A Comprehensive Review of Artificial Intelligence Algorithms Applications for Distributed Generation Sizing and Location Optimization to Enhance Efficiency and Reliability Indices in Radial Distribution Systems

Nawaf Ali H. AlZahrani[1], Mohammad Hamza Awedh[2], Ali M. Rushdi[3]
Department of Electrical and Computer Engineering, King Abdulaziz University, Jeddah, 21589, Saudi Arabia [1,2,3]
Email: Nalzahrani0588@stu.kau.edu.sa

Abstract:

The research aimed to understand radial distribution systems by defining them and exploring their strategies, and to explore methods for applying artificial intelligence algorithms in radial distribution systems, It also aimed to clarify types of indicators in radial distribution systems, highlighting the importance of providing a scientific and applied framework for integrating artificial intelligence in the field of energy distribution.

The significance of the research lies in presenting a comprehensive and up-to-date approach based on the applications of artificial intelligence algorithms to improve the design and organization of distributed production systems in radial distribution systems.

By employing a descriptive and analytical approach, the researcher was able to reach several conclusions, with the most prominent being that the application of artificial intelligence algorithms in radial distribution systems contributes to improving energy efficiency by directing it more accurately and effectively, the ability of artificial intelligence to provide precise data-dependent analyses enhances decision-making processes in radial distribution systems, The integration of artificial intelligence techniques contributes to improving overall efficiency in radial distribution systems, reducing energy losses, and enhancing energy distribution effectively.

The research recommends enhancing integration between artificial intelligence techniques and radial distribution systems to ensure effective and smooth interaction, thereby increasing efficiency, Priority should be given to the safety and protection of data, and effective cybersecurity measures should be implemented to address the growing challenges in this context.

Keywords: Radial distribution systems, Production site, Technology, Artificial intelligence algorithms, Indicators, Efficiency, Reliability.

1. Introduction

The fields of electrical engineering and radial distribution systems are undergoing rapid evolution in the face of continuous technological advancements. Radial distribution systems play a crucial role in efficiently and reliably delivering electrical power. With recent developments in artificial intelligence (AI), attention is shifting toward integrating these technologies to enhance the efficiency and reliability of such systems.

This comprehensive review sheds light on the applications of AI algorithms in the identification and improvement of distributed production sites in radial distribution systems. The research primarily addresses the urgent need to enhance energy efficiency and increase the reliability of these systems, with AI playing a vital role in achieving these goals.

The review conducts a thorough analysis of available literature in this field, examining studies and research that highlight the concepts of AI and its applications in improving radial distribution systems. The research delves into the specific objectives of various studies, the methodologies employed, and focuses on the key results and recommendations provided by these studies.

Particularly, the research concentrates on defining and determining the locations of distributed production, exploring how this process can be enhanced using AI algorithms. The aim of this research is to provide a deep understanding of how modern technology integration can boost the performance of radial distribution systems, ensuring sustainable and reliable provision of electrical energy.

1.1. Research Problem

The scientific problem addressed in this research may revolve around the inefficiency and unreliability in identifying and improving the locations of distributed production in radial distribution systems. Challenges related to current distribution technology might render traditional methods for site identification ineffective in meeting efficiency and reliability requirements. Difficulties in handling big data and complex interactions within distribution systems underscore the necessity of using AI techniques to enhance decision-making processes in this context.

In general, the research problem may focus on overcoming technical and organizational challenges associated with improving the identification and enhancement of distributed production sites using AI algorithms. Understanding how these technologies can be effectively integrated into electric distribution environments is also crucial.

1.2. Research Questions

1. How can the efficiency of identifying distributed production sites in radial distribution systems be improved using AI techniques, and what are the key factors that must be considered to achieve this?
2. How does the location and sizing improvement of distributed production sites through AI impact reliability indicators in radial distribution systems, and what challenges may arise in the widespread implementation of these technologies?
3. Are there tangible benefits, supported by data and statistics, for using artificial intelligence algorithms to enhance distributed system, and how can the impact of these technologies on the performance of radial distribution systems be measured?
4. What practical recommendations exist for effectively and sustainably integrating artificial intelligence technologies into radial distribution systems?

1.3 Research Objectives

1. Understand radial distribution systems, defining them and exploring their strategies.
2. Explore methods for applying artificial intelligence algorithms in radial distribution systems.
3. Clarify types of indicators in radial distribution systems.
4. Highlight the contribution of artificial intelligence in enhancing the efficiency and reliability of indicators.
5. Identify the characteristics and challenges of artificial intelligence in radial distribution systems.

1.4. Research Significance

In general, this research contributes to providing a scientific framework for integrating artificial intelligence in the field of energy distribution. It enhances the sustainability and efficiency of radial distribution systems, contributing to the smart transformation in the energy sector. The scientific significance lies in providing a deep understanding and comprehensive analysis of the impact of artificial intelligence technology on the identification and improvement of distributed production sites in radial distribution systems. The research can contribute to expanding knowledge about the integration of modern technologies in electrical engineering and providing an understanding framework for applying artificial intelligence to enhance the performance of distribution systems.

1.5. Research Methodology:

The research employ an integrated analytical and descriptive methodology to comprehensively achieve its objectives. By using these methodologies together, data can be analyzed deeply, and processes and techniques can be accurately described, contributing to highlighting the impact of artificial intelligence technology on improving the efficiency and reliability of radial distribution systems.

