JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(3), SEPTEMBER, 2026
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com



A Comprehensive Review on Artificial Intelligence-Based Techniques for Performance Enhancement in 11kV Distribution Network

Ogbeche Lawrence Ogbudu, Nseobong Ibanga Okpura, Kufre Michael Udofia
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo

ABSTRACT

The use of Artificial Intelligence in distribution network is instrumental in mitigating power quality degradation due to non-linear loads, and providing optimal integration of renewable energy sources and compensation devices. This study reviews the recent techniques that have been applied to improve the performance in distribution networks, through the use of artificial intelligence and categorized into four areas. The articles were retrieved from IEEE Xplore, ScienceDirect, and Google Scholar and the published papers were from 2020 to 2026. Findings from the study show that hybridized metaheuristic and AI based methods consistently outperform conventional methods and single-algorithm methods in all four themes, with better power loss reduction, voltage profile improvement, fault detection accuracy, and forecasting precision. However, numerous limitations, such as the non-inclusion of battery energy storage systems (BESS) in optimization models, as well as the computational expense of performance and accuracy of the optimization. Furthermore, the majority of studies are based on standard IEEE test systems and not real distribution networks, which might not be generalized, and there is no study that combines placement, reconfiguration, fault detection and forecasting in a single unified AI framework. The study suggests future research to include BESS in system design, test optimized systems on actual distribution networks, build comprehensive AI models that can simultaneously tackle multiple performance metrics, and consider the uncertainty of load and renewable energy.

ARTICLE INFO
Article History
Received: May, 2026
Received in revised form: July, 2026
Accepted: August, 2026
Published online: September, 2026

KEYWORDS
Distribution Network, Renewable Integration, Artificial Intelligence, Optimization, Hybridisation

INTRODUCTION

The use of artificial intelligence has been instrumental in bringing about power quality improvement in the distribution network [1], [2], [3]. With the advent of modern electrical gadgets which are non-linear loads, causes the quality of power in the network to drop [4], hence necessitating the need for compensation [5], [6]. The use of artificial intelligence techniques have significantly enhanced power quality in the distribution system [7], through the integration of renewable sources as well as distribution static compensators [8]. In order to achieve an optimal design, and placement of these renewable sources and compensators for performance enhancement, it becomes imperative to take advantage of artificial intelligence techniques [9], [10], [11]. The impact artificial intelligence has on planning and operation of distributed energy systems in grids is profound [12] as it has been of great benefit to the power distribution network in tackling issues such as grid congestion [13], forecasting energy availability for renewable energy sources [14], as well as optimal planning of distributed generation (DG) planning [15].

However, with hybridization of artificial intelligence techniques, a more robust network performance can be obtained. This study investigates the recent artificial intelligence-based techniques deployed in the performance

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(3), SEPTEMBER, 2026
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

enhancement of distribution network. The scope of this study covers 4 themes, fist of which is; the use of artificial intelligence in optimal placement and sizing of DG, renewable sources, and compensation devices. The second theme of this study is on network reconfiguration for loss minimization and voltage profile improvement, third is machine learning for fault detection, classification, and localization and the final theme is on machine learning for load forecasting, line-loss estimation, and DG effect prediction.

LITERATURE REVIEW

Metaheuristic-Based Optimal Placement & Sizing of DG, Renewable Sources, and Compensation Devices

The use of renewable energy systems as support to the traditional distribution grid comes with a plethora of advantages [16] such as bringing about a reduction in power losses, stabilising voltage as well as lowering carbon emission, creating a better atmosphere, hence mitigating the negative effects posed by global warming [17]. In the study carried out by [18], the optimal placement and sizing of PV sources in distribution grids using a modified gradient-based metaheuristic optimizer was researched. The methodological approach by [18] employed the use of a modified gradient-based metaheuristic optimizer (MGbMO) by utilising master–slave to improve the capability of the MGbMO.

The optimal placement and sizing of the PV sources as well as energy purchasing costs when tested on the IEEE 34-bus shows a greater efficiency when benchmarked with other metaheuristic algorithms such as Newton metaheuristic algorithm, Chu and Beasley genetic algorithm, as well as the GbMO. However, the study by [18] did not factor in battery energy storage system (BESS) in their mathematical formulation as this is very critical for application purposes since the availability of sunshine is stochastic in nature, it becomes imperative that BESS is considered for such optimisation. Similarly, in the study by [19], the optimal placement and sizing of solar PV into distribution system of Nairobi was carried out. The study by [19] implemented a 2-step methodological approach in the optimal placement and sizing of solar PV system.

Firstly, the backward - forward sweep (BFS) algorithm was implemented in order to carryout load flow analysis, so as to identify best fit locations for solar PV installation. The second step involves the implementation of Bacterial Foraging Optimization Algorithm (BFOA) which was used to ascertain the optimal power capacity for the PV unit. The simulation was done in MATLAB and was verified in ETAP environments respectively. The findings from the study shows that optimal placement of 1 PV system can potentially mitigate active and reactive power losses across the local lines as well as improvement of voltage profiles on weak load buses. However, just as in the study by [18], the study by [19] did not also consider battery energy storage as well. Also, the study by [19] utilised a computationally expensive algorithm, that is the BFOA, which is notorious for slow rate of convergence.

