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Techniques Applied to Radial Distribution System for Enhancing System Performance: A Review

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Abstract

Ensuring the dependability of electrical systems remains a pivotal operational imperative for distribution entities. In tandem, a pronounced emphasis is directed toward the mitigation of power losses within the distribution network. The central aim of this study is to find out how to enhance system performance by enhancing our comprehension of prevailing methodologies utilized to elevate reliability, curtail power losses, enhance voltage profiles, and amplify power output within distribution networks. The present work encompasses a comprehensive review of established strategies employed to address these challenges. Within this framework, certain areas of research deficiency are highlighted, accompanied by corresponding suggestions aimed at broadening the horizons of inquiry within this domain

Keywords: *Radial distribution network, system performance, electrical systems, system stability, power loss, voltage profile.*

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1. Introduction

Energy stands as an indispensable cornerstone of modern existence. The rapid progress of nations hinges upon their capacity to fulfill burgeoning energy needs, driven by the expanding realms of industry, commerce, and society. The question of energy resource availability looms large, posing a collective concern. The efficient, cost-effective, and reliable provision of power remains a formidable challenge. Yet, the surge in reactive power requirements at load endpoints begets elevated currents coursing through distribution lines, culminating in suboptimal power factors, heightened energy losses, and diminished nodal voltages. These intricacies present tangible quandaries in distribution systems, attributed to factors such as augmented R/X ratios, burgeoning loads, and the prevalence of inductive loads. Consequently, the pursuit of power loss reduction emerges as an imperative and pivotal theme within the realm of power system research (Elseify et al., 2023).

Distribution networks hold a pivotal role in bridging transmission systems and end consumers. As the most conspicuous facet of the power system framework, they are the most exposed to the critical observations of the system consumers. However, these networks confront challenges in the form of voltage drops and power loss. Ideally, power

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losses in an electrical system should hover around 3 to 6%. Also, the issue of voltage drops reverberates through the network, altering its voltage profile holistically. Chief among the causative factors of voltage reduction is the substantial demand for reactive power owing to the prevalence of inductive loads. Approximately 13% of transmitted power dissipates as active losses, underscoring the imperatives of refining bus voltage profiles and augmenting system efficiency (Romeh et al., 2023).

Historically, power grid tribulations were largely attributed to transmission lines until the turn of the century. However, the paradigm has been shifted with the advent of decentralized electrical networks, significant strides in power energy storage, and a plethora of diverse electrical requisites placed on power systems. This shift spurred a transition from transmission to distribution lines, aimed at alleviating power system quandaries (Huy et al., 2022). The secure administration of power distribution systems is geared toward an array of goals, encompassing the enhancement of power quality and reliability, alleviation of overloads, assurance of voltage stability, and equitable load balancing. Another key objective involves the attenuation of active power losses within distribution networks. The bedrock of power system reliability lies in the uninterrupted and consistently high-quality supply of electrical power to consumers (Shaheen et al. 2023).

2. Radial distribution system enhancing techniques

Several techniques have been harnessed to address these challenges, encompassing network reconfiguration, optimal placement of capacitors, integration of distributed generation, grid reconfiguration through renewable energy resources, judicious allocation of Flexible Alternating Current Transmission System (FACTS) devices, and optimal placement of fuel cells.

2.1. Distributed Generation (DG)

Distributed generation, often abbreviated as DG, serves as a cornerstone in distribution systems, representing an electrical power source intricately linked to the distribution network. DG entails small-scale electric power generation proximate to the load side, typically ranging from 1 kW to 50 MW (Romeh et al., 2023). Optimal Placement and Size of DG units contribute to loss reduction by supplying both active and reactive power to loads, thereby mitigating current from the source (Ahmad, Ali, and Kazmi, 2023). The strategic sitting of DG sources at select system nodes has the potential to curtail line losses, all while being economical (Choudhary, Lodhi, and Nema, 2018). The strategic integration of DGs within distribution networks holds a multitude of issues, including power loss reduction, augmentation of voltage profiles, demand reduction, on-peak operation cost minimization, elevated security and reliability, diminished greenhouse gas emissions, and grid integrity. This placement is primarily anchored near customer loads to attenuate losses and enhance bus voltages (Alam et al. 2018).

