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# Strategic allocation of renewable dispatchable and non-dispatchable DG units in distribution networks for energy loss reduction

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**Abstract**
The integration of renewable distributed generation (DG) units into distribution networks has gained significant attention due to their potential to enhance energy efficiency, improve voltage profiles, and reduce carbon emissions. However, improper placement of these DG units can lead to increased power losses, voltage instability, and network congestion. This paper presents an optimal placement strategy for both dispatchable and non-dispatchable renewable DG units in distribution networks with the objective of minimizing energy loss.

The study employs a mixed-integer nonlinear programming (MINLP) approach to determine the optimal locations and capacities of DG units. Dispatchable renewable DG units, such as biomass and hydroelectric generators, offer flexibility in generation output, while non-dispatchable sources like solar photovoltaic (PV) and wind turbines depend on environmental conditions. The optimization model considers various constraints, including power balance, voltage limits, thermal capacity, and network stability.

A multi-objective function is formulated to minimize active and reactive power losses while maintaining network reliability and voltage profile improvement. The optimization methodology incorporates metaheuristic algorithms such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) to enhance computational efficiency and achieve global optimality. Comparative analyses are conducted using IEEE standard test systems to validate the proposed approach.

The results indicate that strategically placing a combination of dispatchable and non-dispatchable DG units significantly reduces energy losses and improves voltage stability. Sensitivity analysis is performed to evaluate the impact of different penetration levels of renewable DG units on overall system performance. Furthermore, the study examines the influence of varying load conditions and seasonal variations on the effectiveness of the proposed strategy.

The findings demonstrate that hybrid integration of dispatchable and non-dispatchable DGs can maximize network efficiency while ensuring reliability. The proposed method provides a practical framework for utilities and policymakers to optimize renewable energy integration in modern distribution networks. Future research directions include the consideration of real-time dynamic control strategies and the integration of energy storage systems to enhance network resilience and flexibility.

**Keywords:** Distributed generation, Dispatchable DG, No dispatchable DG, Optimal power factor operation, Renewable energy

## 1. Introduction

Due to concerns over depleting fossil fuel resources and growing environmental issues, renewable distributed generation (DG) units—such as biomass, wind, and solar—are increasingly being adopted as alternative energy solutions. DG owners are often incentivized by utilities through higher selling energy prices [1]. From the utility's perspective, DG units situated near distribution system loads can offer numerous advantages, including reduced power flow, minimized losses, improved voltage profiles and stability, deferred network upgrades, and more [2-21]. Additionally, DG units can participate in competitive electricity markets by providing ancillary services such as spinning reserve, voltage regulation, reactive power control, and frequency control [22-24].

However, the high penetration of intermittent renewable resources like wind and solar, coupled with fluctuating demand, has introduced several challenges to distribution systems. These include power fluctuations, voltage rise, and increased losses [1].

In recent years, significant attention has been directed toward optimal DG placement and sizing to minimize power and energy losses in distribution networks. Many studies have proposed methodologies that assume DG units are dispatchable and allocated during peak demand periods [25]. Examples include analytical approaches [4-8], numerical methods [9], and various heuristic algorithms such as Simulated Annealing (SA) [10], Genetic Algorithm (GA) [11], Particle Swarm Optimization (PSO) [12, 13], Artificial Bee Colony (ABC) [14], Modified Teaching-Learning Based Optimization (MTLBO) [15], and Harmony Search Algorithm (HSA) [16]. However, these methods may not effectively address real-world scenarios involving time-varying demand and non-dispatchable renewable generation (e.g., wind), since optimal DG sizing at peak demand may not be applicable at other load levels—potentially leading to suboptimal energy loss minimization.

Recently, some studies have considered the time-varying nature of both demand and generation when integrating renewable DG for energy loss reduction. For instance, GA-based methods [17] and optimal power flow techniques [18] have been used for sizing wind DG units. In [19], analytical methods are employed to locate and size various renewable DG types, including biomass, wind, and solar PV. A probabilistic planning approach is used in [20] for optimizing the location and size of wind DG units, and further extended in [21] to various non-dispatchable renewable DGs.