In the study by [20], genetic algorithm and particle swarm optimisation were proposed as a potent solution for the mitigation of greenhouse gas emission, as well as providing support to the distribution network through the adoption of renewable energy sources such as solar photovoltaic system and wind turbines respectively. Findings from the study shows that particle swarm optimisation (PSO) outperformed genetic algorithm (GA) following performance metrics such as quality of solution, speed of convergence, and run time.

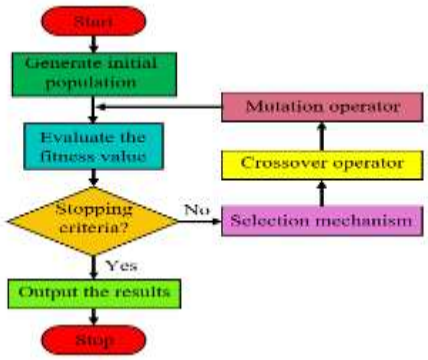


Figure 1. Flowchart of Genetic Algorithm [20]

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(3), SEPTEMBER, 2026
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

However, the use of genetic algorithm is prone to encountering challenges in the proper design of fitness function [21], [22], [23] . In similar vein, the use of PSO is disadvantaged owing to the premature convergence which is an inherent characteristic of the algorithm as well as its inability to deal with high dimensional problems [3], [8], [9], [24]. It becomes imperative for a hybrid of both GA and PSO as seen in **Error! Reference source not found.** and **Error! Reference source not found.** to be formulated in order to create a proper balance between exploration and exploitation, hence creating a hybrid system that outperforms the individual performances of GA and PSO.

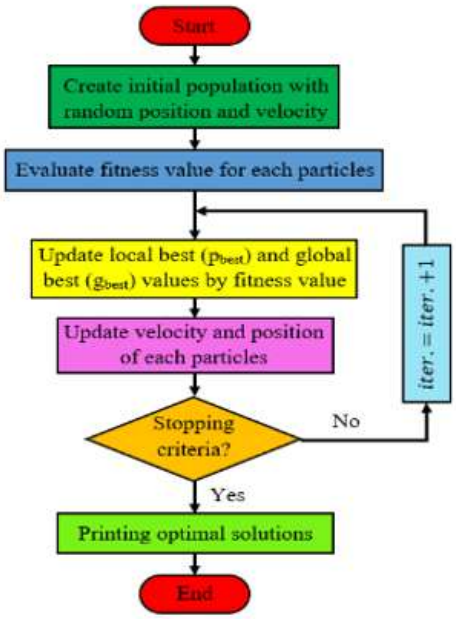


Figure 2. PSO flowchart [20]

Unlike the use of GA and PSO, for optimal distribution generation and placement of renewable energy sources in distribution network for power loss reduction and voltage profile improvement, the study carried out by [25] presents the application of enhanced search group algorithm in order to boost network reliability. The study was benchmarked alongside 4 other algorithms, namely, artificial bee colony (ABC), PSO, GA, and search group algorithm (SGA) as shown in the convergence results in **Error! Reference source not found.**.

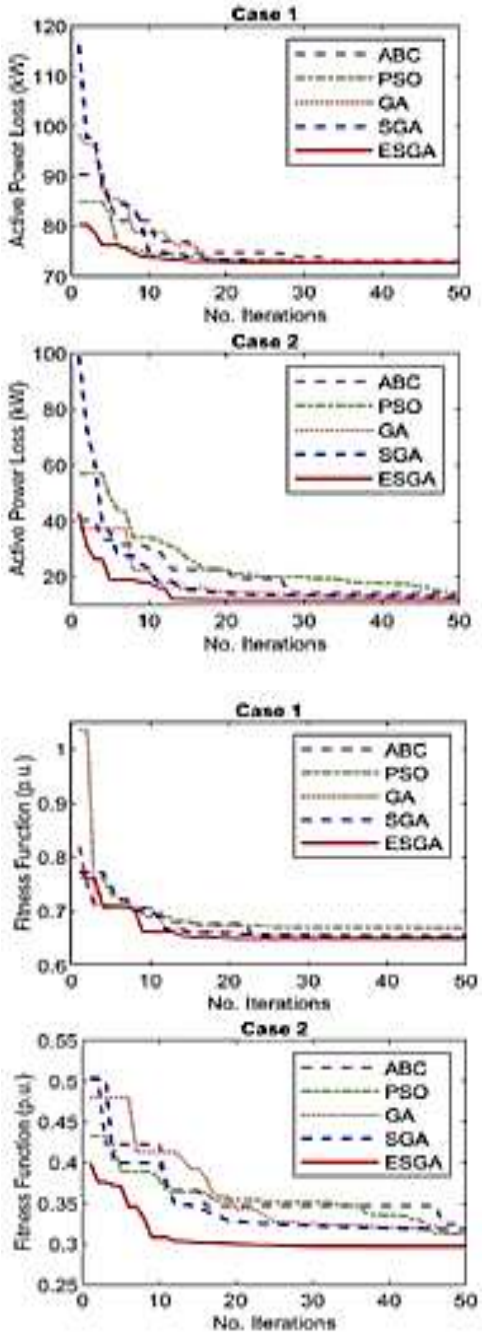


Figure 3. Benchmark convergence performance of ESGA [25]

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(3), SEPTEMBER, 2026
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

The ESGA performed better when compared to the other 4 methods when it comes to the quality of solution, degree of accuracy, and speed of convergence, most especially for larger networks, hence making the ESGA a highly useful technique for renewable energy integration for radial distribution network. In similar study by [26], here both the distributed generation and capacitors were introduced into the distribution network for optimal placement. The PSO algorithm outperformed Artificial Bee Colony (ABC), Stochastic Fractal Search (SFS), and Dragonfly (DF).