2.2. Network Reconfiguration

Network reconfiguration, a method well entrenched in practice, facilitates the redistribution of load from heavily laden feeders to less burdened counterparts while upholding cost-effectiveness. This practice entails altering the opened or closed status of sectionalizing and tying switches within the distribution system, thereby altering the network's topology. Network reconfiguration stands as an instrumental approach to enhancing system performance, which is realized through the fulfillment of diverse objectives and constraints (Ahmad, Ali, and Kazmi, 2023). Paramount among these objectives is the optimization of system topology to minimize active power losses, enhance voltage profiles, fulfill energy demands, and preserve system reliability (Romeh et al., 2023).

2.3. Capacitors

Capacitors emerge as pivotal actors in electrical power systems, effectively serving as voltage boosters. By injecting inductive power, capacitors compensate for the reactive power demand posed by inductive loads. This maneuver curtails current draw to the load, subsequently reducing both power losses and voltage drop. Capacitor incorporation by optimal placement contributes to system performance enhancement and quality improvement (Choudhary, Lodhi, and Nema, 2018). The pivotal concern remains the precise determination of optimal capacitor size and placement to realize targeted objectives.

2.4. Renewable Energy Resources

Renewable energy sources offer the dual advantage of stabilizing voltage and reducing power losses. Solar and wind energy injections can counteract voltage drops and contribute to voltage stability during peak demand periods. The crux of this approach lies in the meticulous sizing and sitting of RESs. Optimal decisions about RES location and magnitude can significantly diminish voltage profile variability and power losses, thus elevating system reliability indices (Alam et al. 2018).

2.5. Flexible Alternating Current Transmission System (FACTS) Devices

For compensating reactive power Flexible Alternating Current Transmission System (FACTS) devices can be used, hinged upon power electronics. These devices orchestrate superior control of alternating current systems, thereby amplifying power system performance. FACTS controllers bridge the chasm between efficient utilization of existing power generation and transmission systems and the prospect of diminished investment, transmission, and generation units. Substantial impact stems from FACTS controllers, which wield influence over parameters like line impedance, voltage profiles, and phase angle differences between buses. These adjustments collectively shape power flow, uphold voltage thresholds, mitigate power losses, and augment power transfer capacity for existing transmission lines. The family of FACTS devices is classified into two generations based on technological nuances. The first generation employs thyristor-switched reactors and capacitors, exemplified by the Static Var Compensator (SVC) and Thyristor-Controlled Series Compensator (TCSC). The second-generation harnesses Voltage Source Converters (VSC) in exemplars such as the Unified Power Flow Controller (UPFC) and the Static Synchronous Compensator (STATCOM). Achieving desired power system enhancements mandates astute consideration of FACTS device placement and size (Onlam et al. 2019).

2.6. Fuel Cells

A rapid evolution unfolds in fuel cell technology, characterized by its high efficiency and reliability, largely attributable to its limited moving parts. The fuel cell's efficacy hinges on its electrolyte composition, prompting categorization based on electrolyte type (Swief, El-Amary, and Kamh, 2022).

. As one of the distributed generation paradigms, fuel cells garner attention due to their merits vis-à-vis conventional resources. These advantages encompass heightened efficiency, augmented reliability, diminished maintenance, exceptional part-load performance, modularity, fuel versatility, and negligible chemical, acoustic, and thermal emissions. Within this context, the judicious placement of distributed generators assumes a pivotal role in elevating voltage profiles and curtailing power losses within distribution networks (Aref et al. 2023). Table 1 shows the advantages and disadvantages of all the last techniques when used for enhancing system performance.

