

# **A COMPREHENSIVE REVIEW OF OPTIMAL DISTRIBUTED GENERATION PLACEMENT IN DISTRIBUTION NETWORKS USING GENETIC ALGORITHM–BASED TECHNO-ECONOMIC APPROACHES**

Divyanshi Tanwar<sup>1</sup>, Sanjay Kumar Bansal<sup>2</sup>

M. Tech – Scholar<sup>1</sup>, Associate Professor<sup>2</sup>

Bikaner Technical University, Bikaner, (Raj.), India

**Abstract:** The increasing penetration of distributed generation (DG) sources such as solar photovoltaic, wind, and hybrid renewable systems has transformed conventional electric power distribution networks into more active and complex systems. Optimal placement and sizing of DG units have therefore become critical to achieving technical efficiency and economic viability while maintaining system reliability. This paper presents a comprehensive review of optimal DG placement in distribution networks using genetic algorithm (GA)–based techno-economic approaches. The review begins with an overview of electric power distribution systems, including primary, secondary, and DC distribution configurations, highlighting their operational characteristics and challenges. A detailed literature survey is then presented, covering conventional mathematical optimization techniques, heuristic algorithms, and hybrid optimization methods applied to DG placement problems. Furthermore, the paper discusses optimization and bio-inspired computational intelligence techniques, emphasizing different computational and

evolutionary approaches used to handle the nonlinear, multi-objective nature of DG planning. Special attention is given to the application of genetic algorithms, outlining their formulation, encoding strategies, fitness functions, and advantages in minimizing power losses, improving voltage profiles, and reducing overall system costs. Finally, potential future research directions are identified, including the integration of smart grid technologies, uncertainty modeling of renewable sources, and real-time optimization frameworks. The review aims to provide researchers and power system planners with a structured understanding of GA-based DG placement methodologies suitable for modern distribution networks.

**Keywords:** Distributed Generation, Genetic Algorithm, Distribution Network Optimization, Techno-Economic Analysis, Power Loss Minimization

## **I. INTRODUCTION**

Increase in the requirement levels of electric power, coupled with the requirement to have more

eco-friendly alternatives of electric power, has caused considerable changes in the configuration of electric power distribution networks. Distributed Generation (DG), which is defined as the localized generation of electric power with the electric power being required at the point of utilization, has become an important alternative in the configuration of modern electric power networks. Some of the main advantages of electric power networks, due to the implementation of the DG alternative, include the reduction of losses in the electric power transmission cable, improvement in the voltage profile of the produced electric power, as well as the utilization of renewable resources.

The locations of DG units are determined in an effort to bring in a delicate balance between the minimization of power loss, system stability, voltage regulation improvement, and economic benefit maximization. On the other hand, inappropriate placement can cause an increase in losses, power quality degradation, and underutilization of resources. Therefore, robust optimization techniques are required, which can handle this multi-objective constrained problem.

Genetic Algorithm is a population-based metaheuristic inspired by the principles of natural selection. It has gained wide acceptance for solving complex optimization problems in power systems. Being inherently adept at exploring big solution spaces and escaping from local optima, GA is quite suitable for the DG placement problem. GA ultimately finds the optimal

configuration of the DG units to achieve desired techno-economic objectives by evolving iteratively a population of candidate solutions[1].

This paper deals with DG placement in distribution system networks using GA, focusing on techno-economic considerations. The objective of the paper includes minimizing active as well as reactive power loss, enhanced voltage profile, as well as economic feasibility analysis of DG integration in distribution networks. The proposed method includes various system constraints, i.e., limitations of power flow, regulations of voltage, etc.

According to the paper, such detailed simulations are used in the research to evaluate the performances of the GA-based approach in different case studies, indicating its efficiency in yielding both economic benefits and technical advancements in the systems involved in the process. Furthermore, it is stated that the results of this particular paper will be highly effective in integrating distributed resources in an efficient manner in terms of economic benefits [2].

## **II. TYPES OF ELECTRIC POWER DISTRIBUTION SYSTEMS**

### **1. Primary Distribution System**

The voltage level in a main distribution system is higher than the voltage level in a usage system. People usually say that voltage values between 3.3 kV and 11 kV are within the range of the three-phase, three-wire primary distribution system.