Although, the study by [27] shows the incremental improvement in the voltage profile through the use of PSO algorithm, however [28] posits that the artificial gorilla troops optimizer (AGTO) is best suited for biomass-based distributed generation applications for performance enhancement in radial distribution networks. Modern power systems have seen the introduction of battery energy storage systems (BESS) over the years [23], the Multiobjective Ant Lion Optimization (MALO) was utilised by [29] and appears to outperform other metaheuristic algorithm, namely; teaching learning-based optimization (TLBO), genetic algorithm (GA), particle swarm optimisation (PSO), Taguchi method (TM), and multiobjective Taguchi approach (MOTA) respectively as shown in **Error! Reference source not found.**.

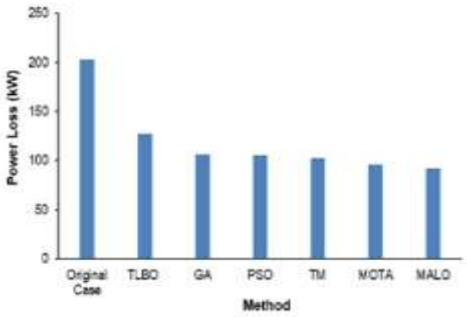


Figure 5. Optimisation result comparison of MALO on IEEE-33 bus

The study carried out by [30] presents an improved lighting search algorithm for the proper installation of distribution static compensator (DSTATCOM) and solar PV array in distribution systems. When benchmarked with other algorithms, the ILSA outperformed the Genetic Algorithm, Harmony Search Algorithm (HAS), Fire Works Algorithm (FWA), and Comprehensive Teaching Learning Harmony Search Optimization (CTLHSO) Algorithm.

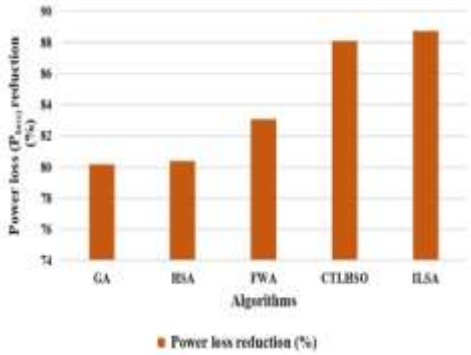


Figure 4. Power loss reduction comparison of ILSA and other algorithms [30]

In order to address the load shedding menace that is prevalent amongst distribution networks, [31] proposes chaotic slime mould optimization algorithm (CSMA), furthermore, [3] stresses on the need for the reduction of harmonics in the network through the use of a hybrid controller, which is based on the soccer league algorithm, and trained by an artificial neural network controller (S-ANNC), for deployment in the shunt active power filter.

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

Table 1. Summary on Metaheuristic-Based techniques

Ref.	Author(s) & Year	AI/Optimization Technique	Application Focus	Key Finding	Gap / Limitation Identified
[18]	Montoya, Grisales-Noreña & Giral-Ramírez (2022)	Modified Gradient-Based Metaheuristic Optimizer (MGbMO), master–slave scheme	Optimal placement and sizing of PV sources in distribution grids	Outperformed Newton metaheuristic, Chu & Beasley GA, and standard GbMO on the IEEE 34-bus system	Did not incorporate battery energy storage system (BESS) despite the stochastic nature of solar irradiance
[19]	Fokui, Saulo & Ngoo	Backward-Forward Sweep (BFS) load flow and Bacterial Foraging Optimization Algorithm (BFOA)	Optimal placement and sizing of PV in the Nairobi (Embakasi) distribution network	Reduced active/reactive power losses and improved voltage profile on weak load buses	No BESS considered; BFOA suffers from a slow rate of convergence
[20]	Purlu & Turkay (2022)	Genetic Algorithm (GA) vs. Particle Swarm Optimization (PSO)	Renewable DG (solar PV, wind) allocation for loss and emission reduction	PSO outperformed GA in solution quality, convergence speed, and run time	GA is prone to poor fitness-function design; PSO suffers premature convergence and struggles with high-dimensional problems
[25]	Huy, Vo, Truong & Van Tran (2023)	Enhanced Search Group Algorithm (ESGA)	DG placement for power loss reduction and voltage profile improvement	Outperformed ABC, PSO, GA, and SGA in solution quality, accuracy, and convergence speed, especially on larger networks	Not stated
[26]	Samyeli, Dogan & Alci	Particle Swarm Optimization (PSO)	Simultaneous DG and capacitor placement	PSO outperformed Artificial Bee Colony, Stochastic Fractal Search, and Dragonfly algorithms	Constant injected power was assumed