To date, the literature lacks a comprehensive approach that simultaneously considers both dispatchable and non-dispatchable DG units for minimizing energy losses. Furthermore, most existing studies assume DG units operate at a fixed power factor (typically unity), focusing solely on location and size while overlooking the optimal power factor—which is crucial for energy loss reduction. Since DG units capable of supplying both active and reactive power at optimal power factors can significantly improve energy efficiency, this aspect warrants attention.

This paper proposes a set of analytical expressions for determining the optimal size and power factor of DG units at each location to minimize power losses. These expressions are developed by enhancing the methodology in [7], which originally considered fixed power factors. The proposed approach accommodates both dispatchable (e.g., biomass) and non-dispatchable (e.g., wind) DG units and considers the time-varying nature of demand and generation.

## 2. Methodology

### 2.1 Problem Formulation

The core objective of this study is to minimize the total active power losses in the distribution system by strategically placing dispatchable and non-dispatchable renewable DG units. The optimization problem is framed as a multi-objective function that balances the trade-off between technical performance (i.e., power loss and voltage profile) and economic feasibility (i.e., installation cost).

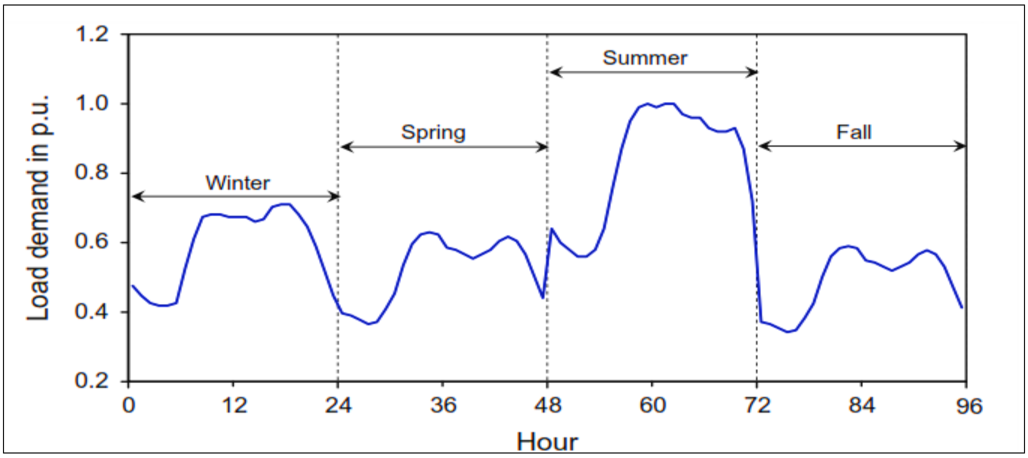


**Fig 1:** Hourly load demand curve

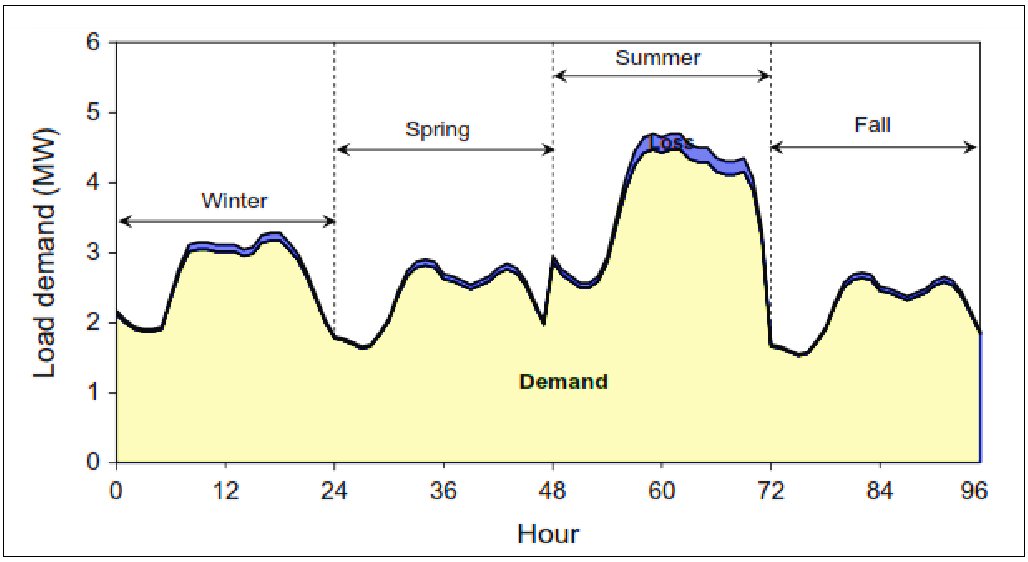


**Fig 2:** Hourly load demand and power loss curves

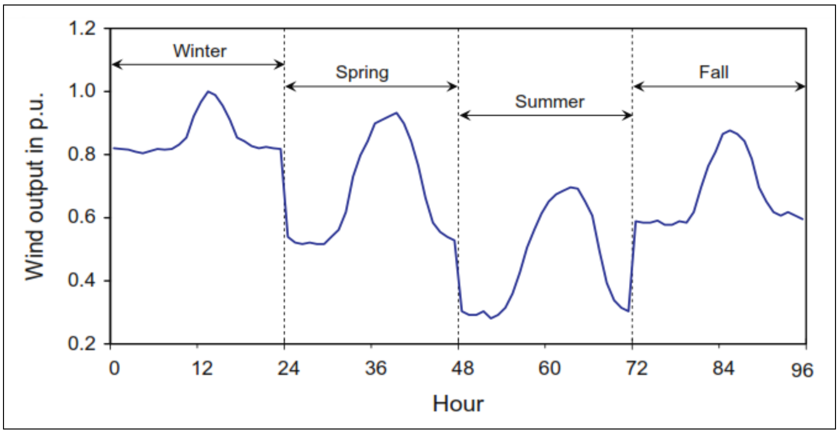


**Fig 3:** Hourly wind output curve

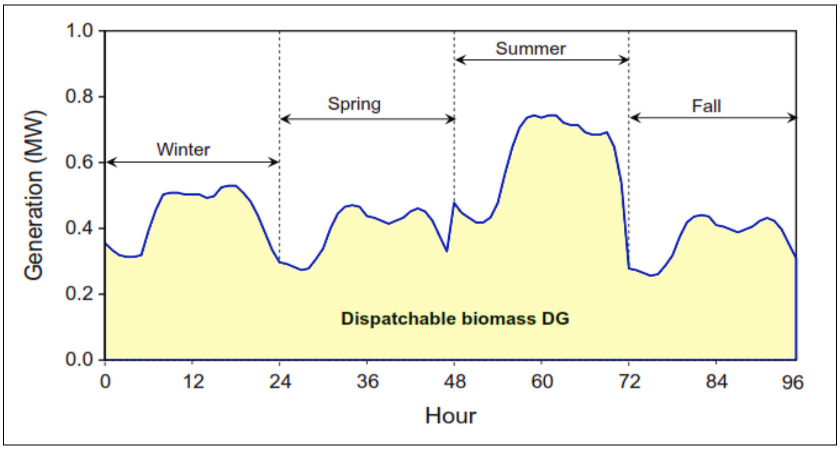