Large users, like business buildings, industrial facilities, and other similar places, get their power from the main distribution system. The power level is lowered to a lower level at the use level by using a step-down transformer. It is close to the consumer site where this transformer is located. The next picture shows how a main distribution system is usually set up.

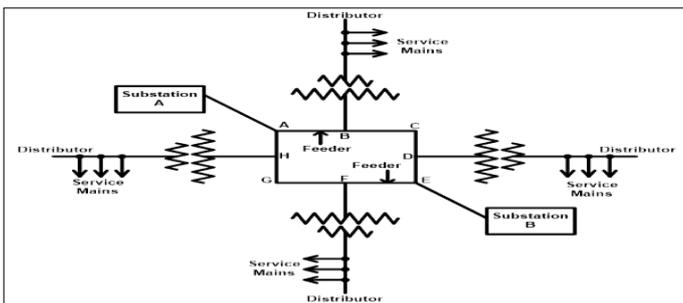


Figure 1: Primary Distribution System

## 2. Secondary Distribution System

The amount of use decides how the power is sent through a secondary distribution chain. Finally, there is a transformer in the main distribution system that changes 11 kV to 415 V. And the lower-end consumers get this power immediately.

Typically, the primary winding of the transformer is linked in a delta configuration, while the secondary winding is configured in a star connection. This results in the formation of a ground terminal.[5] This arrangement is used in most of this transformer. As a result, the secondary distribution system is made up of a three-phase, four-wire system.

This country's rules say that any phase with a neutral input and a voltage of either 230 V or 120

V can be used to make a single-phase supply. For home and small business projects, it is normal to use a single-phase supply.

People who use electricity in three phases, like grain mills, small businesses, and other similar places, need it. People in this type of consumer use the R, Y, B, and N terminals to connect to a three-phase power. There is a diagram below that shows how the secondary delivery network is established.[6]

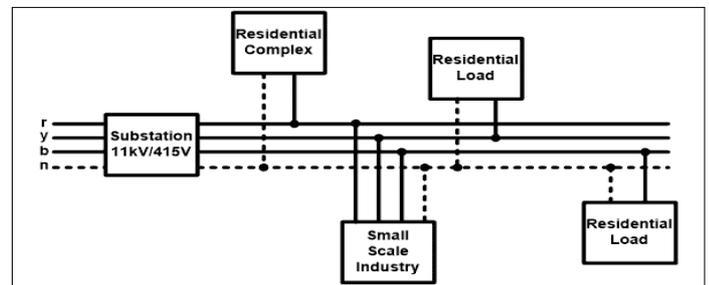


Figure 2: Secondary Distribution System

## 3. DC Distribution System

A lot of the things that are plugged into the grid are AC loads. But there was one time when we needed DC power. DC power is used in the distribution system for these tasks. The DC distribution system is the name of this set of parts.

The conversion of power from alternating current (AC) to direct current (DC) is accomplished through the use of a rectifier or rotating converter. Utilizations requiring direct current (DC) power encompass applications such as traction, DC motors, battery charging, and etching.

According to the connection of DC system, it is classified into two types;

- Two-wire DC distribution system
- Three-wire DC distribution system

#### 4. Two-wire DC Distribution System

One of the lines will have a positive potential level when they are connected, and the other will have a negative potential level, which is also called undefined potential. This kind of distribution device only needs two wires. A wire that is believed to be in good health is one that is connected to a positive potential level.

At the point where two lines meet, the load is linked in parallel. Some of the types of loads that are linked in this method are lamp loads and motor loads. It is possible to connect the load to two ports at a time in this setup. At the bottom of this page is a drawing that shows how this system's parts are connected.[7]

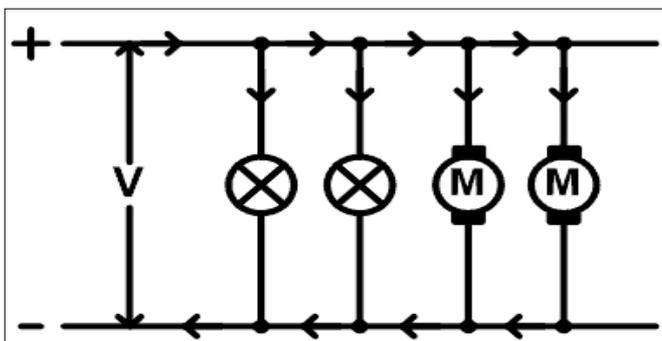


Figure 3: Two-wire DC Distribution System

#### 5. Three-wire DC Distribution System

A distribution system like this needs three wires. Two of the lines are healthy, and the third wire is neutral. People believe that the best thing about this system is that it has two different voltage settings. Take a look at this case: A voltage level