TABLE 1. Advantages and Disadvantages of Different Techniques

Technique	Advantages	Disadvantages
Distributed Generation (DG)	A good monitoring of DG electricity prices can lead to massive price reductions. The DG can be a means of voltage regulation in buses that lie in the distribution level. The reliability of the system is increased, this comes from the fact of having multiple sources in the network (Sa'ed et al. 2019).	Grid operators will request money in exchange for the interconnection action. Apparatus and maintenance fees are required. The addition of control, metering, and protection devices are essential to separate the DG system from the grid; this is very critical to ensure that the complexity of the system does not reflect terribly on the operation of the overall system. Problems that occur far from the DG units can still harm them. More complex and numerous protective devices must be installed to avoid critical situations (Sa'ed et al. 2019).
Network Reconfiguration	Cause optimal network operation. Offering far more efficient. Effectively reduce the network losses. Improve node voltage levels. Balance loads (Diaaeldin et al. 2019).	Cause lack of collaboration between strategies. May lead to sub-optimal overall performance. Cause an inability to model the correlation between the benefits of each strategy (Diaaeldin et al. 2019).
Capacitors	Increase network energy efficiency. Improve power quality. Maximize the long-term return on investment as the network develops. Increase the percentage of energy delivered to consumers (Ivanov et al. 2019).	It is only capable of being applied in small-scale networks. It may not be utilized in the applications of high voltage (Nguyen et al. 2020).
Renewable Energy Resources	Increase demand for power delivery. More secure energy future. Reduce CO2 and greenhouse gas emissions. Increase system reliability.	Cause reverse energy flow from the customer end back into the transmission system. Negligible or reduced reactive power contribution (Loji et al. 2023).

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Technique	Advantages	Disadvantages
	Evidenced substantial technical, environmental, and economic benefits (Loji et al. 2023).	
Flexible Alternating Current Transmission System (FACTS) Devices	Increase system safety. Improve reliability and stability. Improve the efficiency of power systems. Meet the growing electricity demand sustainably and cost-effectively. Improving transient stability in power networks due to their dynamic characteristics. Minimizing or eliminating line overloads. Reducing network congestion management and improving transient stability in power networks due to their dynamic characteristics (Marouani et al. 2023).	The cost of FACTS controllers is also huge. The cost wasn't weighed against the expected benefits (Marouani et al. 2023).
Fuel Cells	Zero-emission energy sources. Higher energy conversion efficiency. Lower energy waste. Better fuel utilization (Abokhalil, Alobaid, and Makky, 2023).	It cannot actively control the frequency. High cost. Low performance. Less durability. Fuel cells have a wide range of power outputs starting from a few watts up to several kilowatts (Abokhalil, Alobaid, and Makky, 2023).

3. Literature Review

In this section, we delve into a range of techniques aimed at addressing these challenges. These methodologies encompass the integration of distributed generation, network reconfiguration, optimal capacitor placement, sizing and positioning of renewable energy sources, the strategic installation of flexible alternating current transmission systems (FACTS), and the utilization of fuel cells. The ensuing discussion sheds light on these techniques, their applications, and the strides they make toward resolving pertinent issues.

Distributed generation plays a prominent role in our exploration. In a study (Nguyen et al. 2020), the integration of DG into a passive distribution system was shown to enhance voltage profiles and elevate power output, effectively curbing power losses. Employing a hybrid approach involving Gray Wolf Optimizer (GWO) and Particle Swarm Optimization (PSO), the authors established an optimal DG placement and size, guided by a multi-objective function encompassing active and reactive power loss reduction and voltage profile optimization. Further research, such as (Loji et al. 2023), homes on optimal DG placement to mitigate power losses, bolster voltage profiles, and minimize voltage deviations within radial distribution systems (RDS). Their methodology accommodates various load types, elucidating the impact of DG penetration. Notably, a particle swarm optimization (PSO) technique was harnessed for precise DG location identification at different penetration levels. Other papers enhanced the system by determining the optimal size and position of DG units in the distribution network for minimizing power loss and enhancing voltage stability as in (Marouani et al. 2023), (Abokhalil, Alobaid, and Makky, 2023), and (Shehata et al. 2022).