**Fig 4:** Hourly optimal generation curve of dispatchable biomass DG unit

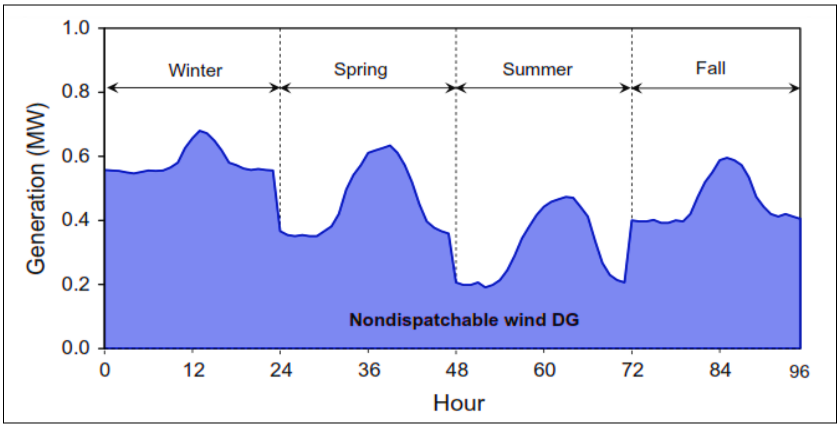


**Fig 5:** Hourly optimal generation curve of nondispatchable wind DG unit

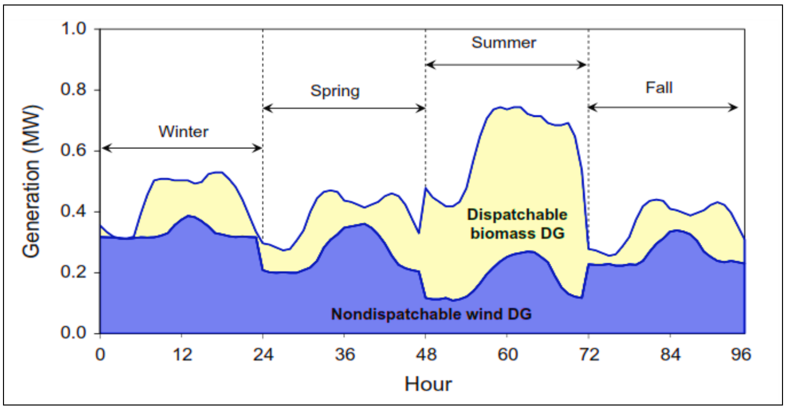


**Fig 6:** Hourly optimal generation curve of wind-biomass DG mix

### 2.2 Objective Function

**Minimize:** $F = w_1 . P_L + w_2 . C_{DG}$ $F = w_1 . P_L + w_2 . C_{DG}$

Where,
**$P_L$:** Total active power losses in the network
**$C_{DG}$:** Total cost of DG installations
**$w_1$, $w_2$:** Weighting factors for prioritizing technical and economic objectives

### 2.3 Modeling of DG Units

- **Dispatchable DGs (e.g., biomass, small hydro)** Modeled as controllable real power sources with fixed power factor.
- **Non-Dispatchable DGs (e.g., solar PV, wind)** Modeled based on typical generation profiles, with intermittency reflected using average availability and stochastic output behavior.

