IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.53

Volume 4, Issue 2, September 2024

Optimal Placement of DG in Radial Distribution using Optimization: A Review

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Abstract: *The restructuring of the electricity market and the shift towards power generation technologies aimed at reducing global greenhouse gas emissions have led to a rise in the use of distributed generation (DG). Recent developments in electric power, along with the challenges of building and maintaining large power plants, have generated significant interest in DG. DG presents a viable solution to issues like load growth, line overloading, supply quality, equipment maintenance intervals, and reducing line losses. Unlike centralized power plants, DG involves setting up power systems as close to consumers as possible. However, implementing DG in radial systems comes with challenges such as active and reactive power loss, voltage profile, sizing, and placement of DG units, and reliability. To address these challenges, researchers have used various biological and evolutionary algorithms, including analytical methods, numerical approaches, metaheuristic approaches, and hybrid approaches. These algorithms take into account design variables (such as location, size, and type of DG units) and load variables (constant or variable power) to meet specific requirements. They have been tested on different bus systems. This paper reviews the techniques proposed for the optimal placement of DG in radial distribution systems, highlighting their effectiveness.*

Keywords: Particle Swarm Optimizer (PSO**),**Radial Distribution System (RDS), Optimal Power Flow (OPS), Distribution Network (DN), Distributed Generator (DG)

I. INTRODUCTION

The optimization and integration of distributed generation (DG) in distribution networks have been extensively studied in recent years, focusing on enhancing system efficiency, reliability, and sustainability.

Teshome and Lian (2018) Their model aims to optimize the network configuration to minimize power losses while maintaining system reliability, demonstrating significant improvements in distribution network performance through strategic DG placement .Wu et al. (2018) This method enhances the resilience and stability of microgrid operations, particularly in scenarios involving multiple interconnected systems. Xing et al. (2018) The study highlighted the importance of strategic planning in integrating renewable energy to reduce environmental impact and improve network sustainability. Wu and colleagues (2018) This method offers a practical solution for handling the complexities associated with DG integration .Cheng, Zeng, and Yao (2018) Their method is based on security distance metrics, which help ensure system stability and security under varying operating conditions. Gaikwad et al. (2018) examined the potential of green and sustainable technology, specifically through solar PV rooftop installations, for DG. Zhang et al. (2018) Their method involves identifying strategic locations that maximize the benefits of DG integration, including loss reduction and voltage profile improvement. Raju and Jain (2018) Their study emphasizes the importance of understanding the interactions between different DG units and the load characteristics in isolated networks. Li et al. (2018) explored optimal DG planning in active distribution networks, particularly focusing on the integration of energy storage systems. Al-Tameemi et al. (2018) Their study highlights the potential of DG units to improve voltage profiles and enhance system stability. Zarei and Parniani (2017) introduced a comprehensive digital protection scheme for low-voltage microgrids with both inverter-based and conventional DG. Kools and Phillipson (2016) discussed the role of data granularity in the optimal planning of DG. Daiva, Saulius, and Liudmila (2017) This work serves as a valuable resource for researchers and practitioners looking to understand the different techniques available for DG planning and their respective advantages and limitations.Sultana et al. (2016) Their work consolidates various approaches, emphasizing the benefits of optimal DG deployment in improving overall network efficiency and stability.