1.6. Research Terms:

1.6.1. Artificial Intelligence Algorithms: These are a set of mathematical and logical guidelines designed to solve complex problems. They rely on knowledge representation techniques and machine learning to make intelligent decisions based on data. (Al-Asyuti, 2020, p.21)

1.6.2. Artificial Intelligence Applications: They are smart applications that use machine learning and integrated algorithms to enhancing efficiency, productivity, and problem-solving capabilities. (Al-Hadi, 2021, p.33)

1.6.3. Distributed Generation System: It is the process of determining the size and locations of dispersed electricity generation sources in multiple locations instead of a single large source. It aims to improve energy efficiency and distribution. (N.H. Khan, 2021, p.47981)

1.6.4. Distributed Generation Location: Refers to the geographical locations where energy generation sources are distributed. It is determined based on factors related to efficiency and sustainability in energy distribution systems. (N.H. Khan, 2021, p.47982)

1.6.5. Radial Distribution Systems: Refers to the structure and networks used to transmit electrical energy from the generation source to consumers through transmission lines and distribution networks. (T.T. Nguyen, 2021, p.1771)

1.6.6. Indicators in Radial Distribution Systems: These indicators include various measurements and evaluations used to determine the efficiency and reliability of radial distribution systems. These indicators may include loss rates, operation time, network strength, voltage performance, and others. (T.T. Nguyen, 2021, p.1771)

2. Literature review:

In this review efforts were made to remain closely aligned with the topic of electrical distribution systems, by surveyed the recent studies in scientific databases like IEEE, google scholar, ResearchGate, and EBSCO etc, for last six years.

1) **Fadel Juma (2021)** the optimal situation for distributed generation using artificial intelligence to improve the active radial distribution system. Distributed generator (DG) units offer various advantages aimed at enhancing the security of distribution power grids. However, these benefits can be optimized through careful sizing and positioning of DG units, as the arbitrary placement of DG units may have adverse effects on power grids, leading to increased power loss and deterioration of the voltage profile. Consequently, multiple approaches have been proposed to ensure the optimal positioning and sizing of DGs. The main objective of this article is to establish a technique for the optimal scheduling and operation of DGs, with the goal of reducing power loss, improving the voltage profile, and enhancing overall network reliability. The researcher mentioned some techniques improving reliability and reducing power loss for example: Simulated Annealing (SA), Machine learning (ML) technique, And for finding the appropriate DG allocation: An improved analytical (IA) technique, Artificial bee colony (ABC) technique, and Cuckoo search (CS) technique, and for power loss reduction Strategies are adopted with renewable DGs: ant lion optimization, a Backtracking search algorithm (BSA), Flower pollination algorithm (FPA) is also utilized for determining size and location of DG. This article employs an artificial intelligence method known as particle swarm optimization (PSO) to identify the optimal site and size for DGs, resulting in decreased power loss and an enhanced voltage profile. This study will execute a detailed performance analysis on 33 bus network with the aim of establishing the robustness of the presented PSO method.

2) **SIMON et.l, (2021)** Applications of Artificial Intelligence in Distribution Power System Operation. This review explains a comprehensive concept about the methodology of algorithms for artificial intelligence in general, and the control systems in power distribution networks, Both types are open, in which human control is involved, and closed, in which artificial intelligence is used in control and prediction, the researchers discussed analyzing power quality, system and voltage stability, locating and isolating the fault, emergency procedures, analyzing economic efficiency, reducing the cost of generation and carbon emissions, coordinating emergency actions, and the AI's algorithms used for this, including: the digital twin, using a deep neural network, fuzzy algorithm, RELIEF algorithm, and biogeography-based optimization algorithm and learning.

3) **Olufemi &, Haoran (2021)**. Artificial Intelligence Techniques in Smart Grid: A Survey, In this article the researchers reviewed 148 studies is this paper related to: load forecasting, power

grid stability assessments, faults detection, and smart grid securit. for Short-Term Load Forecasting, mentioned that wavelet neural network (WNN) and ANN schemes showed the higher performance of the proposed mode, comparing it with other clustering methods . For Mid-Term Load Forecasting and Long-Term Load Forecasting a neural network-based model with particle swarm optimization (PSO) and showed the feasibility and validity of the model. The researchers mentioned many Techniques for power grid stability assessments, faults detection, and smart grid security, most used was ANN, and machine learning. Regarding the challenges for the future of artificial intelligence in smart networks, hacking and cybersecurity pose a major challenge with the integration of the network into cloud computing and the availability of fifth-generation infrastructure.

4) Khan et al, (2022). Optimal Sizing and Allocation of Distributed Generation in the Radial Power Distribution System Using Honey Badger Algorithm. In this article, the researchers discussed the Optimal Sizing and Allocation of Distributed Generation in the Radial Power Distribution System, as the optimal allocation is a non-linear problem, which is solved by powerful metaheuristic optimization algorithms. In this work, an objective function is introduced to optimally size four different types of DGs by utilizing honey badger algorithm (HBA), and comparison is drawn with grey wolf optimization (GWO) and whale optimization algorithm (WOA). The objective is to boost the voltage profile and minimize the power losses.

5) J. Watson, et al, (2016), Impact of solar photovoltaic on the low-voltage distribution network in New Zealand. Examined the influence of solar Photovoltaics on the low-voltage distribution network in New Zealand, presenting power flow outcomes with the integration of different solar PV penetration levels into the model. The simulation results indicate that elevated PV levels result in conductor overloading. Consequently, an investigation into the potential maximum limit of solar PV penetration was conducted. The simulation also explored the impact of employing voltage regulation through PV inverters and proposed measures to address overvoltage issues. The findings suggest the anticipation of additional challenges in the future.