of  $+V$  and  $-V$  can be found on two decent wires. The neutral line can be used in networks with no potential. Between a neutral wire and a healthy wire, there is a voltage of  $V$  volts that can be used. If a load is attached between both of the healthy wires, this makes a voltage of  $2$  volts available. So, when two healthy wires are connected, the load needs a higher voltage. When one healthy wire is connected to a neutral wire, also, the load needs a lower voltage. There is one wire that is linked to both of these voltages. [8]

### III. LITERATURE SURVEY FOR OPTIMAL DG PLACEMENT

DG placement in a system relies primarily on strategically choosing buses for real-time monitoring and ensuring full system observability. Various criteria for selection have been addressed in literature studies that have been previously released.

Network observability is the ability of a state estimator to find a specific state solution based on measurements, their location, and the network's topology. Achieving full observability requires the optimal placement of DG. Installing a DG at every bus of a wide area network is not cost-effective or essential. Currently, power system experts face difficulties in locating Distributed Generation due to multiple factors such as system observability, normal and abnormal conditions, topology constraints, hybrid search methods, realistic costs, and new developments in relaying, as well as the integration of zero-injection and radial buses. The issue of optimal placement of DG addresses the

number of optimal DG units to be utilized and their suitable locations on the power system. The goal is to determine the smallest number of DG necessary to ensure the entire system is observable, along with identifying the best locations for the devices.

In order to obtain an optimal solution, the placement of DG is classified into:

1. Mathematical algorithm
2. Heuristic algorithms
3. Hybrid algorithm

### **1. Conventional Mathematical Optimization Techniques [2]-[3]**

Mathematical algorithm optimization techniques refer to a set of methods and approaches used to improve the performance and efficiency of mathematical algorithms. These techniques aim to find the best possible solution within a given set of constraints, such as time, resources, or objective function. The various mathematical algorithms mentioned in the literature are categorized as [6]:

- **Integer Linear Programming**  
Seyed-Ehsan Razavi, Hamid Falaghi , Chanan Singh , Jamshid Aghaei ,and Ali Esmaeel Nezhad proposed a novel linear approach for PMUs placement to ensure the topological observability taking into consideration the impacts caused by the adjacent zero-injection buses [3].
- **Exhaustive search**

Abdul Aziz G. Mabaning and Jordan Rel C. Orillaza presents an optimized version of exhaustive search (ES) algorithm for OPP. That algorithm reduces the search space and the number of computations compared to the traditional ES. Results indicates that the proposed algorithm performed better than integer linear programming (ILP) and ES in finding all the possible solutions for OPP [4]

- **Weighted Least Squares**

Nikolaos M. Manousakis and George N. Korres presents an iterative weighted least squares algorithm with real placement variables to solve the OPP problem for complete observability. The optimal solution is obtained by an unconstrained nonlinear weighted least squares approach. This algorithm is easy to implement using available routines in existing state estimators, avoiding specialized mathematical optimization libraries. The proposed model is tested on IEEE standard systems (14 bus, 30-bus, 57-bus and 118-bus) and the simulation results indicate the effectiveness of the proposed OPP method [2].

### **2. Heuristic Algorithms [5]-[6]**

Heuristic algorithms for optimization are a class of algorithms that use rules of thumb, intuition, or approximate methods to find good solutions to optimization problems. These algorithms provide

efficient and satisfactory results, especially for complex problems where finding exact solutions is computationally expensive or infeasible. The different heuristic algorithms mentioned in the literature are:

- **Simulated Annealing**

A. Y. Abdelaziz, Amr M. Ibrahim and Reham H. Salem introduced three approaches i.e. Depth First Search, Simulated Annealing and Minimum Spanning Tree to reduce the computational burden. It has been found that the optimal PMU placement decreases the number of PMUs which results in decreasing in the cost, and obtains better power network operation and monitoring [5]

- **Taguchi Binary Bat Algorithm**

Basetti Vedik and Ashwani K. Chandel proposed a hybrid Taguchi binary bat algorithm (TBBA) for optimal placement of PMUs by ensuring complete observability of the power system. TBBA combines the systematic reasoning ability of the Taguchi method with the traditional binary bat algorithm thereby enhances the initial population, and subsequently, improves the computational efficacy of the solution. Results shows that the proposed technique yields multiple global optimal solutions in single experimental run and provides solution with lesser computational time [6].