Kumar, Babu, and Reddy (2017) Their approach leverages the evolutionary algorithm's ability to search for the best solutions in complex, multi-modal landscapes, effectively reducing losses and enhancing the operational performance of the distribution network.Shaik and Hameed (2017) Their study demonstrated that proper DG allocation could significantly reduce line losses, thereby improving the efficiency of power delivery to end-users.Madesha and Kumar (2015) investigated the optimal placement and sizing of multiple DGs for loss reduction in distribution systems. Jahnavi and Kumar (2016) Their methodology accounts for the specific characteristics of primary distribution networks, offering a tailored solution to minimize losses and enhance the overall reliability of power distribution.Sasanka and Guntupalli (2016) explored the allocation of multiple DGs in radial distribution feeders, focusing on minimizing losses. Singh, Ghosh, and Murari (2015) Their study emphasized the importance of sensitivity analysis in understanding the impact of DGs on system parameters, enabling more precise and effective placement strategies.Gupta and Rao (2016) Their study utilized optimization techniques to identify optimal locations for DGs, emphasizing the reduction of power losses across the network. Harika, Kanth, and Babu (2015) Their approach provides a practical means of optimizing DG placement, ensuring that the benefits of distributed generation are maximized.Phanikumar and Rao (2016) compared voltage stability and loss reduction using modal analysis and sensitivity methods. Yang et al. (2016) introduced a cooperative model predictive control (MPC) framework for distributed photovoltaic (PV) power generation systems. Viral and Khatod (2012) This work serves as a valuable resource for understanding the diverse strategies available for DG planning, including economic and technical considerations.Tan et al. (2013). They examined various methodologies, including analytical, heuristic, and hybrid techniques, for integrating renewable energy sources into distribution networks. Montoya, Gil-González, and Grisales-Noreña (2020) presented an exact Mixed-Integer Nonlinear Programming (MINLP) model for the optimal location and sizing of DGs.Mahmoud et al. (2018) focused on fault diagnosis and fault-tolerant operation in DFIG-based wind energy systems. Din et al. (2019) examined the efficient sizing and placement of DGs in cyber-physical power systems.

Overall, these studies contribute to the growing body of knowledge on the optimal deployment of DGs in distribution networks.

II. OBJECTIVE

The main goals of optimally placing DG can be divided into single and multi-objective functions, which include:

- Reducing total power loss and enhancing the voltage profile within a distribution system.
- Identifying design variables such as the size and location for DG placement in a distribution system.
- Ensuring reliability constraints, such as minimizing the system average interruption duration index (SAIDI).
- Maximizing voltage limits load ability, which means ensuring the distribution system can supply the maximum load while keeping all nodes within their voltage limits.
- Different types of DGs based on various attributes are illustrated in Figure 1.
- Figure 2 depicts the integration of photovoltaic (PV) and wind DGs into the distribution network to meet the load demand of various consumer types.

III. TECHNICAL IMPACTS OF DG

When integrating DGs into distribution networks, several technical issues arise that must be addressed to improve system reliability. This section reviews these technical challenges:

A. Capacity- Integrating DG at the distribution level can impact the total power capacity of equipment such as distribution cables, power lines, and transformers.

B. Protective Devices-In RDN, power flow is typically unidirectional without DG. However, connecting DG in parallel with the grid changes the power flow to bidirectional, potentially causing system imbalances.

C. Power Losses- Power losses are directly related to system efficiency. Higher power losses decrease overall system efficiency. Installing DG can reduce line current in parts of the system, thereby decreasing power losses.

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D. Voltage Regulation-Voltage regulation in DN is usually planned based on forecasted load variations. After DG integration, the direction of power flow changes, impacting voltage regulation.

E. Additional Impacts-There are several other technical impacts, including:

Voltage unbalances caused by single-phase DG installations.

Increased short circuit levels, leading to higher fault currents.

Power conditioning issues, such as harmonics when DG technology delivers DC power while AC is required at the consumer end.

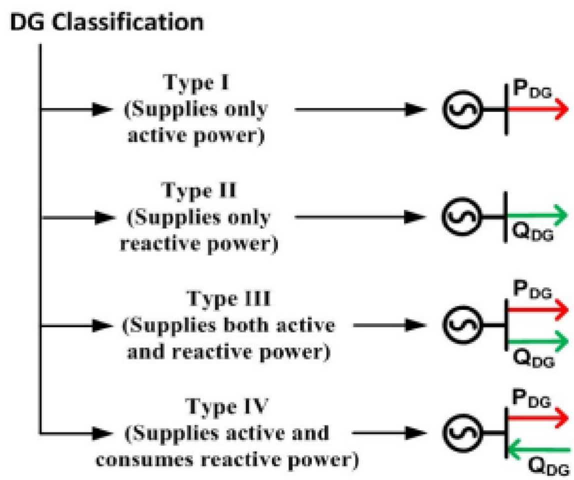

Fig. 1 Types of DGs

IV. STRATEGIES FOR INSTALLATION OF DG

To obtain To achieve the optimal placement of DG, this paper adopts a strategy that identifies and resolves the problem by determining the best locations, sizes, and numbers of DG units. The approach involves using artificial intelligence technology to evaluate design and load variables, which will then be tested on the IEEE bus system.

