, U. "Optimal Placement and Size of Distributed Generation in Radial Distribution System Using Whale Optimization Algorithm", *Suranaree Journal of Science and Technology*, 26(1): pp. 1–12, 2019.

[19] Mirsaeidi, S., Li, S., Devkota, S., Li, M., He, J., Tzelepis, D. and Said, D. M. "A Power Loss Minimization Strategy Based on Optimal Placement and Sizing of Distributed Energy Resources", *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, 35(4): e3000, 2022. https://doi.org/10.1002/jnm.3000

[20] Tan, Z., Zeng, M. and Sun, L. "Optimal Placement and Sizing of Distributed Generators Based on Swarm Moth Flame Optimization", *Frontiers in Energy Research*, 9: 676305, 2021. https://doi.org/10.3389/fenrg.2021.676305

[21] Roy, K., Srivastava, L. and Dixit, S. "Optimal Placement and Sizing of Distributed Generation Using Multi-verse Optimization", *12th International Conference on*

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license.
https://doi.org/10.4314/njt.v44i2.11
http://creativecommons.org/licenses/by-nc-nd/4.0/

Computational Intelligence and Communication Networks (CICN), IEEE, 2020, pp. 268–272. https://doi.org/10.1109/CICN49253.2020.9242614

[22] Prakash, P., Meena, D. C., Malik, H., Alotaibi, M. A. and Khan, I. A. "A Novel Analytical Approach for Optimal Integration of Renewable Energy Sources in Distribution Systems", *Energies*, 15(4): 1341, 2022. https://doi.org/10.3390/en15041341

[23] Wankhede, S. K., Paliwal, P. and Kirar, M. K. "DG Optimal Placement and Sizing Considering Active Power Losses and Voltage Profile Factor", *Recent Advances in Power Systems: Select Proceedings of EPREC-2021*, Springer Nature Singapore, 2022, pp. 659–667. https://doi.org/10.1007/978-981-16-6970-5_48

[24] Nageswari, D., Kalaiarasi, N. and Geethamahalakshmi, G. "Optimal Placement and Sizing of Distributed Generation Using Metaheuristic Algorithm", *Computer Systems Science and Engineering*, 41(2): pp. 493–509, 2022. https://doi.org/10.32604/csse.2022.020539

[25] Radosavljević, J., Arsić, N., Milovanović, M. and Ktena, A. "Optimal Placement and Sizing of Renewable Distributed Generation Using Hybrid Metaheuristic Algorithm", *Journal of Modern Power Systems and Clean Energy*, 8(3): pp. 499–510, 2020. https://doi.org/10.35833/MPCE.2019.000259

[26] Bairwa, A. K., Joshi, S. and Singh, D. "Dingo Optimizer: A Nature-Inspired Metaheuristic Approach for Engineering Problems", *Mathematical Problems in Engineering*, 2021: pp. 1–12, 2021. https://doi.org/10.1155/2021/2571863

[27] Ayanlade, S. O., Jimoh, A., Ogunwole, E. I., Aremu, A., Jimoh, A. B. and Owolabi, D. E. "Simutaneous Network Reconfiguration and Capacitor Allocations Using a Novel Dingo Optimization Algorithm", *International Journal of Electrical and Computer Engineering*, 13: pp. 2384–2395, 2023. https://doi.org/10.11591/ijece.v13i3.pp2384-2395

© 2025 by the author(s). Licensee NIJOTECH.
This article is open access under the CC BY-NC-ND license. http://creativecommons.org/licenses/by-nc-nd/4.0/