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



Ref.	Author(s) & Year	AI/Optimization Technique	Application Focus	Key Finding	Gap / Limitation Identified
[27]	Jumaa, Neda & Mhawesh (2021)	Particle Swarm Optimization (PSO)	Optimal DG placement for active radial distribution systems	Achieved incremental improvement in voltage profile	Only PSO was used
[28]	Roy, Bansal & Bansal (2025)	Artificial Gorilla Troops Optimizer (AGTO)	Biomass-based DG allocation	Identified as best suited for performance enhancement in radial distribution networks	Absence of BESS integration
[29]	Soesanti & Syahputra (2022)	Multiobjective Ant Lion Optimization (MALO)	BESS-integrated distribution network performance improvement	Outperformed TLBO, GA, PSO, Taguchi Method, and Multiobjective Taguchi Approach on the IEEE-33 bus system	MALO is prone to converging at local minima.
[30]	Isha & Jagatheeswari (2021)	Improved Lightning Search Algorithm (ILSA)	Optimal siting of DSTATCOM and solar PV array	Outperformed GA, Harmony Search, Fire Works Algorithm, and CTLHSO in power loss reduction	PV intermittency was not factored in.
[31]	Abid, Apon, Ahmed & Morshed (2022)	Chaotic Slime Mould Algorithm (CSMA)	Optimal load-shedding in distribution systems	Proposed as a solution to the load-shedding problem prevalent in distribution networks	High computational time
[3]	Srilakshmi, Sujatha, Balachandran, Mihet-Popa & Kumar (2022)	Hybrid soccer-league-trained Artificial Neural Network Controller (S-ANNC)	Harmonic reduction via a shunt active power filter	Proposed for harmonic mitigation in three-phase distribution networks	Paper lacks detailed time of execution
Network Reconfiguration for Loss Minimization and Voltage Profile Improvement				One of the ways of boosting distribution system reliability is through network	

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



reconfiguration as this can potentially minimise loss and improve voltage profile [32], [33], [34], [35]. The study by [32] presents a novel quasi-oppositional chaotic neural network algorithm (QOCNNA) for simultaneous network reconfiguration and distributed generations allocation (SNR-DG) in radial distribution networks, while [33] presents the concurrent network reconfiguration as well as placement of switched capacitor banks using modified particle swarm optimization (MPSO) algorithm. However, the firefly algorithm (FA) was utilized by [34] for the purpose of distribution network reconfiguration under environmental uncertainty as it investigates the various annual plans as it relates to seasonal power profiles of DGs and the load to mitigate the combined cost function of
energy loss per year and yearly energy not served, while [35] presents a Binary Dolphin Echolocation Optimization (BDEO) algorithm and has proven to be effective in distribution network reconfiguration.

Table 2. Summary on Network Reconfiguration

Ref.	Author(s) & Year	AI/Optimization Technique	Application Focus	Key Finding	Gap / Limitation Identified
[32]	Tran, Truong, Nguyen, Nguyen, Duong & Vo (2021)	Quasi-Oppositional Chaotic Neural Network Algorithm (QOCNNA)	Simultaneous network reconfiguration and DG allocation (SNR-DG) in radial distribution networks	Presented as a novel approach for combined reconfiguration and DG allocation	Study overlooks dynamics, such as hourly time-series variance of electric vehicle charging demands as well as the intermittency of solar PV and wind generation
[33]	Gebru, Bitew, Aberie & Gizaw (2021)	Modified Particle Swarm Optimization (MPSO)	Concurrent network reconfiguration and switched capacitor bank placement	Proven effective for simultaneous reconfiguration and capacitor placement	Study lacks active distributed generation integration
[34]	Naguib, Omran & Talaat (2022)	Firefly Algorithm (FA)	Network reconfiguration under environmental/seasonal uncertainty	Minimises the combined cost function of annual energy loss and energy not served across seasonal DG/load profiles	Over reliance on static seasonal planning as oppose real-time operation
[35]	Muhammed Neda (2025)	Binary Dolphin Echolocation Optimization (BDEO)	Distribution network reconfiguration	Proven effective for loss minimisation and voltage profile improvement	Reliance on static load modelling

Machine Learning for Fault Detection, Classification, and Localization

Numerous studies have been carried out to gain insights into how machine learning can

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved

be implemented for fault detection, classification and localization [36]. The study by [37] investigates possible ways of addressing high-impedance fault given limited data. The made use of an improved generative adversarial network (IGAN) alongside loss function in order to generate synthetic realistic high-impedance fault dataset, hence making it possible for a super-fast deep classifier. However, the data generated by the IGAN from study lacks interpretability, as such diminishing its credibility and deployment for real-life application. Although, some studies show that Recurrent Neural Network (RNN) performs better when benchmarked against Long ShortTerm Memory (LSTM), Gated Recurrent Unit (GRU), Feed Forward Neural Network (FFNN), and Artificial Neural Network (ANN) for deployment in the detection and classification of faults in electrical secondary distribution [38]. However, study by [39] shows how AI- powered drones can be utilised for early identification of power system distribution assets. In spite of such advancement in the distribution power system, the deployment of such drones in real-life application will be greatly affected due to adverse weather effects from wind, rain or snow.