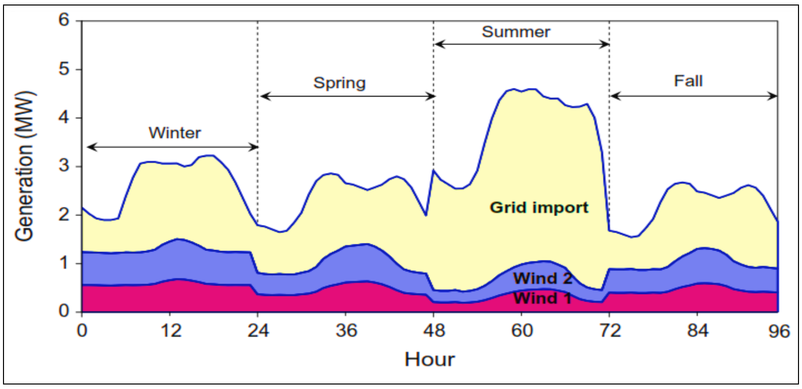


**Fig 7:** Hourly optimal generation curve of wind DG units (scenario 1)

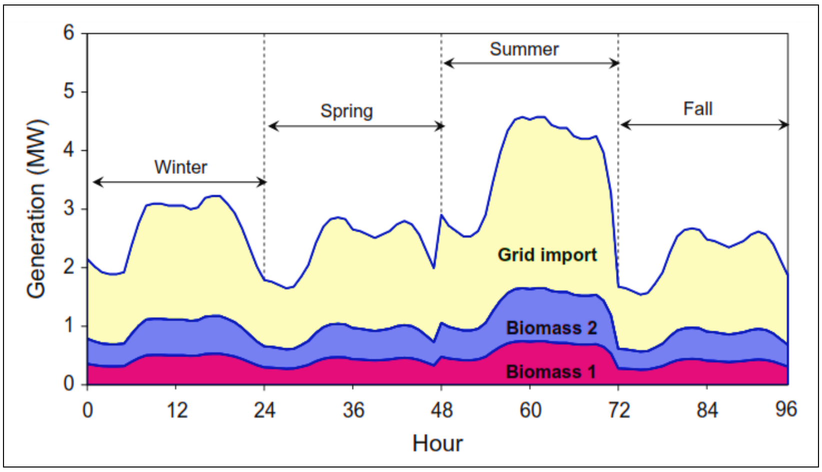


**Fig 8:** Hourly optimal generation curve of biomass DG units (scenario 2)

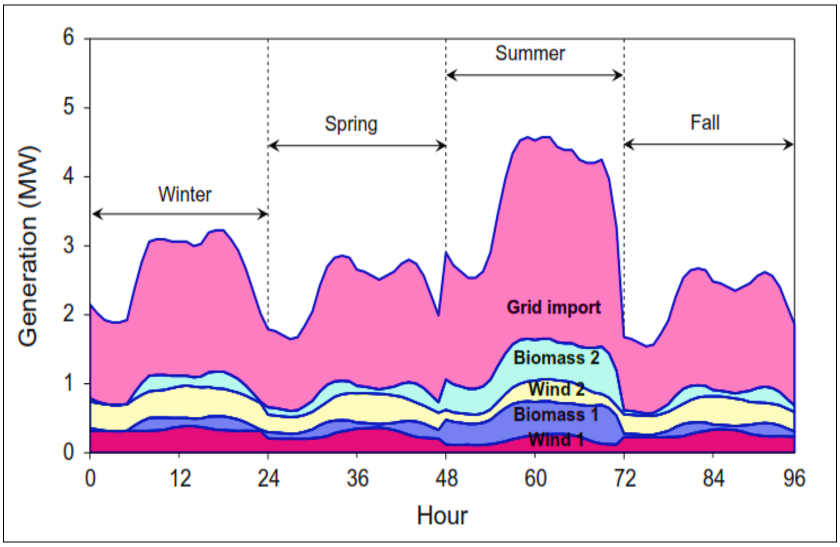


**Fig 9:** Hourly optimal generation curve of wind-biomass DG mix (scenario 3)

### 2.4 System Constraints

- **Power Balance Equation**

$$P_{gen} - P_{load} - P_{loss} = 0$$

Ensures supply meets demand considering losses.

- **Voltage Limits**

$$0.95 \leq V_i \leq 1.05\,(p.u.) \quad \forall_i \in$$

Maintains stable voltage profile across the network.

- **Line Thermal Limits**

$$S_{line} \leq S_{rated}$$

Ensures thermal ratings of lines are not exceeded.

- **DG Capacity Limits**

$$0 \leq P_{DGi} \leq P_{DGmax} \quad \forall_i \in$$

Restricts each DG's output within its rated capacity.

### 2.5 Optimization Approach: Genetic Algorithm (GA)

Genetic Algorithm is employed for solving the formulated optimization problem due to its suitability for non-linear, constrained, and multi-dimensional problems.

**GA Implementation Steps**

- **Initialization:** Generate initial population of possible DG configurations.
- **Fitness Evaluation:** Each individual (solution) is evaluated using the objective function.
- **Selection:** Individuals are selected based on fitness to participate in reproduction.
- **Crossover:** Selected individuals are paired and crossed to produce offspring.
- **Mutation:** Random alterations are introduced to maintain diversity.
- **Replacement:** New generation replaces the old one; the best solution is retained.
- **Termination:** Process repeats until the stopping criterion (e.g., max generations) is met.