3. Theoretical Framework:

Artificial Intelligence represents an exciting field witnessing rapid developments, actively transforming numerous sectors. Among these sectors, the spotlight is on the Radial Distribution Systems for electrical power, given that Artificial Intelligence serves as a fundamental pillar in the modern technological landscape.

Its ability to achieve significant transformations across various domains is noteworthy. The impact of Artificial Intelligence is closely linked to enhancing the effectiveness of systems and innovatively developing them. Notably, one of the systems undergoing significant transformation is the Radial Distribution Systems for electrical power. (Al-Asyuti, 2020, p.27)

This study addresses specific topics related to this context, focusing on the importance and role of Radial Distribution Systems in efficiently securing energy supplies with reliable dependence. The investigation explores the impact of using Artificial Intelligence in this context and how Artificial Intelligence techniques can play a vital role in improving and developing Radial Distribution Systems. The research includes an analysis of key indicators that assess the performance of these systems, shedding light on the characteristics and challenges of employing smart technology in this context. This study aims to gain a profound understanding of how advancements in Artificial Intelligence can be integrated to enhance efficiency and sustainability in electrical power distribution systems.

3.1. Radial Distribution Systems

3.1.1. Explanation of Radial Distribution Systems

Radial Distribution Systems are an essential part of the infrastructure for electrical power distribution. These systems transport and direct energy from generation stations to consumers through complex networks. This is achieved through a set of devices and equipment that enable efficient and effective energy routing. The design and operation of these systems aim to achieve balance and stability in electricity distribution. These systems continuously evolve to become more intelligent and efficient. Artificial Intelligence contributes to advancing their operation and management, enhancing energy distribution efficiency, and contributing to sustainability goals. (N.H.Khan, 2021, P47983)

3.1.2. Distributed Generation in Radial Distribution Systems

Distributed generation in Radial Distribution Systems refers to generating electrical power from diverse and widely distributed sources, rather than consolidating in a single source. This includes utilizing various sources such as solar cells, wind energy, and microgenerators. This approach allows reducing energy loss during its transmission across the network, promoting sustainability. Strategically distributing points of distributed generation meets the needs of consumers at the neighborhood or residential levels. Distributed generation enhances network stability and improves its adaptability to changing energy demand challenges.

Artificial Intelligence plays a role in enhancing the operation of these distributed systems by improving energy routing and efficiency. (Z. Hamadouche, 2021, P101)

3.2. Distributed Generation Sizing and location in radial distribution systems:

Determining and directing distributed generation in Radial Distribution Systems refer to the process of identifying effective locations for energy generation within the distributed network. This approach is a vital part of strategies to improve energy distribution. Production locations are determined based on factors such as energy needs in the area and opportunities to utilize renewable energy sources like solar and wind. Control and monitoring systems benefit from Artificial Intelligence techniques to analyze energy data and maximize the use of diverse production sources. Artificial Intelligence can dynamically guide production based on demand and environmental conditions, improving network balance and increasing its efficiency. Determining and directing distributed generation is a key aspect of sustainability and improving the performance of Radial Distribution Systems. (N.H.Khan, 2021, P47989)

3.2.1. Definition of Distributed Generation Sizing:

Distributed generation identification refers to the process of determining and directing the production of electrical energy from diverse and widespread sources within various locations across a wide scale within the power distribution system. This approach aims to enhance energy efficiency usage and promote the sustainability of the electrical system. It involves the use of artificial intelligence techniques and smart control systems to analyze energy data and make effective decisions regarding the locations of distributed energy generation. The goal is to improve production direction flexibly based on energy needs and changing conditions.

Types of distributed generation sizing approaches: Peak Load Sizing, Average Load Sizing, Hybrid System Sizing, Renewable Sizing, Grid Support and Ancillary Sizing.

3.2.2. Distributed Generation Methodologies and Influencing Factors: (T.T. Nguyen, 2021, p.1772)

1. **Load and Consumption Analysis**: Examines energy consumption in the target area and determines expectations for electric load, utilizing **load prediction models** and statistical analysis to estimate future requirements.
2. **Geographic Site Evaluation:** Studies the environment, topography, and geographical conditions to identify optimal locations for energy generation. It relies on criteria such as sun availability and wind speed to determine the suitability of renewable energy sources.

3. **Cost Economics Analysis:** Involves estimating the financial cost of implementing distributed projects, including cost-benefit analysis and assessing long-term investment value.
4. **Production Technology:** Requires an examination of requirements and techniques for available energy sources, such as solar, wind, and microgenerator technologies, including a study of energy conversion techniques and their production efficiency.

It is also to take into account the application of the methodology for improving the DGs: Identify the locations with high voltage drop and low voltage levels, as these are potential sites for DG installation, Using iterative methods or optimization algorithms to find the DG capacity that provides the maximum reduction in power losses, Sizing DG units to improve voltage levels and maintain them within acceptable limits, Identifying critical nodes where small changes in DG capacity can significantly affect system parameters, Using financial metrics such as Net Present Value (NPV) or the Levelized Cost of Electricity (LCOE) to assess the economic feasibility of different DG sizes, Determining the ability of DG units to provide backup power during outages and their impact on system reliability indices, Consideration of the intermittency and variability of renewable sources and their impact on system stability, Using dynamic simulation tools to assess the transient behavior of the distribution system with integrated DG, Evaluating the impact of DG on system stability, voltage regulation, and fault response.