In the realm of network reconfiguration and DG deployment, an adaptive optimization algorithm, termed the Adaptive Shuffled Frogs Leaping Algorithm (ASFLA), took center stage (Onlam et al. 2019). By minimizing power losses and enhancing voltage stability indices, ASFLA demonstrated remarkable efficacy in optimizing network reconfiguration and DG installation. Parallel investigations, such as (Das, Das, and Patra, 2014)., (Subramanyam, Tulasi, and Subrahmanyam 2016), (Alyu et al. 2023), (Lokesh et al. 2023), (Siregar et al. 2023), and (Khan et al. 2022), have proposed diverse algorithms for optimal DG allocation, attaining improvements across voltage stability, reliability, system performance, voltage profiles, and power loss minimization. In addition, DG was applied to the distribution system with other techniques. In (Haider et al. 2021), the coupling of DG with shunt capacitors (SCs) leveraged multi-objective optimization, encompassing power loss reduction, voltage deviation mitigation, and bolstered voltage stability. Employing techniques like MOLA and MOTEO, the optimal sizing and placement of regenerative SCs and DGs were discerned. In (Haider et al. 2021), DG was applied with capacitor banks for enhancing the performance of the RDS by using a hybrid enhanced grey wolf optimizer and particle swarm optimization (EGWO-PSO) algorithm to find the optimal size and location of DG and capacitor banks in the RDS.

The application of network reconfiguration techniques extended further to (Romeh et al. 2023), where an optimal switching combination facilitated heightened voltage profiles and reduced power losses. The methods' potency was paralleled in (Shaheen et al. 2023), aimed at enhancing electrical system reliability and minimizing power losses, and in (Khasanov, Kamel, and Abdel-Mawgoud, 2019), seeking to pinpoint optimal distribution network configurations for optimized voltage profiles and power loss reduction. References (M'hamdi, Teguar, Tahar, 2020), (Khasanov et al. 2023) showed the advantages of reconfiguration based on optimal power flow mathematical models, harnessing distinct optimization techniques to mitigate losses and amplify voltage profiles. Others applied network reconfiguration techniques for enhancing the performance of the RDS as (Sayed et al. 2022), (Muhammad et al. 2019). (Barnwal, Yadav, Verma, 2022), (Venkatesan et al. 2021), (Acheampong et al. 2023), (Sriram et al. 2023), (Karimulla, Ravi, 2021), (Salau, Gebru, and Bitew 2020), (Swaminathan et al. 2023), (Kandasamy et al. 2022), and (Yan, Zhan, 2023).

Shunt capacitors emerged as pivotal assets within the distribution system. Reference (Swief et al. 2022) spotlighted their role in compensating reactive power and system performance enhancement through a meta-heuristic approach that determines optimal sizing and placement. In addition, for system voltage stability enhancement and power or energy loss reduction, capacitor banks were/are placed in distribution networks as in (Pereira, Barbosa, and Vasconcelos 2021), (Jakus et al. 2020), (Kahouli et al. 2021), (El-Sayed, El-Hameed, and El-Arini, 2019), (Ayalew, Khan, and Alaas, 2022), (Almabsout et al. 2020), (Rodrigues, Araujo, and Penido, 2019), (Babu, 2021), and (Tahir, Rasheed, and Rahmat, 2022). In tandem, (Nguyen et al. 2020), (Salimon et al. 2021), (Bilal et al. 2021), (Pareja, Lezama, and Carmona, 2023), (Biswal et al. 2021), (Mahfoud et al. 2020), (Shaheen and Sehiemy, 2021), (Djidimbélé et al. 2022), (KC and Alkhwaildi, 2021), and (Hraiz et al. 2020) presented varying renewable energy systems, specifically PV and wind, as potent tools to amplify system voltage and attenuate power losses.

Energy storage systems (ESS) also took the limelight in (Ali et al. 2023), where allocation and sizing strategies fortified distribution system reliability by minimizing energy not supplied costs, investment expenses, ESS operational costs, and power losses. In (Fathi, Tousi, and Galvani, 2023) authors applied methodology for identifying the locations for installing battery energy storage system (BESS) in RDS to enhance the reliability of the system.

FACTS devices constitute a category of power electronic systems and devices engineered to amplify the manageability and adaptability of alternating current (AC) power transmission within electrical grids. Their purpose is to enhance the effectiveness, dependability, and stability of power transmission systems. Employing power electronics and cutting-edge technologies, FACTS devices dynamically oversee the voltage, current, and reactive power flow along AC transmission lines. Notable examples of FACTS devices encompass the Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), and Static Compensator (STATCOM). These devices deliver various advantages, such as the regulation of voltage, control of power flow, improvement of system stability, and augmentation of transmission capacity. FACTS devices are applied in several research for system stability as in (Prakash et al. 2022), (Ali et al. 2022), (Adewuyi et al. 2021), (Azad et al. 2021), (Jiang and Zhang, 2023), (Vadhera and Lata, 2020), (Wu, Conejo, and Mathew, 2021), (Khattab and Zanaty, 2021), (Henao, Montoya, and Rodríguez, 2023), (Reddy et al. 2022), (Dandotia et al. 2023), and (Moustafa et al. 2023).