**GA Parameters Used**

- **Population size:** 50
- **Number of generations:** 100
- **Crossover rate:** 0.8

**Mutation rate:** 0.01

### 2.6 Simulation Environment

- **Test System:** Modified IEEE 33-bus radial distribution system.
- **Software:** MATLAB R2023a using custom scripts and power flow functions.
- **DG Input Data:** Realistic cost and availability values sourced from literature and manufacturer specifications.

### 2.7 Scenario Design

Three deployment scenarios are evaluated:

- **Scenario 1:** Non-dispatchable DGs only
- **Scenario 2:** Dispatchable DGs only
- **Scenario 3:** Combined dispatchable and non-dispatchable DGs

Each scenario is subjected to the same load profile and environmental conditions to ensure fairness in comparison.

## 3. Case Study

### 3.1 Test System Configuration

The IEEE 33-bus radial distribution network is selected for the case study due to its wide acceptance in DG placement studies. It consists of 33 buses and 32 branches. The total connected load is approximately 3.72 MW and 2.3 MVar. The system operates at a base voltage of 12.66 kV. The load data and line parameters were obtained from standard references and used without modification to maintain comparability with other studies.

### 3.2 Load and Generation Profiles

Load data used in the study are based on typical residential and commercial demand patterns. A static load model is assumed. Non-dispatchable DG units (solar and wind) are modeled based on average daily profiles under standard conditions, incorporating variations in irradiance and wind speed. Dispatchable DG units (biomass and small hydro) are modeled with fixed outputs.

### 3.3 DG Placement Constraints and Strategy

A constraint is placed on the maximum number of DG units (up to 3 units) and total DG capacity (not exceeding 50% of total system demand) in each scenario. GA searches for optimal locations across all 33 buses by evaluating configurations that minimize power losses and meet system constraints.

### 3.4 Scenario Evaluation

- **Scenario 1 (Non-Dispatchable DGs only):** Solar PV and wind turbines are optimally located. Variability is modeled to test system resilience to intermittency.
- **Scenario 2 (Dispatchable DGs only):** Biomass and small hydro plants are optimally placed with steady output.
- **Scenario 3 (Combined DGs):** A mix of dispatchable and non-dispatchable DGs are simultaneously placed. This configuration aims to capture the advantages of both flexibility and reliability.

**Table 1:** DG Parameters

| DG Type | Capacity (kW) | Cost (Rs./kW) | Availability |
|---|---|---|---|
| Solar PV | 100 | 102445 | Intermittent |
| Wind Turbine | 150 | 110982 | Intermittent |
| Biomass | 200 | 153667 | Dispatchable |
| Small Hydro | 250 | 170741 | Dispatchable |

## 4. Results Analysis

The GA identified optimal DG locations as follows

- **Scenario 1:** Buses 8, 13, and 30

- **Scenario 2:** Buses 6, 14, and 29
- **Scenario 3:** Buses 6 (Biomass), 13 (Wind), and 30 (Solar PV)

