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Optimal DG Placement in Distribution Networks with Genetic Algorithm-Based Approach and Techno-Economic Evaluation

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Abstract: In radial distribution grids, correctly locating appropriately sized Distributed Generation (DG) units can greatly enhance system performance. The most significant techno-economic advantages come from decreasing yearly economic losses, which involve deployment, operation, and maintenance costs as well as voltage fluctuations and power loss at the buses. The current issue is being evaluated with different multi-objective frameworks, and the Pareto-optimal solution is also discussed as the optimal compromise solution. When addressing a multi-objective optimization problem, specific equality and inequality constraints are also considered. This paper concentrates on a unique multi-objective approach called whale optimization.

Utilizing genetic algorithms to solve problems with multiple objectives. In order to evaluate its efficiency, the proposed method is applied to IEEE-33 radial bus distribution systems for testing. This paper also contains a comparison with other recent multi-objective algorithms like opposition-based chaotic Differential evolution (OCDE), Krill herd algorithm (KHA), and Power Loss Sensitivity Factor and Simulated Annealing (LSFSA). The proposed method may enhance power loss, annual economic loss mitigation, and voltage profile improvement, as found in research.

I. Introduction

The increasing demand for electricity, coupled with the need for sustainable energy solutions, has led to a significant transformation in the design and operation of power distribution networks. Distributed Generation (DG), which refers to the localized generation of electricity near the point of consumption, has emerged as a critical component in modern power systems. DG units offer numerous advantages, such as reducing transmission losses, improving voltage profiles, enhancing power quality, and integrating renewable energy sources like solar and wind. However, the placement and sizing of

DG units in distribution networks are complex optimization problems that significantly impact both the technical performance and economic viability of the system.

Optimal placement of DG units requires a delicate balance between minimizing power losses, maintaining system stability, improving voltage regulation, and maximizing economic benefits. Suboptimal placement can lead to increased losses, power quality issues, and underutilization of resources. This necessitates the development of robust optimization techniques capable of handling the multi-objective and constrained nature of the problem.

II. Proposed Methodology

Problem Formulation

The optimization objective includes:

Minimizing Active Power Losses: Reducing line losses to enhance overall system efficiency.

Improving Voltage Profiles: Ensuring voltage levels remain within acceptable limits across all buses.

Techno-Economic Analysis: Balancing the technical benefits with the cost of DG installation and operation.

The constraints include:

Voltage limits:

Vmin≤Vi≤VmaxVmin ≤Vi ≤Vmax for all buses.

Power flow balance: Ensuring power generation meets load demand.

DG capacity limits: DG units must operate within specified capacity ranges.

Genetic Algorithm (GA) for DG Placement

GA is a metaheuristic inspired by natural evolution, effectively handling multi-objective optimization problems. Its steps for DG placement in the IEEE 33-bus system are:

Initialization: Generate an initial population of candidate solutions, each representing DG placement and sizing combinations.

Fitness Evaluation: Calculate the fitness of each solution based on objectives like power loss minimization and voltage improvement.

Selection: Select parent solutions based on fitness, using techniques like tournament or roulette-wheel selection.

Crossover and Mutation: Generate offspring by combining parents and introducing small mutations to enhance diversity.

Replacement: Form a new population by replacing less-fit solutions with better-performing offspring.

Termination: Stop the algorithm once convergence criteria, such as a maximum number of iterations or minimal fitness improvement, are met.

Cuckoo Search Optimization (CSO) for DG Placement

CSO is inspired by the brood parasitism behavior of cuckoos. It combines Lévy flight-based random search with efficient global exploration. The steps for DG placement in the IEEE 33-bus system are:

Initialization: Generate an initial population of solutions (nests), each representing DG placement and sizing.

Fitness Evaluation: Evaluate the fitness of nests based on power loss minimization and voltage profile improvement.

Lévy Flight Update: Perform a random walk using Lévy flights to explore the search space and create new solutions.

Selection and Abandonment: Retain the best solutions and replace the worst-performing nests with new random solutions.

Convergence: Repeat steps 2-4 until convergence criteria, such as maximum iterations or minimal improvement, are satisfied.