Table 3. Summary on Fault Detection, Classification, and Localization

Ref.	Author(s) & Year	AI/Optimization Technique	Application Focus	Key Finding	Gap / Limitation Identified
[37]	Guo, Liu, Gao & Chen (2023)	Improved Generative Adversarial Network (IGAN) with a custom loss function	High-impedance fault detection under limited/imbalanced data	Generated synthetic high-impedance fault datasets, enabling a super-fast deep classifier	Synthetic data lacks interpretability, reducing credibility and real-life deployment readiness
[38]	Mnyanghwalo, Kundaeli, Kalinga & Hamisi (2020)	Recurrent Neural Network (RNN), benchmarked vs. LSTM, GRU, FFNN, ANN	Fault detection and classification in electrical secondary distribution networks	RNN performed better than the other benchmarked models	Gradient stability
[39]	Tian, Jia, Guo & Lan (2025)	AI-powered drones	Early identification of power distribution assets/hazards	Enables early identification of distribution assets in the field	Real-life deployment is hindered by adverse weather (wind, rain, snow)

Machine Learning for Load Forecasting, Line-Loss Estimation, and DG Effect Prediction

The data of substation load profile is vital and needed by distribution system operators for effective grid management. However, in developing countries such data are almost none existent. The study by [40] presents a geographic information system (GIS) framework for load assessment in order to boost reliability in the distribution network. In the study carried out by [40], the approach appears promising especially in areas were sensors are not yet deployed for real-time data gathering. In the research carried out by [22] which was done in the bid to avert the complexity in ascertaining the values of line losses in the distribution system as this process is computationally expensive. Here, genetic algorithm as well as artificial neural network were

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



adopted using MATLAB software. The study by [41] presents a proposed hybrid machine learning and deep learning algorithm, utilising Support Vector Machine (SVM) as the primary model and makes use of Random Forest and Radial Neural Networks as classification algorithms for predicting DG position with high level of accuracy. The emerging load prediction approach and distribution generation integration study was done by [42]. In their study, load forecasting was conducted using adaptive neuro-fuzzy inference system (ANFIS) and ANN, after which the performance analysis of the network which is subjected to several load scenarios using PSO in MATLAB environment. However, the study fails to account for the uncertainty in renewable energy sources.

Table 4. Summary on Machine Learning for Load Forecasting, Line-Loss Estimation, and DG Effect Prediction

Ref.	Author(s) & Year	AI/Optimization Technique	Application Focus	Key Finding	Gap / Limitation Identified
[40]	Bosisio, Moncecchi, Morotti & Merlo (2021)	Geographic Information System (GIS)-based machine learning framework	Substation load assessment for grid reliability	Promising approach, particularly in areas lacking real-time sensor deployment	Relies on static geospatial assumptions
[22]	Chen, Deng, Wu, Wen & Liu (2026)	Genetic Algorithm (GA) and Artificial Neural Network (ANN)	Line-loss estimation in distribution networks	Simplifies the otherwise computationally expensive process of calculating line losses	Physical constraints are not considered
[41]	Jain & Gupta (2024)	Hybrid Support Vector Machine (primary model) with Random Forest and Radial Neural Network classifiers	DG position prediction	Predicts optimal DG position with a high level of accuracy	Strong reliance on massive data for training
[42]	Teferra (2025)	Adaptive Neuro-Fuzzy Inference System (ANFIS) and ANN, with PSO-based performance analysis	Load forecasting and DG integration performance evaluation	Combines load forecasting with PSO-based performance analysis under multiple load scenarios in MATLAB	Does not account for uncertainty in renewable energy sources

METHODS

The comprehensive review was carried out by utilising articles from reputable journals. In order to ensure that the state of the art on artificial intelligence-based techniques for performance enhancement in distribution network was well captured, 3 databases were searched, namely, IEEE Xplore, ScienceDirect and Google Scholar, covering all research articles published from 2020 – 2026.

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



RESULTS AND DISCUSSION

In all the 4 themes discussed in this study, the artificial intelligence and metaheuristic techniques are seen to have outperformed the conventional and single algorithm techniques [20], [25], [38]. This makes the artificial intelligence the go-to approach for performance enhancement in distribution network. Furthermore, hybridisation has proven to produce a much better robust performance outcome as seen in the study, since it combines the strength and weaknesses of individual algorithm. However, certain limitations are observed across numerous literature in this review such as the omission of the use of battery energy storage system (BESS) [18], [19], [26] which is a key factor in renewable energy integration, since renewable energy sources such as wind and solar are stochastic in nature, hence necessitating the need for a more realistic mathematical model which can be utilised for real-life application. Another limitation in the study is that of the trade-offs between cost of computation verses accuracy in the results [19], [30].

Where backward-forward sweep alongside Foraging Optimization Algorithm (BFOA) was used to reduce active and reactive power losses as improving voltage profile on weak load buses. Although this method yielded high degree of accuracy, but the computation is extensive making it not suitable for real-time network control. Another limitation from the use of metaheuristic in the performance enhancement of the distribution network is that of premature convergence as seen PSO [20], [24], and MALO [29]. However, as earlier stated, hybridisation of 2 or more metaheuristic algorithms can avert such an issue. Adoption for real-world deplorability is further mitigated due to data dependency for most machine learning techniques [32], [34], [35], [37], [39], [41], where obtaining such data in developing countries is almost impossible due to the backwardness in terms of technological advancements, hence making it pertinent for the use of physics informed machine learning, which utilises laws of physics and limited data.