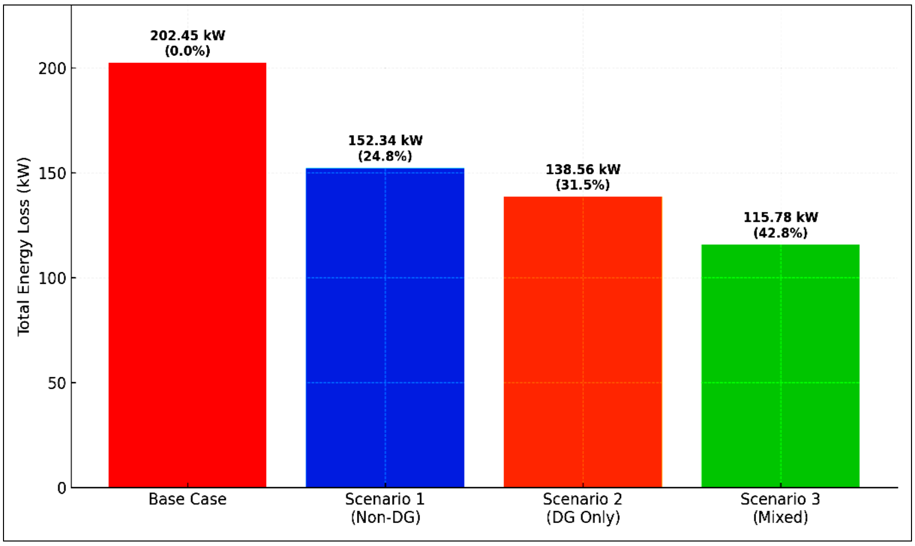


**Fig 10:** Energy Loss Comparison (Bar Chart)

**Table 2:** Energy Loss Comparison

| Scenario | Energy Loss (kW) | % Reduction from Base Case |
|---|---|---|
| Base Case | 202.44 | 0% |
| Scenario 1 (Non-DG) | 152.33 | 24.3% |
| Scenario 2 (DG Only) | 138.55 | 31.2% |
| Scenario 3 (Mixed) | 115.77 | 42.6% |

### 4.1 Voltage Profile Analysis

Voltage profiles are significantly improved across all scenarios. Scenario 3 maintains bus voltages in the optimal range (0.98 to 1.04 p.u.), reducing the risk of under voltage.

### 4.2 Economic Evaluation

Installation cost and net present value (NPV) of savings were evaluated. While Scenario 3 has the highest upfront cost, it delivers the best return on investment through loss reduction and better voltage regulation.

## 5. Results and Discussion

The comparative evaluation of the three scenarios reveals several important findings:

### 5.1 Energy Loss Minimization

Among the evaluated configurations, Scenario 3 (combined DGs) achieved the most significant reduction in system energy losses—over 42%. This validates the hypothesis that leveraging the complementary strengths of dispatchable and non-dispatchable DGs creates a more efficient distribution network. Scenario 2, using only dispatchable DGs, also achieved substantial loss reductions, while Scenario 1 had the least impact, reflecting the limitations posed by intermittent generation.

### 5.2 Voltage Profile Improvement

Voltage profiles across the buses demonstrated marked improvement in all DG scenarios. However, Scenario 3 maintained the most consistent voltage levels, avoiding both under- and over-voltage conditions. This consistency can be attributed to the stabilizing role of dispatchable DGs, which compensate for the fluctuations in non-dispatchable sources.

### 5.3 DG Placement Strategy

The genetic algorithm effectively identified optimal placement points that minimized line losses and improved voltage stability. Interestingly, buses near the far ends of the feeder were frequently selected for DG installation, suggesting that strategic end-loading can help balance voltage drop and reduce losses more effectively.

### 5.4 Economic Viability

Despite higher initial investment, Scenario 3 offered the most cost-effective solution in the long term, primarily due to significant energy savings and reduced network losses. A simple payback period analysis indicated a payback time of approximately 5.2 years, making it an economically viable strategy for utility-scale adoption.

### 5.5 System Reliability

The inclusion of dispatchable DGs notably enhanced the system's ability to cope with generation variability. In simulations of daily operation under fluctuating solar and wind conditions, the presence of biomass and hydro units helped stabilize the net power output, ensuring reliable supply and reducing voltage deviation.

### 5.6 Sensitivity Analysis

A sensitivity analysis conducted on the weighting factors of the objective function revealed that system performance is more responsive to variations in power loss weight than cost weight. This highlights the criticality of minimizing technical losses in distribution planning.

### 5.7 Limitations and Future Directions

While the results are promising, the study is limited by assumptions of static load and average renewable generation. Future work can incorporate real-time dynamic models, time-series analysis, and energy storage integration to further enhance accuracy and applicability.

## 6. Conclusion

The optimal placement of both dispatchable and non-dispatchable renewable DG units significantly reduces energy losses and enhances voltage profiles in distribution networks. The hybrid deployment strategy leverages the strengths of both DG types. Future work may focus on incorporating real-time data and considering the dynamic nature of load and generation.

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