Implementation in IEEE 33-Bus System

System Modeling: Model the IEEE 33-bus distribution system, including line and load data.

Input Data: Define DG parameters (size and cost), system constraints, and algorithm settings.

Algorithm Execution:

Run GA and CSO separately to determine the optimal DG placement and sizing.

Compare performance metrics such as power loss reduction, voltage profile improvement, and computational efficiency.

Comparative Analysis

GA: Offers strong global search capabilities and is effective in exploring diverse solutions but may converge slowly for complex problems.

CSO: Provides faster convergence due to Lévy flight's exploratory nature but may require fine-tuning of parameters for optimal results.

IEEE 33-Bus System

The IEEE 33-bus system is a standard radial distribution network widely used in research for testing algorithms related to load flow analysis, optimization, and distributed generation placement. It consists of 33 buses, 32 branches, and operates with a base voltage of 12.66 kV and base apparent power of 100 MVA. The network starts from a single substation (source) and supplies power downstream to various loads. It has a total real power demand of 3.715 MW and a reactive power demand of 2.3 MVAr. Due to its simplicity and practical relevance, it serves as an effective benchmark for studying power loss minimization, voltage stability improvement, and the integration of renewable energy sources in distribution systems.

Load bus: Here at the load bus, both the reactive and real forces are shown. Neither the voltage nor the phase angle is defined. This bus is not connected to any engines.

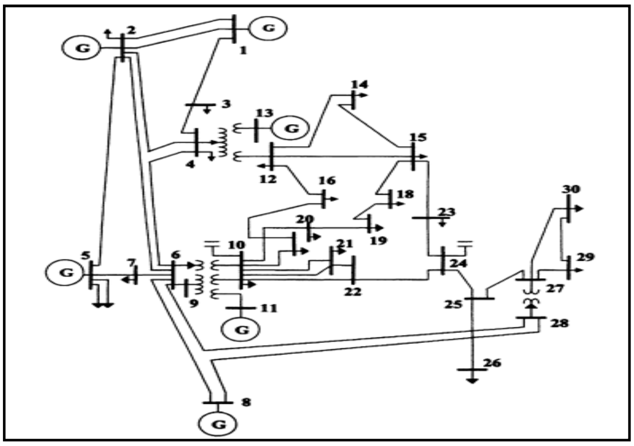

Fig. 1: IEEE 30 Bus System

Slack Bus: The voltage-controlled bus is another name for the generator bus. This bus has another name. In this part of the standard, the real power (Pg) and the voltage magnitude that match the generator voltage are given. In the equations for line flow, the reactive power generation (also called Qg) and the voltage phase angle are the unknown parameters. This kind of bus is also called a Slack Bus or a Swing Bus. In this bus, it is assumed that the size of the voltage and the phase angle are factors that are known. Pg, which stands for "real power," and Qg, which stands for "reactive power," are both thought to be unknown factors.

The slack bus is the only bus in the power system that is not constrained by the power balance equation, which means that the voltage magnitude and phase angle at the slack bus are not directly affected by changes in power flows and injections at other buses in the system. Instead, the voltage and frequency at the slack bus are controlled by the generator connected to it.

By using the slack bus as a reference point, the voltage and frequency at other buses in the system can be adjusted to maintain system stability. This is typically done using automatic voltage regulators (AVRs) and other control systems that adjust the power output of generators connected to other buses in the system to maintain voltage and frequency within acceptable limits.[73]

Optimization Algorithm

Distributed Generation (DG) plays a crucial role in modern power distribution systems by improving efficiency, reducing power losses, and supporting renewable energy integration. However, the placement and sizing of DG units are complex optimization problems due to the nonlinear and multi-objective nature of power flow dynamics. This section presents two robust optimization techniques — Genetic Algorithm (GA) and Cuckoo Search Optimization (CSO) — for determining the optimal placement and sizing of DG units in the IEEE 33-bus distribution system.

III. Results

In this part of the article the various results obtained to satisfy the proposed objectives of the paper.