A. Number of DG units:

Single DG

Multiple DG

IEEE bus test system

Design variables with load variables.

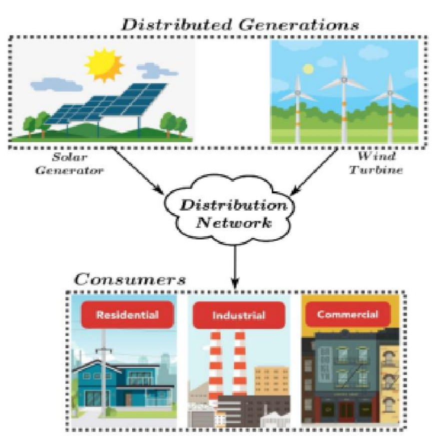

Fig. 2 Interconnection of DGs

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V. OPTIMIZATION TECHNIQUES

Optimization Techniques in Distribution Systems

Optimization techniques are crucial for enhancing the performance, reliability, and efficiency of distribution systems. Here are some common types of optimization techniques used:

1. Analytical Methods

Mathematical Programming- Includes linear programming (LP), nonlinear programming (NLP), and mixed-integer programming (MIP). These methods provide precise solutions but can be computationally intensive for large systems.

Optimal Power Flow (OPF) - Used to determine the optimal operating conditions for power systems, considering various constraints and objectives such as minimizing power loss or improving voltage profiles.

2. Heuristic and Metaheuristic Methods

Genetic Algorithms (GA)-These evolutionary algorithms mimic natural selection processes to find optimal solutions by evolving a population of potential solutions over several generations.

Particle Swarm Optimization (PSO)-Inspired by the social behaviour of birds and fish, this method optimizes a problem by having a population of candidate solutions, called particles, move around the search space.

Ant Colony Optimization (ACO)- Mimics the foraging behaviour of ants to find optimal paths and is particularly useful for solving combinatorial optimization problems.

3. Artificial Intelligence (AI) Techniques

Artificial Neural Networks (ANN)-These are computational models inspired by the human brain, capable of pattern recognition and learning from data, useful for load forecasting and fault diagnosis.

Fuzzy Logic - Used to handle uncertainty and approximate reasoning, making it useful for complex decision-making processes in power systems.

Machine Learning-Techniques such as support vector machines (SVM) and reinforcement learning (RL) are used for predictive analysis and adaptive control in distribution systems.

4. Hybrid Methods

Combination of Heuristic and Analytical Methods-These methods leverage the strengths of both approaches to provide more efficient and robust solutions. For example, hybrid methods may use GA for global search and LP for local refinement.

Multi-Objective Optimization-Techniques like Pareto optimization handle multiple conflicting objectives, providing a set of optimal solutions known as Pareto fronts, which help in decision-making processes.

5. Simulation-Based Methods

Monte Carlo Simulation- Used to understand the impact of uncertainty and variability in system parameters by performing repeated random sampling.

Agent-Based Modeling-Simulates the actions and in Optimization Techniques in Distribution Systems

Each of these optimization techniques has its advantages and applications, often chosen based on the specific requirements and constraints of the distribution system problem at hand. teractions of autonomous agents to assess their effects on the system, useful for understanding complex dynamics in distribution networks.

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VI. CONCLUSION

This paper offers a concise review of various methodologies and optimization strategies for the placement of Distributed Generators (DG). The review highlights that the primary aim of most studies is to minimize power loss and optimize the load design of the system for DG placement, considering both site selection and size. It is observed that many models necessitate multiple DG placements. Previous research has explored numerous techniques, including analytical, numerical, heuristic, and hybrid methods. While the analytical method is straightforward and quick to execute, genetic algorithms and various meta-heuristic algorithms are noted for their popularity and efficiency. The results of a new proposed algorithm are compared within this context. Potential drawbacks of these algorithms could inform future research, which may focus on new objectives such as dynamic optimal placement of DG, dependent and stochastic optimization, and island operation.

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