Moreover, the integration of fuel cells bore significance in voltage profile improvement and power loss reduction, whether in conjunction with other renewable energy sources or as standalone contributors, as demonstrated in (Diaaeldin et al. 2019), (Ivanov et al. 2019), and (González, Montoya, and Rodríguez, 2023). These diverse methodologies collectively chart a trajectory toward optimized voltage stability, diminished power losses, and an overall enhanced distribution network performance.

Table 2 shows some of the technical methods applied to the achievement of the different objective functions to attain system reliability as voltage profile improvement and loss reduction, with a very relevant consideration of the reliability enhancement by applying the different techniques mentioned above.

TABLE 2. Decision-Making Using Different Techniques with Various Algorithms For Enhancing RDN

Reference Number	Proposed Algorithm	Objective Functions	Network	Results	Decision Variables
(Aref et al. 2023)	Modified analytical technique	-Optimize the index of the voltage profile - Optimize the index of voltage stability - Reduced loss of power – Reduced energy loss annually	IEEE 33-bus, 69-bus, and 25-bus 500 kV Egyptian Power System (EPS) distribution network	Proposed Modified analytical technique > particle swarm optimization > genetic algorithm	locating Renewable Energy Sources and DG
(Alyu et al. 2023)	-Hybrid approach of Gray Wolf Optimizer (GWO) and Particle	-Optimize the profile of voltage	a practical utility network, which is a network in the	Reduction in real and reactive power losses	Site and size of DG

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Reference Number	Proposed Algorithm	Objective Functions	Network	Results	Decision Variables
	Swarm Optimization (PSO)	-Reduced loss of power -Increase the output of power	Ethiopian distribution system in the city of Dilla	by 58.1175% and 58.2189%. -Increase the voltage profile by 2.1739%	
(Elseify et al. 2023)	-Multipurpose Heat Exchange Optimization (MOTEO) -Multipurpose Lichtenberg Algorithm (MOLA)	-Optimize deviation of voltage. - Optimize stability of voltage. - Reduced loss of power.	IEEE 69-bus system	Multipurpose heat exchange optimization > multipurpose Lichtenberg Algorithm	Site and size of DG and SCs
(Romeh et al. 2023)	- Binary particle swarm optimization (BPSO) -Binary Jaya (BJA) -Grasshopper Optimization algorithm (GOA)	- Increase drop in voltage -Reduce losses of power	IEEE 33-bus system	Binary Jaya algorithm > grasshopper optimization algorithm > binary particle swarm optimization	Site and size of DG and Network Reconfiguration (Open switches)
(Shaheen et al. 2023)	-Modified Jellyfish Search (MJFS)	-Enhance the electrical systems' reliability -Reduce losses of power	IEEE 137-bus system	Proposed modified jellyfish search > gray wolf optimizer > transition state optimization	Network Reconfiguration (Open switches)
(Sriram et al. 2023)	-Beetle swarm optimization algorithm (BSOA)	- Reduction of loss of active power -Enhancement of voltage stability - Savings of fuel cost - Reduction of emission -Optimize deviation of voltage.	IEEE 30-bus, 57-bus, and 118-bus systems 0	Proposed beetle swarm optimization algorithm > regulatory algorithm > modified sine-cosine algorithm > particle swarm optimization with inertia weight approach > sine cosine algorithm	Optimal power Flow (OPF) solution
(Siregar et al. 2023)	-Heap-Based Optimizer (HBO)	-Improve voltage profile – reduce power loss -Reduce operation cost -minimize gas emission	IEEE 33-bus system	Proposed Heap-Based Optimizer > Grasshopper Optimization algorithm > Salp Swarm Algorithm > sine cosine algorithm	Network Reconfiguration (Open switches)
(Lokesh et al. 2023)	-Particle swarm optimization (PSO)	-Improve voltage profile – reduce power loss -Voltage deviation	IEEE 33-bus system	The largest reduction in losses occurred at a DG penetration level of 60% of the total system load.	Size and site of DG
(KC and Alkhwaildi, 2023)	-Particle Swarm Optimization (PSO)	- Reduce power loss - Regulate voltage level	IEEE 33, and 69 bus systems	Power reduction and voltage level stabilization improved on the IEEE 69 bus standard more than the IEEE 33 bus system	sizing hybrid renewable energy systems and energy storage systems Site of DG
(Swief et al. 2022)	The marine predator optimization	-Minimize power losses -Improving voltage profiles	IEEE 69 bus systems	For only the capacitor, placemen a 6% reduction in power loss, but after installing FoC 54% was achieved.	sizing and placement of capacitors