IEEE 33 Bus System

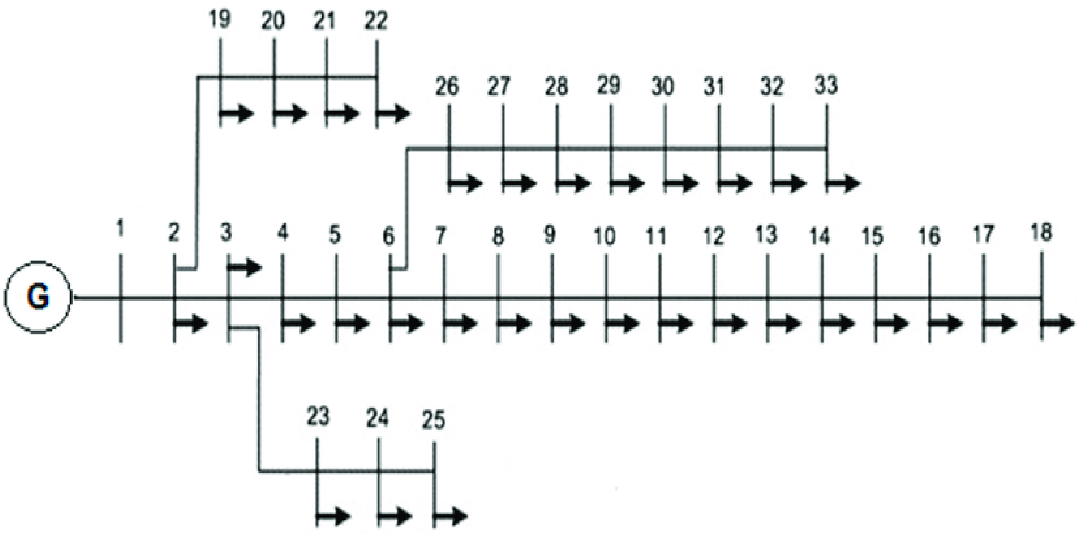

Figure 4.1: IEEE 33 Bus System

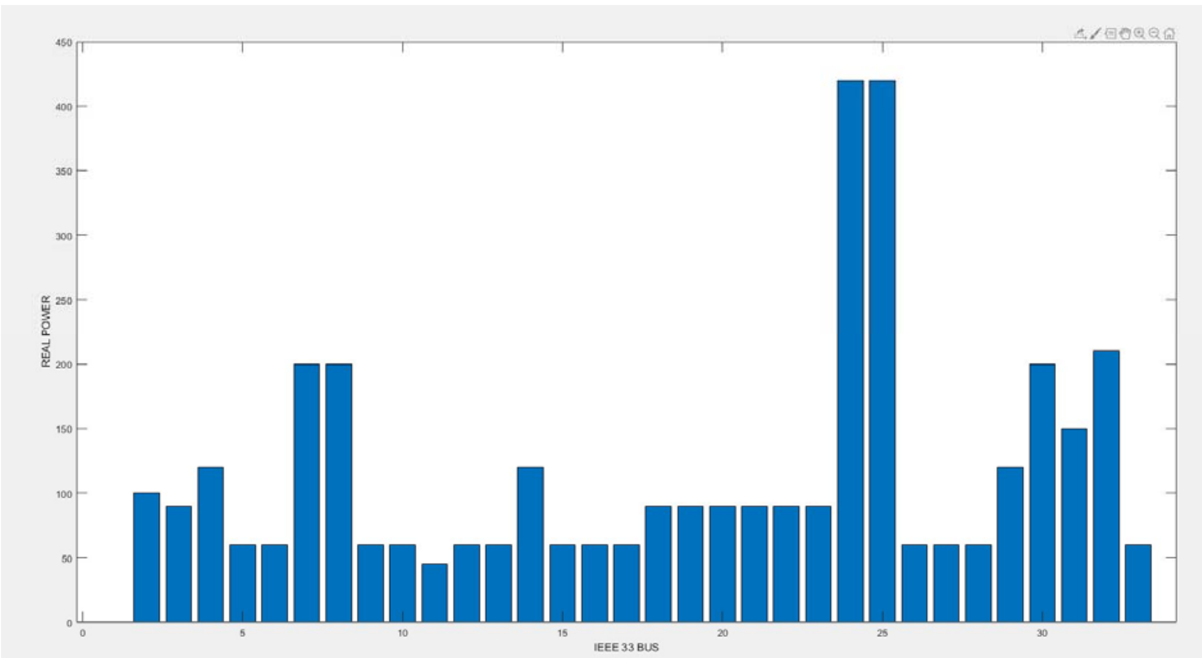

Figure 4.2: IEEE 33 Bus Real Power

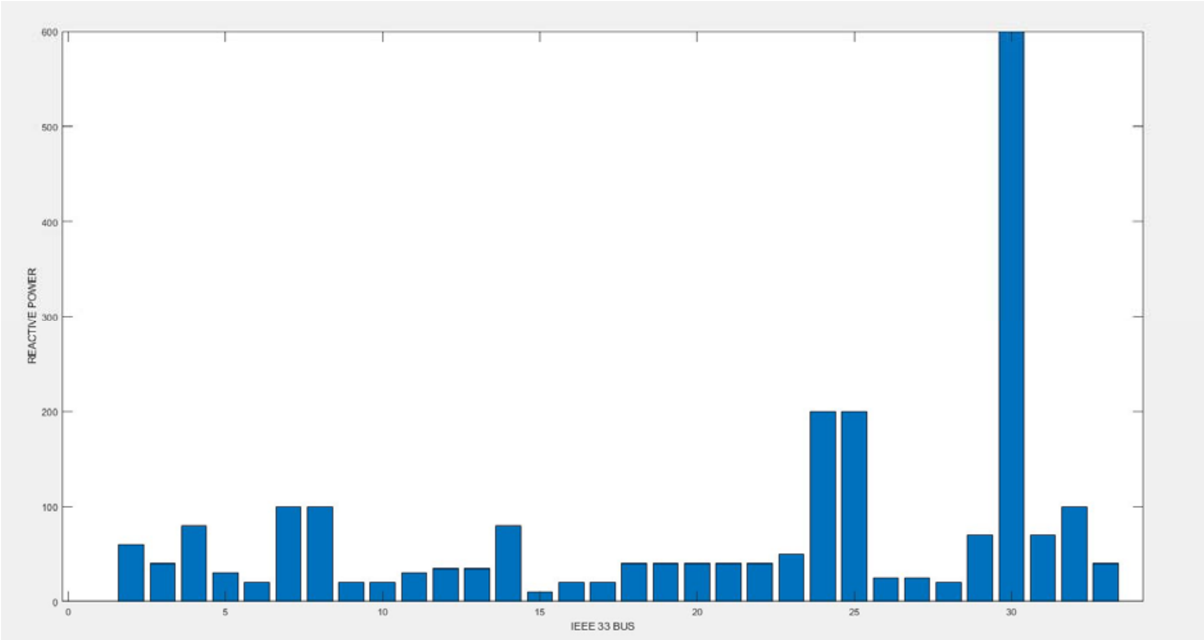

Figure 4.3: IEEE 33 Reactive Power

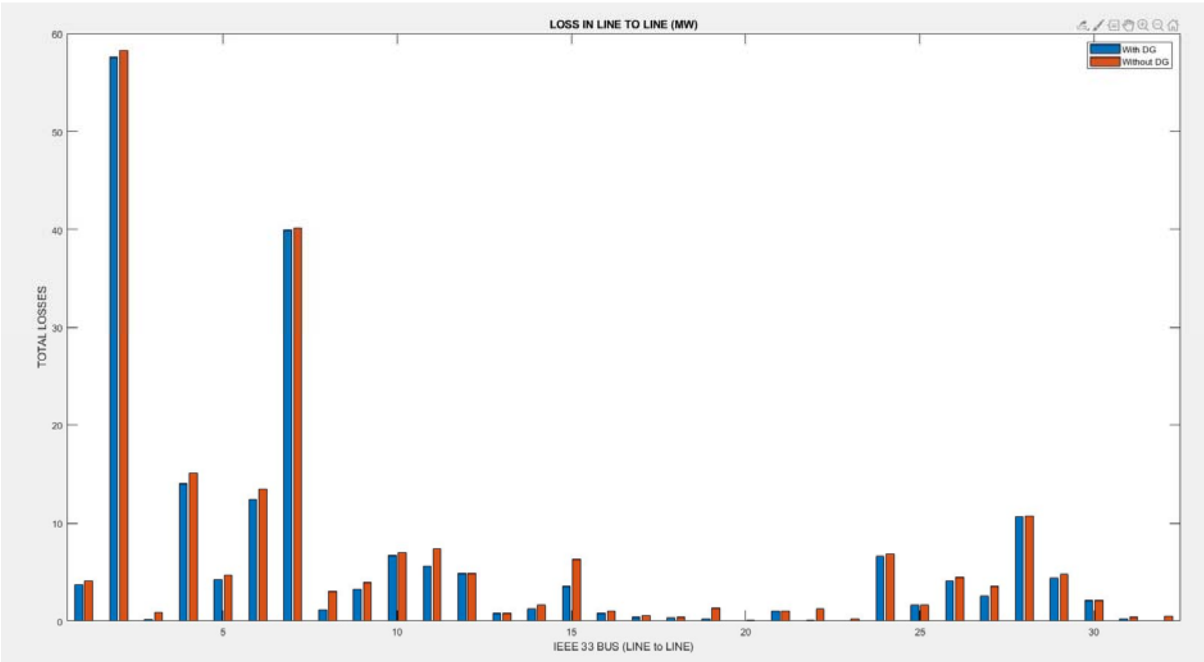

Figure 4.4: IEEE 33 Line to Line Total Losses

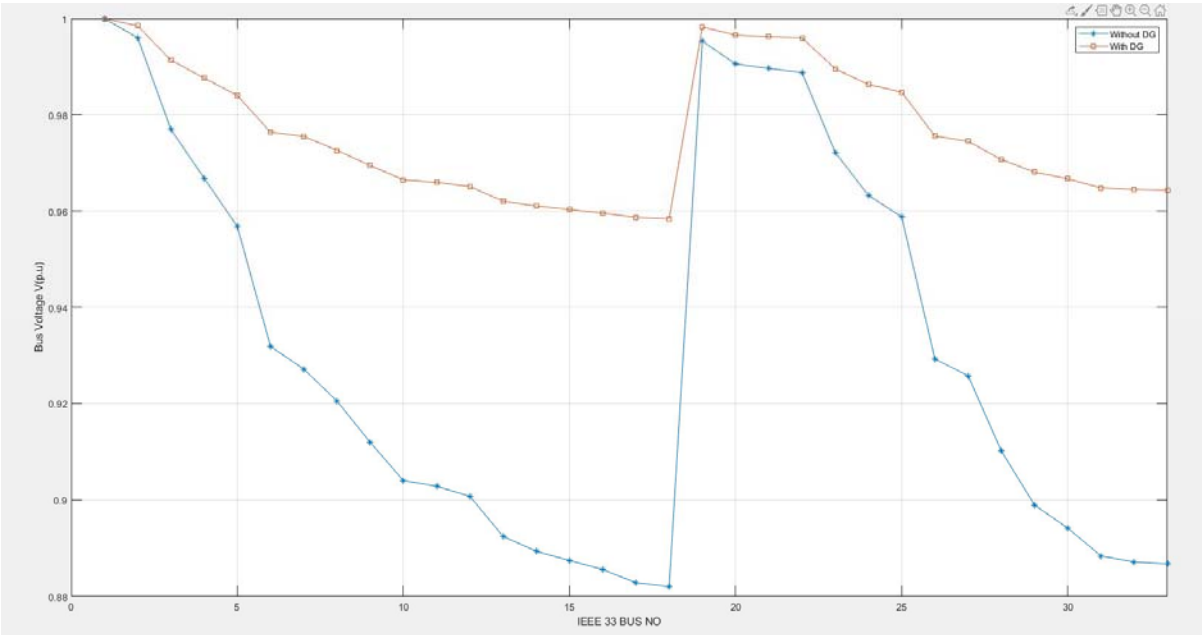

Figure 4.5: IEEE 33 Bus Voltage

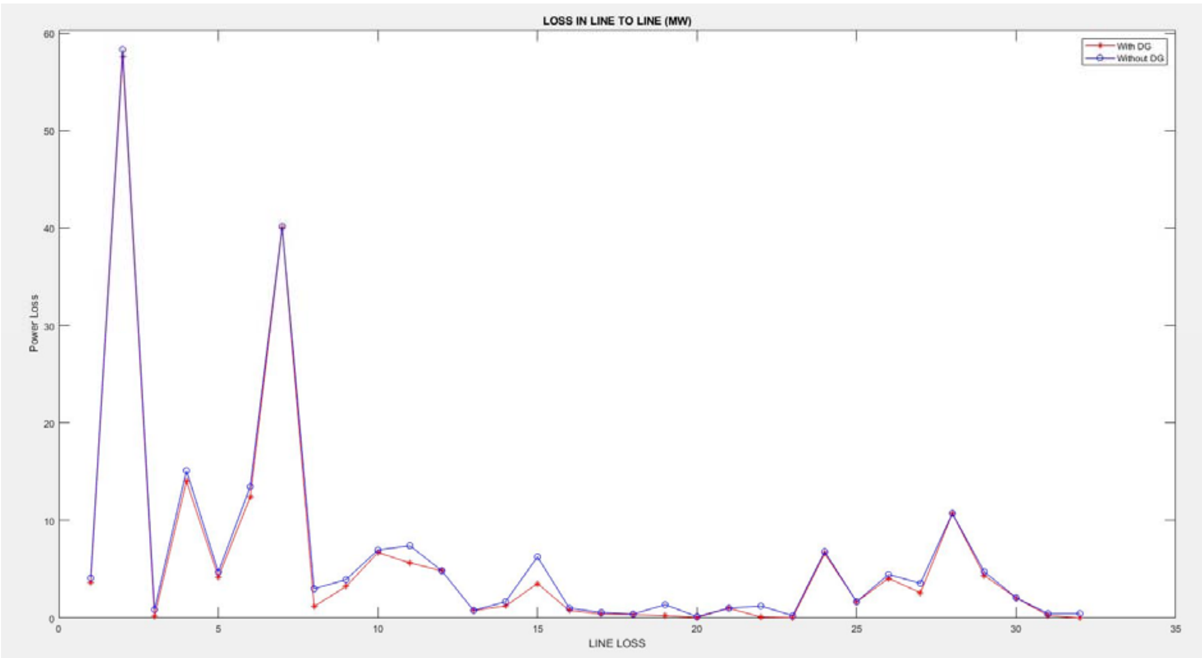

Figure 4.6: IEEE 33 Line to Line Losses

IV. Conclusion

In this paper, an enhanced GA -Cuckoo Search technique is introduced for positioning optimally sized DGs in ideal locations. In order to demonstrate its efficiency, the proposed technique was evaluated on various test systems for radial distribution, such as the IEEE-33 bus systems. Two goals which include loss of power and yearly economic loss, alongside a multiple objective approach.

The main goal of assessing these objectives is to decrease the total annual economic loss, minimize real power loss, and improve the voltage profile to optimize overall annual savings. When appropriately sized DGs are placed in suitable locations, there is a notable decrease in annual economic loss and real power loss, leading to an enhanced voltage profile. There has been a significant rise in the yearly economic gain due to a decrease in the annual economic loss. When comparing the outcomes of the recommended method with those of alternative approaches, it becomes apparent that the proposed method yields superior results.

The following inferences can be drawn:

- The proposed method is appropriate for determining optimal placements and sizes of DG in a distribution network.
- The multi-objective whale optimization method is employed for optimal integration of DGs, leading to a decrease in total real power losses and cost of energy losses.
- According to numerical results, the proposed method outperforms other methods in the literature and is considered satisfactory.
- WOA has found an improved answer for the optimal positioning of many Showing strong uniformity and fast convergence traits, DGs in radial distribution systems stand out.

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