In most of the studies, validation was done using the IEEE 33 and 34-bus, this to a large extent does not portray the behaviour of most distribution network as the performance of most techniques could turn out bad when tested on different topology and loading conditions respectively, hence limiting the generalisability of such techniques. None of the existing studies was able to combine placement, reconfiguration, fault detection, and forecasting of the distribution network into 1 A.I framework for a more computationally efficient approach.

CONCLUSION AND RECOMMENDATION

This study reviewed the various artificial intelligence-based techniques for performance enhancement in distribution network. Findings from the study shows that hybridized metaheuristic and artificial intelligence-based techniques outperformed conventional methods in terms of loss reduction in power, improvement of voltage profile, fault detection accuracy, and forecasting. However, most of the studies only implemented and validated these metaheuristic and artificial intelligence-based techniques on standard IEEE test systems as oppose to actual distribution networks.

Future study should incorporate BESS in the system design as well as testing of the optimized system on a real distribution network. Also, further study should develop an A.I model that would together handle placement optimization, reconfiguration, fault detection, and forecasting. Lastly, since renewables are brought into the mix, future study should address load and renewable energy uncertainty.

REFERENCES

[1] A. U. Rehman, M. Ali, S. Iqbal, A. Shafiq, N. Ullah, and S. A. Otaibi, "Artificial Intelligence-Based Control and Coordination of Multiple PV Inverters for Reactive Power/Voltage Control of Power Distribution Networks," *Energies*, vol. 15, no. 17, p. 6297, Aug. 2022, doi: 10.3390/en15176297.

[2] A. R. Singh *et al.*, "AI-enhanced power quality management in distribution systems: implementing a dual-phase UPQC control with adaptive neural networks and optimized PI controllers," *Artif. Intell. Rev.*, vol. 57, no.

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



11, p. 311, Sep. 2024, doi: 10.1007/s10462-024-10959-0.

[3] K. Srilakshmi, C. N. Sujatha, P. K. Balachandran, L. Mihet-Popa, and N. U. Kumar, "Optimal Design of an Artificial Intelligence Controller for Solar-Battery Integrated UPQC in Three Phase Distribution Networks," *Sustainability*, vol. 14, no. 21, p. 13992, Oct. 2022, doi: 10.3390/su142113992.

[4] I. K. Saeed and K. Sheikhyounis, "Power quality improvement of distribution systems asymmetry caused by power disturbances based on particle swarm optimization-artificial neural network," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 25, no. 2, p. 666, Feb. 2022, doi: 10.11591/ijeecs.v25.i2.pp666-679.

[5] K. Okpara Uwho, H. Nyebuchi Amadi, and O. Chikezie, "IMPLEMENTING ARTIFICIAL NEURAL NETWORK BASED DVR TO IMPROVE POWER QUALITY OF RUMUOLA-RUMUOMOI 11kV DISTRIBUTION NETWORK," *J. Res. Eng. Appl. Sci.*, vol. 7, no. 4, pp. 404–419, Mar. 2023, doi: 10.46565/jreas.202274404-419.

[6] D. B. Sapkota, P. Neupane, K. Pokharel, and S. Khan, "An artificial neural network based approach for harmonic component prediction in a distribution line," *Energy Rep.*, vol. 12, pp. 3861–3873, Dec. 2024, doi: 10.1016/j.egyr.2024.09.060.

[7] G. Pandu Ranga Reddy, G. Harshitha, P. Lakshmi Priya, J. V. N. S. Roshini, and M. Harshiya, "Enhancement of Power Quality in Grid-Connected Distribution Systems Employing AI-Based Controllers," *E3S Web Conf.*, vol. 540, p. 10015, 2024, doi: 10.1051/e3sconf/202454010015.

[8] Y. Kachaou, M. Bidi, and I. Aloui, "Simultaneous integration of photovoltaic distributed generation and distribution static compensators for technical performance enhancement in distribution networks using PSO with velocity pausing and adaptive strategy," *J. Energy Syst.*, vol. 9, no. 4, pp. 380–404, Dec. 2025, doi: 10.30521/jes.1756747.

[9] X. Liu, P. Zhao, H. Qu, N. Liu, K. Zhao, and C. Xiao, "Optimal Placement and Sizing of Distributed PV-Storage in Distribution Networks Using Cluster-Based Partitioning," *Processes*, vol. 13, no. 6, p. 1765, Jun. 2025, doi: 10.3390/pr13061765.

[10] M. P. Bakht, M. N. H. Mohd, U. U. Sheikh, and N. Khan, "Optimal Design and Performance Analysis of Hybrid Renewable Energy System for Ensuring Uninterrupted Power Supply During Load Shedding," *IEEE Access*, vol. 12, pp. 5792–5813, 2024, doi: 10.1109/ACCESS.2024.3349594.

[11] D. S. Cruz-Garzón, H. D. Sanchez-Celis, O. D. Montoya, and D. S. Guzmán-Romero, "Optimal Placement and Sizing of PV-STATCOMs in Distribution Systems for Dynamic Active and Reactive Compensation Using Crow Search Algorithm," *Eng*, vol. 7, no. 3, p. 110, Mar. 2026, doi: 10.3390/eng7030110.