Influencing Factors:

1. **Energy Demand:** Estimating energy consumption in the region influences the volume and direction of distributed energy production.
2. **Technology Used**: The type and efficiency of the technology used affect the costs and performance of energy production.
3. **AI-Guided Flexibility**: The use of artificial intelligence techniques in flexibly directing energy production based on changing conditions.
4. **Policies and Legislation**: Local laws and regulations play a role in guiding policies related to distributed production and determining permissible locations.
5. **Sustainability and Environmental Impact:** Verifying the alignment of distributed production projects with sustainability goals and reducing environmental impact.

3.2.3. Definition of Distributed Generation location:

A distributed generation site refers to carefully selected geographical locations for implementing electrical energy generation from diverse and widespread sources, such as solar or wind energy, on a broad scale within the electrical distribution system. The aim is to improve the sustainability and efficiency of the grid. Another source states that the distributed generation site in Radial Distribution Systems represents the specified optimal locations within the electrical distribution system where energy is generated from various sources. These locations are chosen based on geographic and technological criteria to achieve the best distribution and utilization of energy.

3.2.4. Optimal Distributed Generation placement Strategies: (Prakash, Khatod, 2015, p115,118)

1. **Load and Consumption Analysis:** by Analyzing historical load data to identify locations where DG can best match the load profile, reducing transmission losses and enhancing system efficiency.
2. **Voltage Improvement :** by Identifying locations with voltage violations or low voltage levels and install DG units to improve the overall voltage profile
3. **Integration of AI Technologies:** Relies on using artificial intelligence techniques to analyze data and make accurate decisions about the locations of distributed energy generation, including the use of algorithms and predictive models for optimal network performance improvement.
4. **Geography and Environment Analysis:** Relies on the analysis of geography and environmental conditions to effectively determine diverse energy generation locations, taking into consideration the availability of natural resources such as sun and wind and guiding the selection of high-efficiency locations.
5. **Cost Economics Assessment**: Relies on a meticulous evaluation of costs and financial benefits for each potential site to strike a balance between efficiency and cost, including a study of investment costs and operational and maintenance costs.
6. **Resilience and Security**: Takes into account critical infrastructure points and install DG units strategically to ensure a resilient power distribution system in the face of unforeseen events or attacks.
7. **Demand Response Integration:** Identifying locations with high demand during peak periods and install DG units to support demand response initiatives, reducing strain on the grid during peak hours.

3.3. Application of Artificial Intelligence Algorithms in Radial Distribution Systems

3.3.1 AI Algorithms Used in Radial Distribution Systems:

Artificial intelligence contributes to the radial distribution system through machine learning, artificial neurons, and predictive ability based on historical data in predicting loads, regulating voltage, detecting and diagnosing faults, Optimal Reconfiguration, Volt/VAR Control, and Distributed Energy Resources. (Yahya Taher et al, 2022, P14038), Below we mention the most important algorithms that rely on artificial intelligence:

1. **Particle Swarm Optimization (PSO):** Employed to enhance energy distribution and identify efficient generation locations using search and optimization techniques.
2. **Ant Colony Optimization (ACO):** optimize the integration of distributed energy resources, such as solar panels or energy storage devices, into the distribution system.
3. **Artificial Neural Networks (ANN):** Rely on artificial intelligence models inspired by the human brain to analyze and predict load patterns and optimally direct production. In addition, it can learn patterns from historical load data and can predict future demand based on various factors such as time of day, day of the week, and season.
4. **Machine Learning Algorithms:** Leverage the system's ability to learn from data and adapt responses over time to improve network performance. These algorithms can identify when maintenance is likely needed.
5. **Genetic Algorithms**: Used to determine the optimal balance between performance and cost through simulating evolution and adaptation. And explore different configurations to find the most efficient layout in terms of losses, reliability, or other specified criteria.
6. **Decision tree algorithms:** used for fault diagnosis by creating a tree-like model that represents the decision-making process based on observed symptoms.
7. **Fuzzy Logic Systems:** Employed for fault detection and diagnosis in distribution systems**.**
8. **Smart Aggregation:** Utilized to efficiently gather and analyze data to understand load behavior and suggest improvements in production distribution.
9. **Intelligent Decision Algorithms:** Depend on making enlightened decisions automatically using available data to enhance energy distribution management.
10. **Reinforcement learning algorithms:** used for Volt/VAR control to optimize voltage levels and reactive power flows in the distribution system**.**

11. **Multi-objective Optimization Algorithms:** Algorithms like NSGA-II (Non-dominated Sorting Genetic Algorithm II) or MOEA/D (Multi-Objective Evolutionary Algorithm based on Decomposition) can be used when multiple conflicting objectives need to be considered in the optimization process.
12. **Prediction and Analysis Algorithms**: Employed to analyze previous consumption records and forecast future needs based on efficient prediction models.

The use of these algorithms can significantly contribute to improving the performance of Radial Distribution Systems and achieving a balance between efficiency and sustainability.