- **Modified Imperialist Competitive Algorithm**

Seyed Abbas Taher, Hamed Mahmoodi and Hojjat Aghaamouei presented a modified imperialist competitive algorithm (MICA) for optimal placement of phasor measurement units (PMUs) in normal and contingency conditions of power systems. Depending on the starting point, the optimization scheme may generate different sets of optimal solutions. To obtain the best solution among the different sets of solutions, measurement redundancy must be maximized. Results showed that MICA is a very fast and accurate algorithm for OPP solution [7].

- **Genetic Algorithm**

M. Meenakshi Devi, M. Geethanjali and A. Rama Devi introduced a method to locate the fault for multi-terminal transmission lines with optimal number of Phasor Measurement Units. For optimization, the Genetic algorithm is used. The pre-fault and post-fault data (voltage and current values) recorded by the Phasor Measurement Units are used to estimate the exact location of the fault. The test results shows the accuracy and the enhancement of spotting the exact location of the fault with latitude and longitude [8].

### **3. Hybrid Optimization Techniques [7]-[8]**

Hybrid optimization techniques combine two or more algorithms to hold their respective strengths and overcome their limitations. By combining

different optimization approaches, hybrid techniques aim to enhance the optimization process and improve the quality of solutions obtained.

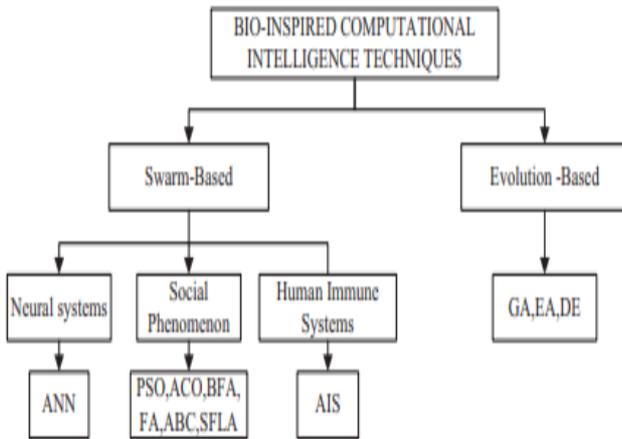
Fang Zhang ,Lin Cheng ,Xiong Li, Yuanzhang Sun, Wenzhong Gao and Weixing Zhao proposed a real time data compression and adapted protocol technique for wide area measurement system (WAMS).Their compression algorithm combines Exception compression (EC) with swing door trending (STD) compression. The compression techniques and protocols were applied to PMUs of a hydro power plant in Guizhou Power Grid in South-West China.The results demonstrated that this compression can reach the compression ratio in the range of 6 to 11. This compression and adapted protocol technique can reduce the size of data packets by approximately 75% with high accuracy in both steady and dynamic states [9]. Due to the high cost involved in a PMU, the Optimal PMU Placement (OPP) problem has become a critical task for power system on-line applications. N.P. Theodorakatos , N.M. Manousakis, and G.N. Korres solved this problem by using genetic algorithm and a binary integer linear programming (ILP) method. Simulation results shows that The ILP is a powerful optimization tool for the solution of the OPP problem as well as its computational time is quite small and the genetic algorithm can give multiple optimal PMU placement sets with different measurement redundancies [10].

#### **IV. OPTIMIZATION & BIO-INSPIRED COMPUTATIONAL INTELLIGENCE (CI) TECHNIQUES**

Essentially, CM is a complex issue involving numerous variables that can be solved using optimization algorithms. Modern power systems face intricate challenges because of their complicated architecture, large geographical variations, and unpredictable factors. Continuous improvements have been made in metaheuristics optimization algorithms to decrease computational time, enhance solution quality, and tackle larger instances. Hybridizing techniques are intriguing for their adaptability to a diverse range of issues, making them particularly noteworthy. Swarm intelligence and metaheuristics algorithms are categorized as bio-inspired algorithms that have a extensive track record in addressing optimization problems.