[12] P. Arévalo and F. Jurado, "Impact of Artificial Intelligence on the Planning and Operation of Distributed Energy Systems in Smart Grids," *Energies*, vol. 17, no. 17, p. 4501, Sep. 2024, doi: 10.3390/en17174501.

[13] H. Iqbal, A. Stevenson, and A. I. Sarwat, "Impact Analysis and Optimal Placement of Distributed Energy Resources in Diverse Distribution Systems for Grid Congestion Mitigation and Performance Enhancement," *Electronics*, vol. 14, no. 10, p. 1998, May 2025, doi: 10.3390/electronics14101998.

[14] A. M. A. El Hamid, H. H. Elzohri, and K. Sayed, "Integrated machine learning forecasting and grey wolf optimization for optimal operation of virtual power plants in smart distribution networks," *Sci. Rep.*, vol. 16, no. 1, p. 24535, Aug. 2026, doi: 10.1038/s41598-026-65123-1.

[15] P. Li, Y. Shen, Y. Shang, and M. Alhazmi, "Innovative distribution network design using GAN-based distributionally robust optimization for DG planning," *IET Gener. Transm. Distrib.*, vol. 19, no. 1, p. e13350, Jan. 2025, doi: 10.1049/gtd2.13350.

[16] S. Ahmad and A. U. Asar, "Reliability Enhancement of Electric Distribution Network

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



Using Optimal Placement of Distributed Generation," *Sustainability*, vol. 13, no. 20, p. 11407, Oct. 2021, doi: 10.3390/su132011407.

[17] A. Kumar, R. Verma, N. K. Choudhary, and N. Singh, "'Optimal placement and sizing of distributed generation in power distribution system: a comprehensive review,'" *Energy Sources Part Recovery Util. Environ. Eff.*, vol. 45, no. 3, pp. 7160–7185, Aug. 2023, doi: 10.1080/15567036.2023.2216167.

[18] O. D. Montoya, L. F. Grisales-Noreña, and D. A. Giral-Ramírez, "Optimal Placement and Sizing of PV Sources in Distribution Grids Using a Modified Gradient-Based Metaheuristic Optimizer," *Sustainability*, vol. 14, no. 6, p. 3318, Mar. 2022, doi: 10.3390/su14063318.

[19] W. S. T. Fokui, M. Saulo, and L. Ngoo, "Optimal Placement and Sizing of a Photovoltaic System into Nairobi Distribution Network: Case of Embakasi," in *Proceedings of the Sustainable Research and Innovation Conference*, pp. 27–32.

[20] M. Purlu and B. E. Turkay, "Optimal Allocation of Renewable Distributed Generations Using Heuristic Methods to Minimize Annual Energy Losses and Voltage Deviation Index," *IEEE Access*, vol. 10, pp. 21455–21474, 2022, doi: 10.1109/ACCESS.2022.3153042.

[21] E. A. Almabsout, R. A. El-Sehiemy, O. N. U. An, and O. Bayat, "A Hybrid Local Search-Genetic Algorithm for Simultaneous Placement of DG Units and Shunt Capacitors in Radial Distribution Systems," *IEEE Access*, vol. 8, pp. 54465–54481, 2020, doi: 10.1109/ACCESS.2020.2981406.

[22] T. Chen, T. Deng, J. Wu, M. Wen, and C. Liu, "Adaptive Calculation Method of Line Loss of Distribution Network Based on Genetic Algorithm and Artificial Neural Network," *Eng. Rep.*, vol. 8, no. 4, p. e70678, Apr. 2026, doi: 10.1002/eng2.70678.

[23] S. Khunkitti, P. Boonluk, and A. Siritaratiwat, "Optimal Location and Sizing of BESS for Performance Improvement of Distribution Systems with High DG Penetration," *Int. Trans. Electr. Energy Syst.*, vol. 2022, pp. 1–16, Jun. 2022, doi: 10.1155/2022/6361243.

[24] N. Pompern, S. Premrudeepreechacharn, A. Siritaratiwat, and S. Khunkitti, "Optimal Placement and Capacity of Battery Energy Storage System in Distribution Networks Integrated With PV and EVs Using Metaheuristic Algorithms," *IEEE Access*, vol. 11, pp. 68379–68394, 2023, doi: 10.1109/ACCESS.2023.3291590.

[25] T. H. B. Huy, D. N. Vo, K. H. Truong, and T. Van Tran, "Optimal Distributed Generation Placement in Radial Distribution Networks Using Enhanced Search Group Algorithm," *IEEE Access*, vol. 11, pp. 103288–103305, 2023, doi: 10.1109/ACCESS.2023.3316725.

[26] S. Samyeli, A. Dogan, and M. Alci, "Assessment and Optimization of Distributed Generationand Capacitor Allocation in Distribution Systems Using Artificial Intelligence Approaches".

[27] F. A. Jumaa, O. M. Neda, and M. A. Mhawesh, "Optimal distributed generation placement using artificial intelligence for improving active radial distribution system," *Bull. Electr. Eng. Inform.*, vol. 10, no. 5, pp. 2345–2354, Oct. 2021, doi: 10.11591/eei.v10i5.2949.