3.3.2 Application of Artificial Intelligence Algorithms in Sizing Optimization:

The application of artificial intelligence algorithms in optimizing the identification of distributed energy generation sizing is a fundamental aspect of developing Radial Distribution Systems. These algorithms provide efficient methods to enhance energy utilization and increase the efficiency of these systems. Researchers benefit from intelligent optimization algorithms to analyze big data and guide decision-making processes toward identifying optimal locations for energy generation. These algorithms analyze future loads and environmental variables such as sun and wind, providing accurate guidance on locations that best suit the system's requirements. (Yahya Taher et al, 2022, P14041)

Below we will mention two examples with an explanation of their working mechanism.

1- Artificial Neural Networks (ANN) for Predictive Analysis:

Artificial Neural Networks (ANN) in radial distribution systems involves the use of machine learning techniques to determine the most suitable size and location for distributed generators within a power distribution network, Here's a general overview of how this process work: 1- Gather historical data on the radial distribution system, including load profiles, system topology, and operational constraints, line capacities, transformer capacities, and other relevant parameters, 2- Identify the relevant features and parameters that will be used as input to the ANN, 3- Normalize and preprocess the data to ensure that it is suitable for training the neural network, 4- Design the architecture of the Artificial Neural Network, 5- Using historical data to train the ANN. During training, the network learns the relationships between the input features and the optimal DG size, 6- Validation the trained ANN using a separate set of data that it has not seen before, once the ANN is trained and validated, it can be used to predict the optimal DG size for new scenarios and Integrating the ANN into the decision-making process for DG placement and sizing.

Decision-makers can use the ANN predictions along with other relevant factors to make informed decisions on where and how large the DG units should be installed.

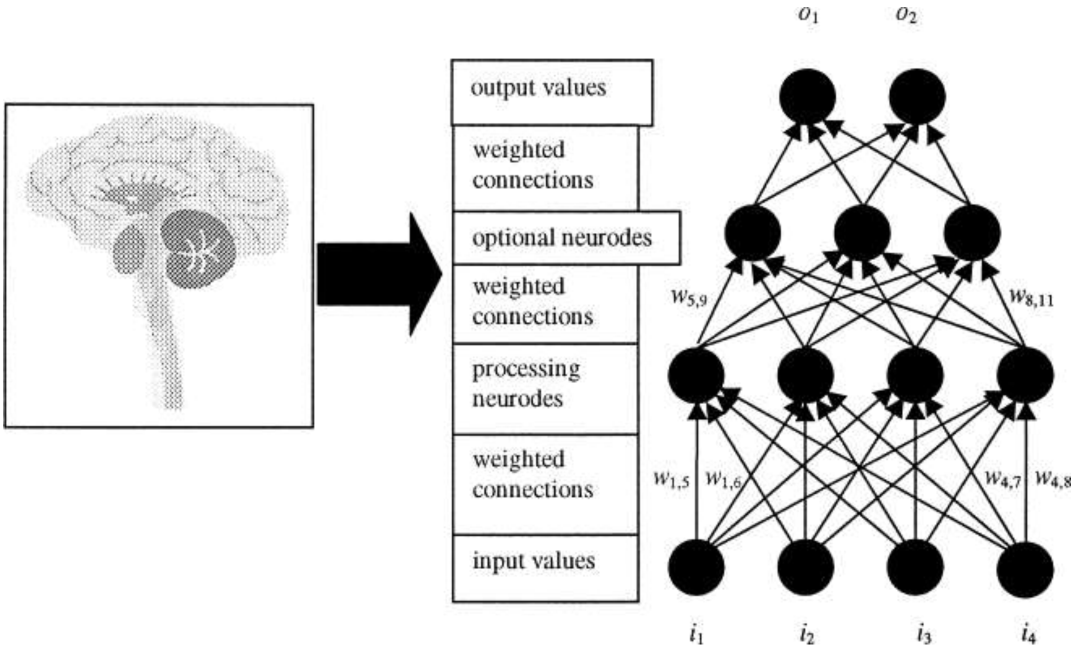

Figure 1. Sample artificial neural network architecture, (Steven & Narciso, 2003)

2- Deep Q-Learning, Reinforcement learning algorithms:

Deep Q-Learning (DQL) is a reinforcement learning technique that combines deep learning with Q-learning, a classical reinforcement learning algorithm. It has been applied to optimization Distributed Generation (DG) Sizing in radial distribution systems. Here's a general overview of how this process work: 1- state the system includes information about the current configuration of the distribution system, load levels, and the presence of existing DG units, 2- Define a reward function based on the chosen actions such as (voltage stability, reduce power losses, and improve overall system reliability), 3- Implement a deep neural network (Q-network) that takes the state as input and outputs Q-values for each possible action, 4- Training the Q-network using historical data or simulation results, during training, the Q-network is updated iteratively based on the temporal difference between predicted Q-values and actual rewards. 5- Exploration and exploitation: During training, once the Q-network is trained, it can be used to predict optimal DG sizing decisions for a given state of the distribution system.