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Reference Number	Proposed Algorithm	Objective Functions	Network	Results	Decision Variables
(Shehata et al. 2022)	Autonomous Groups Particle Swarm and Grey Wolf optimizers (AGPSO-GWO)	-Minimize active power system losses -Minimize voltage deviation -Minimize system operational costs	IEEE-30, and 118 bus systems	Proposed autonomous groups particle swarm and grey wolf optimizers > autonomous groups particle swarm optimization> gray wolf optimizer > particle swarm optimization	size and placement of FACTS devices such as SVC, TCSC, and UPFC
(Karimulla and Ravi, 2021)	Enhanced Sine Cosine Algorithm (ESCA)	-Cost minimization -Loss minimization -Voltage stability index (VSI) -Emission reduction	IEEE Standard 30 bus system	Enhanced sine cosine algorithm > flower pollination algorithm > improved particle swarm optimization algorithm > strength Pareto evolutionary algorithm > particle swarm optimization > genetic algorithm	optimal mathematical power flow solution (OPF)
(Hraiz et al. 2020)	e Multi-Objective Hybrid Training Learning Based Optimization-Grey Wolf Optimizer (MOHTLBOGWO)	-Reduce power losses -Improve reliability - Improve the minimum voltage	IEEE 33 bus systems	Multi-Objective hybrid Training Learning Based Optimization-Grey Wolf Optimizer > Multi-Objective Grey Wolf Optimizer > Multi-Objective hybrid Training Learning Based Optimization	placement of renewable energy resources (PV – wind)
(Wiguna, Aripriharta, and Fadlika, 2020)	The data used in this study are obtained from the State Electricity Utility (PLN) of Malang Raya and corroborated through simulation	-Reduce excessive power loss -Meet the load demands	Malang transmission system	The transmission network that adds a new network has a smaller power loss of 355.7 kW, where the initial power loss of 598.2 kW.	Analytical calculations of power losses
(Ali et al. 2023)	Jaya algorithm	-Reduce active power losses -Achieving very high penetration levels -Improve voltage profile	IEEE-33 bus test system	The results showed the effectiveness of the proposed algorithm in reducing energy losses and enhancing voltage profiles	size and location of photovoltaic (PV) systems
(Onlam et al. 2019)	Adaptive Shuffled Frogs Leaping Algorithm (ASFLA)	-Power loss minimization -Voltage stability index (VSI) improvement	IEEE 33- and 69-bus system	Adaptive shuffled frogs leaping algorithm provides better power loss reduction and voltage stability index	sizing and location of DGs
(Ahmad, Ali, and, Kazmi, 2019)	multiple-criteria decision analysis (MCDA) techniques, PROMETHEE and Weighted Product Model (WPM),	-Improve voltage stability -Improve reliability -Improve system performance	Radial distribution systems RDS and mesh distribution systems (MDS).	Algorithms applied on mesh distribution systems> radial distribution system	sizing and location of DGs
(Khasanov, Kamel, and Abdel-Mawgoud, 2019)	Electrostatic Discharge Algorithm (ESDA)	-Minimize power loss -Improve voltage stability index (VSI).	IEEE 69-bus system	The proposed electrostatic discharge algorithm achieves significant power loss reduction and voltage stability index improvement	sizing and location of DGs