[28] K. Roy, S. K. Bansal, and R. C. Bansal, "Performance enhancement of radial distribution system with optimal DG allocation," *Int. J. Model. Simul.*, vol. 45, no. 1, pp. 245–263, Jan. 2025, doi: 10.1080/02286203.2023.2196657.

[29] I. Soesanti and R. Syahputra, "Multiobjective Ant Lion Optimization for Performance Improvement of Modern Distribution Network," *IEEE Access*, vol. 10, pp. 12753–12773, 2022, doi: 10.1109/ACCESS.2022.3147366.

[30] G. Isha and P. Jagatheeswari, "An Improved Lightning Search Algorithm Employed Performance Enhancement in Distribution System," *Int. J. Comput. Intell. Syst.*, vol. 14, no. 1, p. 196, Dec. 2021, doi: 10.1007/s44196-021-00045-6.

[31] Md. S. Abid, H. J. Apon, A. Ahmed, and K. A. Morshed, "Chaotic slime mould optimization

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved



algorithm for optimal load-shedding in distribution system," *Ain Shams Eng. J.*, vol. 13, no. 4, p. 101659, Jun. 2022, doi: 10.1016/j.asej.2021.101659.

[32] T. V. Tran, B.-H. Truong, T. P. Nguyen, T. A. Nguyen, T. L. Duong, and D. N. Vo, "Reconfiguration of Distribution Networks With Distributed Generations Using an Improved Neural Network Algorithm," *IEEE Access*, vol. 9, pp. 165618–165647, 2021, doi: 10.1109/ACCESS.2021.3134872.

[33] Y. Gebru, D. Bitew, H. Aberie, and K. Gizaw, "Performance enhancement of radial distribution system using simultaneous network reconfiguration and switched capacitor bank placement," *Cogent Eng.*, vol. 8, no. 1, p. 1897929, Jan. 2021, doi: 10.1080/23311916.2021.1897929.

[34] M. Naguib, W. A. Omran, and H. E. A. Talaat, "Performance Enhancement of Distribution Systems via Distribution Network Reconfiguration and Distributed Generator Allocation Considering Uncertain Environment," *J. Mod. Power Syst. Clean Energy*, vol. 10, no. 3, pp. 647–655, 2022, doi: 10.35833/MPCE.2020.000333.

[35] O. Muhammed Neda, "OPTIMAL DISTRIBUTION NETWORK RECONFIGURATION FOR LOSS MINIMIZATION AND VOLTAGE PROFILE IMPROVEMENT BASED ON ARTIFICIAL INTELLIGENCE," *Kufa J. Eng.*, vol. 16, no. 2, pp. 263–279, Apr. 2025, doi: 10.30572/2018/KJE/160216.

[36] J. Wang *et al.*, "Smart Fault Detection, Classification, and Localization in Distribution Networks: AI-Driven Approaches and Emerging Technologies," *IEEE Access*, vol. 13, pp. 141664–141693, 2025, doi: 10.1109/ACCESS.2025.3596791.

[37] M.-F. Guo, W.-L. Liu, J.-H. Gao, and D.-Y. Chen, "A Data-Enhanced High Impedance Fault Detection Method Under Imbalanced Sample Scenarios in Distribution Networks," *IEEE Trans. Ind. Appl.*, pp. 1–14, 2023, doi: 10.1109/TIA.2023.3256975.

[38] D. Mnyanghwalo, H. Kundaeli, E. Kalinga, and N. Hamisi, "Deep learning approaches for fault detection and classifications in the electrical secondary distribution network: Methods comparison and recurrent neural network accuracy comparison," *Cogent Eng.*, vol. 7, no. 1, p. 1857500, Jan. 2020, doi: 10.1080/23311916.2020.1857500.

[39] H. Tian, C. Jia, Y. Guo, and P. Lan, "Dynamic identification method and engineering verification of power distribution network hazard AI," in *International Conference on Automation and Intelligent Technology (ICAIT 2025)*, J. Zhou and M. Khoo Boon Chong, Eds., Wuhan, China: SPIE, Sep. 2025, p. 20. doi: 10.1117/12.3083620.

[40] A. Bosisio, M. Moncecchi, A. Morotti, and M. Merlo, "Machine Learning and GIS Approach for Electrical Load Assessment to Increase Distribution Networks Resilience," *Energies*, vol. 14, no. 14, p. 4133, Jul. 2021, doi: 10.3390/en14144133.

[41] A. Jain and S. C. Gupta, "Optimal placement of distributed generation in power distribution system and evaluating the losses and voltage using machine learning algorithms," *Front. Energy Res.*, vol. 12, p. 1378242, Apr. 2024, doi: 10.3389/fenrg.2024.1378242.

[42] D. M. Teferra, "Performance Evaluation of a Radial Distribution Network Under Emerging Load Prediction Modeling Approach and DG Integration Using a Particle Swarm Optimization Algorithm," *J. Electr. Comput. Eng.*, vol. 2025, no. 1, p. 1352068, Jan. 2025, doi: 10.1155/jece/1352068.

Corresponding author: Ogbeche Lawrence Ogbudu
ogbechelaw@gmail.com
Department of Electrical/Electronics Engineering, Faculty of Engineering, University of Uyo.
© 2026. Faculty of Technology Education. ATBU Bauchi. All rights reserved