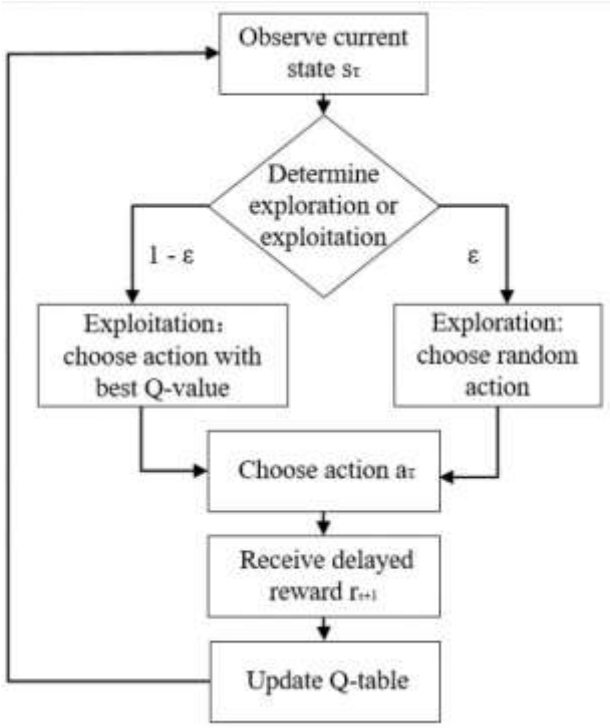

Figure 2. Q-learning algorithm flowchart. (Fangyuan et al., 2019)

3.3.3. Application of AI Algorithms in optimal placement of distributed generation

Artificial intelligence is used to determine the optimal distribution location, especially regarding the diversity of generation sources. Below we will mention two examples with an explanation of their working mechanism.

1- **Genetic Algorithms for Optimal DG Placement:**

Genetic Algorithms can be applied to solve the optimal DG placement problem in a radial distribution system by represented each potential solution as a set of variables that correspond to possible locations for placing DG units, These variables may represent bus numbers or line sections where DG units can be installed, then Define an objective function that quantifies the performance of a particular solution based on the goals of the optimization, such as minimizing power losses, improving voltage profile, or achieving a balance between conflicting objectives. Then representing each potential solution as string corresponds to a decision variable (DG placement location). then Creating an initial solution represents a possible arrangement of DG units in the distribution system, then Evaluating the fitness of each solution in the population using the objective function According to the optimization criteria. Then Using a selection mechanism to choose solutions with higher fitness values are more likely to be selected, then recombination and Replacement.

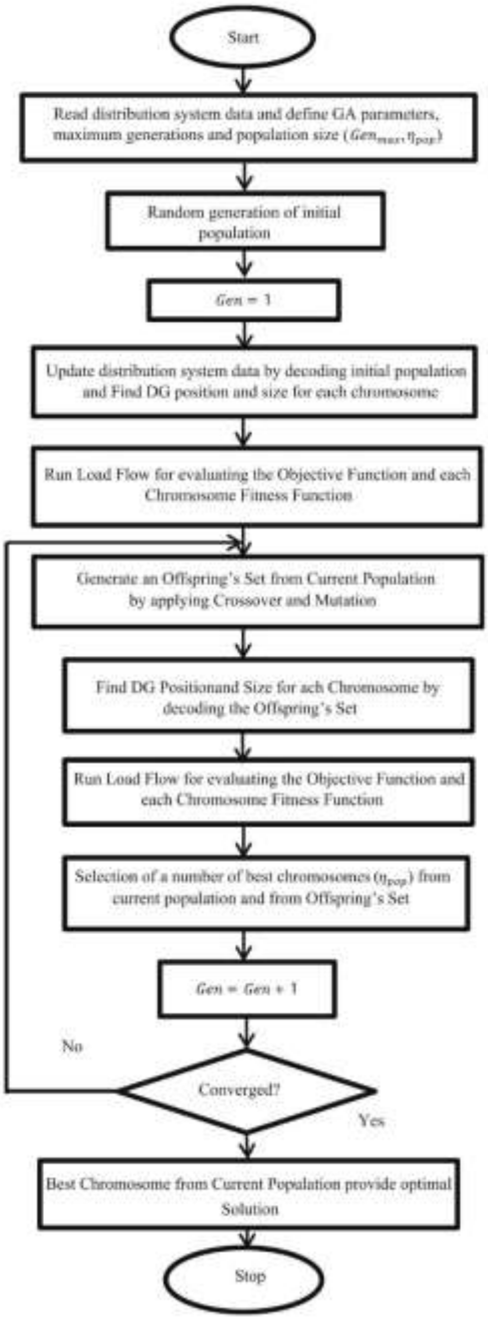

Figure. 3 Proposed genetic algorithm approach for optimal placement of DG. (M. Kashyap et al., 2019)

2- Particle Swarm Optimization (PSO):

Particle Swarm Optimization (PSO) is a metaheuristic optimization algorithm inspired by the social behavior of birds and fish. It's often used to solve optimization problems, including optimal Distributed Generation (DG) placement in radial distribution systems. The goal of optimal DG placement is to determine the best locations for placing DG units in a power distribution network to improve its overall performance, such as minimizing power losses, voltage deviations, or enhancing system reliability. Here's a basic overview of how PSO works for optimal DG placement in a radial distribution system: 1- Defining an objective function that represents the goal of the optimization problem such as minimizing power losses, voltage deviations, or other relevant performance indices, 2- Representing each potential DG placement as a particle in the search space, 3- Initializing a population of particles randomly within the search space, 4- Evaluating the fitness of each particular DG placement configuration performs then updating particle velocity and position by using specific function, then the algorithm aims to find the optimal locations (nodes in the distribution system) for placing DG units such that the overall system performance is improved., other swarm intelligence algorithms can be used such as bee algorithms or firefly algorithms may be employed for optimization tasks.