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Reference Number	Proposed Algorithm	Objective Functions	Network	Results	Decision Variables
(M'hamdi, Teguar, and Tahar, 2020)	Grey Wolf Optimization Algorithm (GWO), Whale Optimization Algorithm (WOA), and Particle Swarm Optimization (PSO)	-Minimize power loss -Improve voltage profile	IEEE 33-bus and 69-bus system	It is found that DG units operating at lagging power factor yield better results in terms of loss reduction and minimum bus voltage than unity p.f.	sizing and location of DGs
(Khasanov et al. 2023)	Mayfly Algorithm	-Minimize power loss -Improve voltage profile	IEEE 69-bus system	Power loss reduction is 69.14% for three PV-type DG and 98.09% for three WT-type DG units.	sizing and location of DGs
(Haider et al. 2021)	Teacher Learning Based Optimization (TLBO)	-Improve the reliability of the distribution system -Minimizing the cost of energy not supplied -Minimize the operation cost of ESS -Minimize power loss.	IEEE 33- and 69-bus system	Teacher Learning based Optimization> particle swarm optimization> genetic algorithm	allocation and sizing of energy storage systems (ESS)
(Das, Das, and Patra, 2014)	MATLAB Simulink	-Improving voltage profile -Maintaining grid frequency	Distribution network with an infinite bus, distribution network with a 10 node, and integration of two SOFCs to the distribution network.	Solid oxide fuel cell model improving voltage profile and maintaining grid frequency	operation of a Solid Oxide Fuel Cell (SOFC) stack model-based distributed generation (DG)
(Shokouhandeh et al. 2020)	Lightning Search Algorithm (LSA)	-Reduce losses -Improve voltage stability -Enhance voltage regulation index	IEEE 33 bus system	Lightning search algorithm > particle swarm optimization	location, and size of wind, solar, and fuel cell sources
(Subramanyam, Ram, and Subrahmanyam, 2016)	Hybrid technique of Genetic Algorithm (GA) and Recurrent Neural Network (RNN)	-Minimum power loss -Improved voltage profile	MATLAB/ Simulink platform and its effectiveness are analyzed by different algorithms	The proposed hybrid technique of genetic algorithm and recurrent neural network > particle swarm > genetic algorithm	location and sizing of the fuel cell
(Fathi, Tousi, and Galvani, 2023)	improved salp swarm algorithm (ISSA)	-power loss reduction -improve reliability	IEEE 33 and 69- bus system	Proposed improved salp swarm algorithm > salp swarm algorithm	PV and wind turbine locations with the reconfiguration network
(Mahdavi et al. 2023)	Whale Optimization Algorithm (WOA)	Minimum power loss -Regulate voltage levels	IEEE 33- and 69-bus system	Proposed Whale Optimization Algorithm > adaptive cuckoo search algorithm > uniform voltage distribution-based constructive reconfiguration algorithm > stochastic fractal search	Network Reconfiguration and location and size of DG
(Sellami et al. 2022)	Hybrid optimization technique (SAMPSO) combining the simulated	-Minimum power loss -Improved voltage profile	IEEE 69-bus system	Proposed hybrid optimization technique	Network Reconfiguration only and with wind energy integration

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Reference Number	Proposed Algorithm	Objective Functions	Network	Results	Decision Variables
	annealing algorithm (SA) with a modified particle swarm optimization (MPSO)			combining the simulated annealing algorithm with a modified particle swarm optimization > Modified particle swarm optimization	
(Ahmad and Asar, 2021)	Artificial neural network (ANN) technique	-increase efficiency – Increase the reliability of the system	The Roy Billiton Test System (RBTS)	SAIFI value reduced by 40%, SAIDI by 25%, and EENS by 25%	Locating of DG
(Khan et al. 2021)	Modified Salp swarm algorithm (MSSA)	-Minimum power loss -Improved voltage stability -minimize voltage deviations	IEEE 30 and 57-bus systems	Proposed algorithm Modified salp swarm algorithm > salp swarm algorithm	Sizing and location of FACTS devices using static synchronous series compensator (SC)
(Soesanti and Syahputra, 2022)	Multiobjective ant lion optimization (MALO)	-Power loss minimization -Voltage profile enhancement	IEEE 33-bus system	155.44 kW power loss after optimization which is better than 202.71 kW in the original network	location and capacity of distributed energy resources (DER)
(Chethan and Ravishankar, 2019)	MATLAB Simulink	-Voltage profile enhancement -Loss minimization	IEEE 12, 33 and 69- bus system	achieved at a specific penetration level	optimal placement of capacitors along with sizing of Distributed generators (DG)
(Hemeida et al. 2023)	A hybrid Genetic Archimedes optimization technique (GAAOA)	-Minimize energy losses -Improve voltage profile	IEEE 33 and 69- bus system	Proposed hybrid genetic Archimedes optimization>genetic algorithm	Sizing and location of DGs, fuel cells, PV, and wind turbine