During the optimization of a specific problem, Bio-inspired optimization algorithms like GA and PSO have various behavioral parameters that influence their effectiveness. Efficient optimization is promoted by a carefully chosen set of parameters. Adjusting parameters by hand is a time-consuming process. Bio-inspired optimization algorithms demonstrate the ability to produce optimal results in scientific applications.

Figure 4: Classification of Bio-Inspired CI Techniques



Engineering solutions to complex computational problems in recent years. The Bio-inspired CI Techniques classification is shown in Fig. 4.1. The literature [40–43] used CI techniques in pool and hybrid models of DPM for finding the best position and control of FACTS devices to mitigate congestion.

Table 1: Different CM Approaches

CM Method	Methodology	Demerits
<b>Generation Rescheduling</b>	For CM, an adequate number of generator power outputs have been rescheduled.	Any variation in generator power outputs would result in a restructuring of economic aids among GENCOs and economic income loss
<b>FACTS devices</b>	Here, congestion is alleviated by positioning FACTS devices at appropriate sites based on power flow control in the network	There is a little financial burden on the system, and frequent monitoring is needed because of load fluctuations and RES uncertainties.
<b>Optimization techniques</b>	Quickly mitigate congestion in DPM, although they are multi-objective or complex systems.	Optimization methods are mostly depending on non-linearity and the number of variables of the problem. In some cases, the computation time is more.
<b>Re-dispatch</b>	Congestion has been alleviated by controlling generator outputs up and down based on ISO instructions	Influence other generator's profits. Many generators reduce their level of efficiency while others increase their generation

<b>ATC</b>	At the time of dispatch, congestion was relieved here based on ATC values.	Line loading exceeds the full capacity of the line, ATC technique not successful for CM.
<b>Demand Response</b>	Here, customer involvement in power market activities has eased congestion. DR supports the cycle of rescheduling load equipment, i.e., moving loads from vital hours to non-critical hours and adjusting load patterns.	The operations of the market are becoming complex. More needs for broad demand response techniques are needed for monitoring, communications, and exact forecasting technology
<b>Distributed generation</b>	The optimum number of DG units is in a good position based on changes in the system's power flow and injects power at buses to minimize congestion.	To preserve the system's safety, reliability, and stability due to RES uncertainties, the DPM needs to monitor market activities complexly and with high standards.

**V. USE OF GENETIC ALGORITHM FOR OPTIMAL DISTRIBUTED GENERATION PLACEMENT IN DISTRIBUTION NETWORKS**

This diagram illustrates how a Genetic Algorithm (GA) is used to determine the optimal placement and sizing of Distributed Generation (DG) units in a distribution network. It starts with input data such as load demand, network topology, candidate DG locations, and cost relevant for modern Indian distribution systems integrating renewable energy under smart grid initiatives.

constraints, followed by population initialization. The GA then iteratively performs selection, crossover, mutation, and fitness evaluation to minimize power losses and improve voltage profiles. Through repeated evolution, the algorithm converges to the best DG locations (e.g., solar or wind), resulting in reduced losses and enhanced voltage stability—an approach especially