$G_{besti} = (g_{besti,1} , g_{besti,2}$

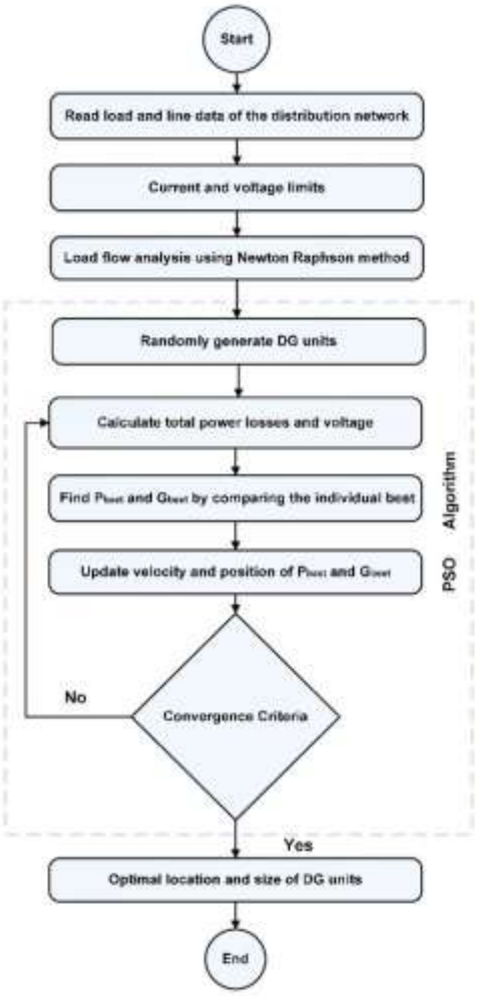

Figure 4. Flow chart of PSO algorithm for the distribution network. (Waseem et. al, 2021)

3.4. Indicators in Radial Distribution Systems

3.4.1 Types of Indicators in Radial Distribution Systems:

These indicators are based on diverse requirements that align with the goals of radiant distribution, providing comprehensive support for performance assessment and system improvement:

1. Efficiency Indicators: Evaluate the system's efficiency in energy distribution, including energy conversion and transmission efficiency.
2. Sustainability Indicators: Measure the system's ability to sustain and meet current needs without adversely affecting the future.
3. Power Quality Indicators: Relate to the quality of distributed energy, such as voltage levels, current, and load balance.
4. Consumption and Demand Indicators: Measure actual energy consumption and estimate future demand.
5. Safety and Reliability Indicators: Concern the system's ability to handle challenges and ensure reliable energy supply.
6. Technology Indicators: Measure the effectiveness and efficiency of the technology used in the radiant distribution system.
7. Economic Indicators: Relate to the costs and financial savings associated with the operation and maintenance of the system.

3.4.2. Importance of Enhancing Efficiency and Reliability of Indicators

Enhancing the efficiency and reliability of indicators in Radial Distribution Systems is of significant importance. By improving indicator efficiency, the overall system performance can be enhanced, leading to improved resource utilization and increased reliability. Enhanced indicators contribute to cost reduction and promote a balance between efficiency and economy. Making indicators more reliable also facilitates the achievement of sustainability goals and minimizes environmental impacts. Moreover, they aid in guiding strategic decisions and meeting user needs. In general, focusing on enhancing the efficiency and reliability of indicators contributes to achieving a comprehensive balance between performance and sustainability in Radial Distribution Systems.

3.4.3. AI's Contribution to Enhancing Efficiency and Reliability Indices

Artificial intelligence significantly contributes to enhancing the efficiency and reliability of indicators in radial distribution systems through various means: (Bilal, 2019, pp. 23-26)

- **Big Data Analysis:** Artificial intelligence enhances the efficiency and reliability of radial distribution systems by effectively analyzing massive amounts of data. This analysis helps extract accurate information about system performance and understanding its dynamics.
- **Improving Control Systems:** Artificial intelligence techniques are applied to control systems to balance production and consumption better, leading to improved energy direction and utilization.
- **Enhancing Prediction:** Artificial intelligence contributes to improving the predictive capabilities of system states and future changes, enabling more intelligent and effective decision-making.
- **Resource Utilization Improvement:** Distribution systems benefit from improved resource direction and utilization using artificial intelligence techniques, contributing to increased system efficiency.
- **Quality of Energy Improvement:** Artificial intelligence techniques are used to control energy quality, reducing interference and ensuring the provision of high-quality energy.
- **Predictive Maintenance:** Predictive maintenance systems can be implemented using artificial intelligence, reducing downtime and improving system reliability.
- **Improving Integration:** Artificial intelligence is integrated into distribution systems to enhance integration between different elements and achieve more distinguished performance.
- **Enhancing Network Technology:** Artificial intelligence techniques are used to improve the design and operation of network technology, enhancing its efficiency and flexibility.

Artificial intelligence applications and algorithms also improve performance indicators by reducing the Total Distribution System Losses, Substation Losses and Regulation the Voltage, improve the System Reliability Indices (SAIDI, SAIFI, MIFI, SART, CAIDI, CAIFI, VSI, FOM), Power Factor at Various Nodes, Load Distribution, Fault Detection and Restoration Time, Grid Stability with Distributed Generation, Implementation of Smart Meters, Automation and Remote Monitoring. Through these methods, artificial intelligence demonstrates a positive impact on enhancing the efficiency and reliability of radial distribution systems.