4. Critical Evaluation

A literature review has dealt with several methods that were implemented in previous studies to improve the performance of the radial distribution system, whether in terms of improving voltage, reducing lost energy, or improving voltage stability. Studies discussed DG, reconfiguration networks, capacitors, RES, and FACTS. Most of them relied on changing the size and location of each of them. Few studies discussed the application of fuel cells to improve the performance of networks.

There is still a need for new studies that discuss the application of using DG or other equipment by controlling operations instead of changing their position and size. There is also a lack of methods that combine renewable energies and fuel cells to improve the network, whether by changing their size and location or by controlling their operation.

5. Discussion

Voltage stability improvement and power loss reduction are crucial aspects of optimizing the performance and efficiency of electrical networks. These factors have significant implications for the overall reliability, economic viability, and environmental impact of power distribution systems. Voltage stability improvement and power loss reduction in a network are often employed to enhance energy efficiency, reduce losses, and extend the lifespan of equipment. Integrating various methods, including Distributed Generation (DG), network reconfiguration, shunt capacitors, renewable energy sources, and fuel cells, can collectively contribute to achieving these goals. The best strategies for these goals are renewable energy resources and fuel cells.

Combining fuel cells with renewable energy resources in hybrid systems can offer synergistic benefits. Incorporating fuel cells and renewable energy resources into the power grid requires careful planning, control systems, and integration with existing infrastructure. The variability of renewable sources can be complemented by the consistent output of fuel cells. During periods of low renewable energy generation, fuel cells can step up to provide reliable power and contribute to voltage stability. However, their ability to provide reliable and sustainable electricity generation can contribute significantly to voltage stability and power loss reduction, ultimately leading to a more efficient and resilient electrical network.

Utilizing a combination of these methods requires careful planning, comprehensive analysis, optimization, control strategies, and coordination to achieve optimal results. Advanced technologies like smart grid systems, real-time monitoring, and predictive analytics enhance the effectiveness of these methods in achieving voltage optimization, stability, and power loss reduction. The selection and integration of these techniques depend on network characteristics, load profiles, and environmental factors, ensuring a well-balanced and efficient distribution network operation.

In conclusion, Voltage stability improvement and power loss reduction are critical elements in the ongoing evolution of modern power distribution systems. As the energy landscape continues to transform, optimizing these factors will remain a top priority to ensure a resilient, efficient, and environmentally responsible electricity supply for communities and industries alike.

6. Conclusion

In conclusion, radial distribution networks constitute a significant component of power systems, and efforts to minimize power losses and enhance voltage stability within these networks have been of paramount importance. The integration of Distributed Generation (DG), Photovoltaic (PV) systems, wind turbines, and fuel cells has emerged as a pivotal strategy to achieve these objectives.

The incorporation of DG, capacitors, FACTs, renewable energies, and fuel cells into radial distribution networks brings about a paradigm shift, where energy generation is decentralized, efficient, and environmentally friendly. However, challenges remain, including optimal resource allocation, control strategies, and seamless integration into the grid. Collaborative efforts between researchers, industry stakeholders, and policymakers are crucial in navigating these challenges and maximizing the benefits of these technologies. As our energy landscape continues to evolve, the integration of these renewable and distributed energy sources will play a pivotal role in shaping the future of radial distribution networks, ultimately leading to more resilient, efficient, and sustainable power systems.

Credit Authorship Contribution Statement

Honey A. Zedan: Conceptualization, Methodology, Software, Writing; Mohamed M. Ismail: Writing- Reviewing and Editing; Ahmed A. Salem: Investigation, Supervision; Basem E. Elnagy.: Software, Validation, Writing- Reviewing and Editing.

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