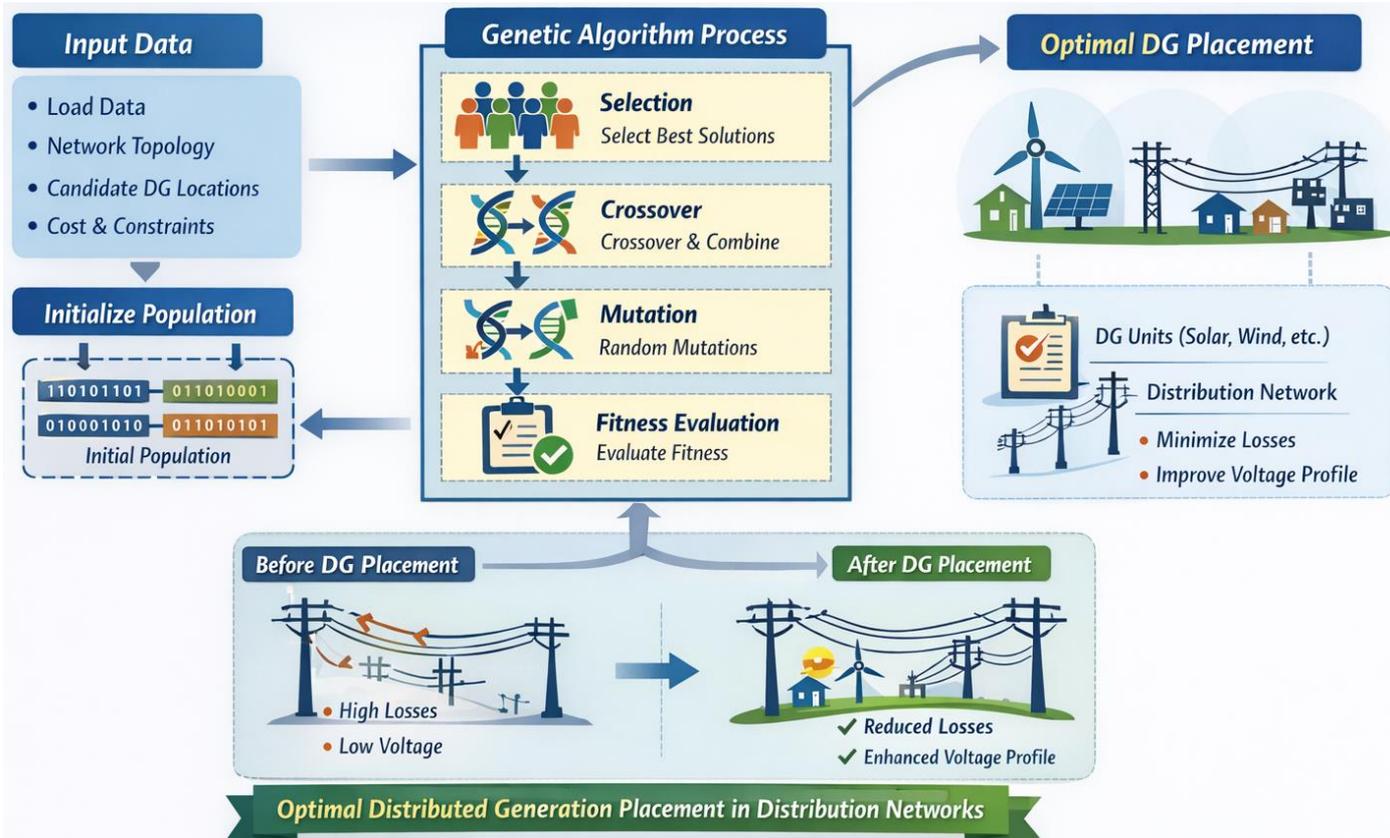


Fig. 5 Optimal Distributed Generation using Genetic Algorithm

## VI. DISCUSSION AND CONCLUSION

This comprehensive review concludes that genetic algorithm-based techno-economic approaches represent one of the most effective solutions for optimal DG placement in distribution networks. By efficiently exploring a wide search space and avoiding local optima, GAs outperform many conventional and heuristic methods in terms of solution quality and flexibility. The integration of GA with bio-inspired and hybrid computational intelligence techniques further enhances system performance and planning accuracy. Future research should focus on real-time and adaptive GA frameworks, incorporation of uncertainty in renewable generation, and coordination with advanced distribution management systems. Such

advancements will support the development of resilient, efficient, and sustainable distribution networks aligned with evolving power system requirements.

## VII. FUTURE WORK

Future studies may explore the economic aspect of identifying the shortest time period needed for profits from reducing technical losses to offset the costs of implementing, operating, and upkeeping distributed generation units, considering different demand scenarios. Future research may also focus on hybrid optimization techniques that combine Genetic Algorithms with other advanced metaheuristic or artificial intelligence methods, such as Particle Swarm Optimization, Machine

Learning, or Reinforcement Learning. Such hybrid approaches could improve convergence speed, solution accuracy, and computational efficiency, especially for large-scale distribution networks.

The scope of this work can further be extended by incorporating energy storage systems (ESS) and electric vehicle (EV) charging infrastructure into the optimization model. Coordinated planning of DG, storage, and EVs would be highly relevant for future distribution systems, supporting initiatives such as smart cities, electric mobility, and renewable energy integration under national missions like “Digital India” and “National Smart Grid Mission.”

Finally, real-time implementation and hardware-in-the-loop (HIL) validation of the proposed optimization framework can be explored in future studies. This would bridge the gap between simulation-based research and practical deployment by distribution utilities, enabling adaptive and intelligent DG planning solutions for modern power distribution networks.

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