4. Conclusion:

In conclusion, it is evident that artificial intelligence constitutes a qualitative leap in the development of radial distribution systems for electrical energy. By analyzing vast amounts of data and improving decision-making processes, artificial intelligence can enhance energy direction and predict future events. Despite challenges such as data security and achieving a balance between safety and efficiency, the undeniable benefits of integrating artificial intelligence technologies into radial distribution systems are apparent. Research and innovations in this field are expected to continue, further enhancing the ability to achieve sustainable and effective improvements in energy distribution systems.

4.1. Results:

1. Studies demonstrate that the application of artificial intelligence algorithms in radial distribution systems contributes to improving energy utilization efficiency by directing it more accurately and effectively.
2. The ability of artificial intelligence to provide accurate, data-driven analyses enhances decision-making processes in radial distribution systems.
3. Artificial intelligence techniques enable better energy direction, contributing to achieving an optimal balance between production and consumption.
4. Studies observe progress in the predictive capabilities of artificial intelligence-supported radial distribution systems, enhancing the sustainability and reliability of these systems.
5. The integration of artificial intelligence technologies contributes to overall efficiency improvement in radial distribution systems, reducing energy loss and effectively improving energy distribution.
6. Artificial Intelligence techniques generally rely on self-learning from historical and input data and training before being applied.
7. An appropriate AI's algorithm is used based on the situation, and the desired solution and the problem.
8. The most important challenges facing the application of artificial intelligence algorithms in the radial distribution system are the cyber threat and the availability of smart infrastructure such as integration with the fifth generation network.

4.2. Recommendations:

1. It is recommended to enhance integration between artificial intelligence technologies and radial distribution systems to ensure effective and seamless interaction, maximizing efficiency.

2. Data integrity and protection should be prioritized, and effective cybersecurity measures should be developed to address the growing challenges in this context.
3. Effective strategies should be developed to train smart systems to maximize the benefits of artificial intelligence capabilities and ensure their responsiveness to changing conditions.
4. Encouragement is given to raise awareness and train professionals in the field of radial distribution systems about the benefits and uses of artificial intelligence to ensure effective and secure adoption.
5. Continued research and development in artificial intelligence technology are encouraged to improve techniques and expand their applications in radial distribution systems.
6. Developing the infrastructure of traditional distribution system and replacing them with smart networks.

5. References:

1. Al-Asyouti, Ayman (2020) Application of Artificial Intelligence, first edition, Egyptian House for Publishing and Distribution, Egypt.
2. Al-Hadi, Mohamed Mohamed. (2021), Artificial Intelligence Processing and its Applications, first edition, Egyptian Lebanese Publishing House, Egypt.
3. Bilal, Ahmed Habib, Musa, Abdullah (2019). (Artificial Intelligence is a revolution in technology, first edition, Arab Group for Training and Publishing, Cairo.
4. Burns, J. N., (2017) et al. Criterion-related validity of the Big Five general personality factors from TIPI to IPIP. International Journal of Selection and Evaluation.
5. Fadel Juma (2021) entitled: The optimal situation for distributed generation using artificial intelligence to improve the active radial distribution system, Al-Furat Al-Awsat Technical University, Department of Electrical Power Engineering, Iraq.
6. J. Watson, et al, (2016) "Impact of solar photovoltaic on the low-voltage distribution network in New Zealand," IET Generation, Transmission & Distribution, vol. 10, no.
7. K. Mahmoud M. Abdel Nasser, (2019) "A fast and accurate energy loss assessment approach for PV energy analysis/sizing in distribution systems using machine learning," in IEEE Transactions on Sustainable Energy, vol. 10, no. 3.
8. N. H. Khan et al., (2021) "A Novel Modified Lightning Attachment Procedure Optimization Technique for Optimal Allocation of the FACTS Devices in Power Systems," in IEEE Access, vol. 9.

9. Prem Prakash, Dheeraj K. Khatod (2015) Optimal Sizing and Siting Techniques for Distributed Generation in Distribution Systems: A Review, Center for Alternative Hydropower, I.I.T. Roorkee, Uttarakhand, India.
10. T. T. Nguyen,(2021)" Optimization of location and size of distributed generations for maximizing their capacity and minimizing power loss of distribution system based on cuckoo search algorithm," Bulletin of Electrical Engineering and Informatics, vol.10.
11. Yahya Taher et al. (2022) Introduction to Artificial Intelligence in Early Radiation, Environmental Science and Pollution Research, under exclusive license to Springer-Verlag GmbH, https://doi.org/10.1007/s11356-021-16771- Germany.
12. Z. Hamadouche "(2021) Intelligent voltage regulator for distributed generation-based network," Indonesian Journal of Electrical Engineering and Computer Science, vol. 23, no. 1, pp. 98-109, 2021.
13. Simon Stock, Davood Babazadeh & Christian Becker. (2021). Applications of Artificial Intelligence in Distribution Power System Operation, IEEE Access, V9
14. Olufemi Omitaomu, Haoran Niu. (2021). Artificial Intelligence Techniques in Smart Grid: A Survey. Smart Cities
15. Muhammad Haris Khan, Abasin Ulasyar ,Abraiz Khattak, Haris Sheh Zad ,Mohammad Alsharef, Ahmad Aziz Alahmadi, andNasim Ullah. (2022). Optimal Sizing and Allocation of Distributed Generation in the Radial Power Distribution System Using Honey Badger Algorithm, Energies, Volume 15, Issue 16.

Doi: https://doi.org/10.52132/Ajrsp.e.2023.56.2