

Optimal Placement Of Mono-Facial PV With EVCS In Distribution Systems Using Grey Wolf Optimization

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Abstract:

This study proposes a novel Grey Wolf Optimization (GWO) strategy for optimal Electric Vehicle Charging Station (EVCS) placement in power distribution systems to minimize losses and improve voltage stability. Evaluated on the IEEE 33-bus benchmark against Particle Swarm Optimization (PSO), GWO demonstrates superior performance in reducing power losses and enhancing voltage profiles within operational limits. A probabilistic analysis further validates its robustness under uncertain EV charging patterns, offering distribution operators a reliable approach to integrate growing EV fleets while cutting costs and ensuring grid reliability.

Keywords: Electric Vehicle Charging Stations , Power distribution system , Particle Swarm Optimization algorithm , Grey Wolf Optimization algorithm, Optimization, Monofacial PV, IEEE 33-bus System.

Introduction:

This study introduces a novel strategy for optimizing the placement of Electric Vehicle Charging Stations within a power distribution system to minimize power losses. The proposed methodology leverages the Grey Wolf Optimization algorithm, a metaheuristic inspired by the hunting behaviour of grey wolves, to identify the most strategic locations for EVCSs. The effectiveness of the GWO-based approach is rigorously evaluated using the IEEE 33 bus system, a standard benchmark in distribution system analysis. The performance of the GWO algorithm is compared against the Particle Swarm Optimization algorithm, a widely used optimization technique. Results demonstrate the GWO algorithm's superiority in minimizing power losses and enhancing voltage profiles across the distribution network. The study analyses system voltage levels in relation to the nominal voltage, ensuring compliance with operational limits. Furthermore, a probabilistic assessment is conducted to evaluate the robustness of the optimal EVCS placement under uncertain EV charging patterns. This analysis considers the stochastic nature of EV charging behaviour, providing insights into the strategy's resilience to real-world variations. The proposed GWO-based optimization strategy offers a significant contribution to enhancing the efficiency and reliability of power distribution systems accommodating increasing EV penetration. By minimizing power losses and optimizing voltage profiles, the strategy reduces operational costs and improves the overall stability of the grid. The probabilistic assessment further strengthens the strategy's practicality by accounting for the inherent uncertainties in EV charging demands. This research provides valuable insights for distribution system operators and planners seeking to integrate EVCSs effectively while maintaining system performance.

The increasing global adoption of electric vehicles presents both opportunities and challenges for power distribution systems. While EVs offer a cleaner and more sustainable transportation alternative, their integration into the existing grid

infrastructure necessitates careful planning and management to ensure system stability and efficiency. Uncoordinated EV charging can lead to increased power losses, voltage deviations, and potential overloads, jeopardizing the reliability of the distribution network. Therefore, strategic placement of EV charging stations is crucial for mitigating these challenges and maximizing the benefits of EV integration [1], [2], [3].

The optimal placement of EVCSs is a complex optimization problem with multiple conflicting objectives. Minimizing power losses is a primary concern, as it directly impacts the operational efficiency and cost-effectiveness of the distribution system. Maintaining voltage profiles within acceptable limits is equally critical to ensure the proper functioning of electrical equipment and prevent voltage-related issues. Furthermore, the stochastic nature of EV charging patterns introduces uncertainty into the optimization process, requiring robust solutions that can accommodate variations in charging demand [4].

Traditional approaches to EVCS placement often rely on simplified assumptions and deterministic models, which may not accurately reflect the dynamic and uncertain nature of real-world EV charging behaviour. These methods may lead to suboptimal solutions that fail to adequately address the challenges of EV integration. Therefore, advanced optimization techniques are needed to effectively determine the most strategic locations for EVCSs, considering both system constraints and the probabilistic nature of EV charging demands [5], [6], [7].

Metaheuristic algorithms have emerged as powerful tools for solving complex optimization problems in various engineering domains. These algorithms, inspired by natural processes such as biological evolution or animal behaviour, offer several advantages over traditional methods. Their ability to explore a wider solution space and escape local optima makes them particularly well-suited for addressing the complexities of EVCS placement optimization. Among these algorithms, the Grey Wolf Optimizer has gained significant attention due to its effectiveness and simplicity [8], [9].

The GWO algorithm, inspired by the hunting behaviour of grey wolves, mimics the social hierarchy and cooperative hunting strategies observed in wolf packs. The algorithm employs a population-based search strategy, where each individual represents a potential solution to the optimization problem. Through iterative updates and information sharing among individuals, the algorithm converges towards the optimal solution. The GWO algorithm has demonstrated promising results in various optimization applications, including power system optimization, and its application to EVCS placement offers a novel and effective approach.

This study proposes an optimal strategy for placing EVCSs within a power distribution system using the GWO algorithm. The objective is to minimize power losses while maintaining voltage profiles within permissible limits. The IEEE 33 bus system, a widely used benchmark for distribution system studies, is employed to validate the effectiveness of the proposed approach. The performance of the GWO-based method is rigorously compared against the results obtained from the Particle Swarm Optimization algorithm, a well-established optimization technique commonly used in power system analysis.

The study also includes a comparative analysis between the system voltage levels and the nominal voltage, ensuring compliance with operational standards. Additionally, a probabilistic assessment of the optimal EVCS placement is conducted, considering uncertainties in EV charging patterns. This analysis incorporates the stochastic nature of EV charging behaviour, providing insights into the robustness of the proposed strategy under real-world conditions.

The contributions of this study are as follows:

- Development of an optimal EVCS placement strategy using the GWO algorithm to minimize power losses and enhance voltage profiles.
- Comparative analysis of the GWO algorithm's performance against the PSO algorithm on the IEEE 33 bus system.
- Evaluation of system voltage levels in relation to the nominal voltage to ensure operational compliance.
- Probabilistic assessment of the optimal EVCS placement considering uncertainties in EV charging patterns.

The remainder of this paper is organized as follows: Section 2 provides a comprehensive literature review of existing EVCS placement strategies and optimization techniques. Section 3 details the proposed methodology, including the GWO algorithm and the system modelling approach. Section 4 presents the simulation results and comparative analysis. Section 5 discusses the findings and their implications. Finally, Section 6 concludes the study and outlines future research directions.

Proposed GWO-Based Approach for Optimal CS Placement

This section elucidates the utilization of the Grey Wolf Optimization algorithm to pinpoint the strategic placement of Electric Vehicle Charging Stations within the power distribution network.

Grey Wolf Optimization: An Overview

Mimicking the hierarchical hunting behaviour of grey wolves, the Grey Wolf Optimizer is a metaheuristic optimization technique. As illustrated in Fig. 1, the algorithm categorizes the wolf population into four distinct groups [10], [11].

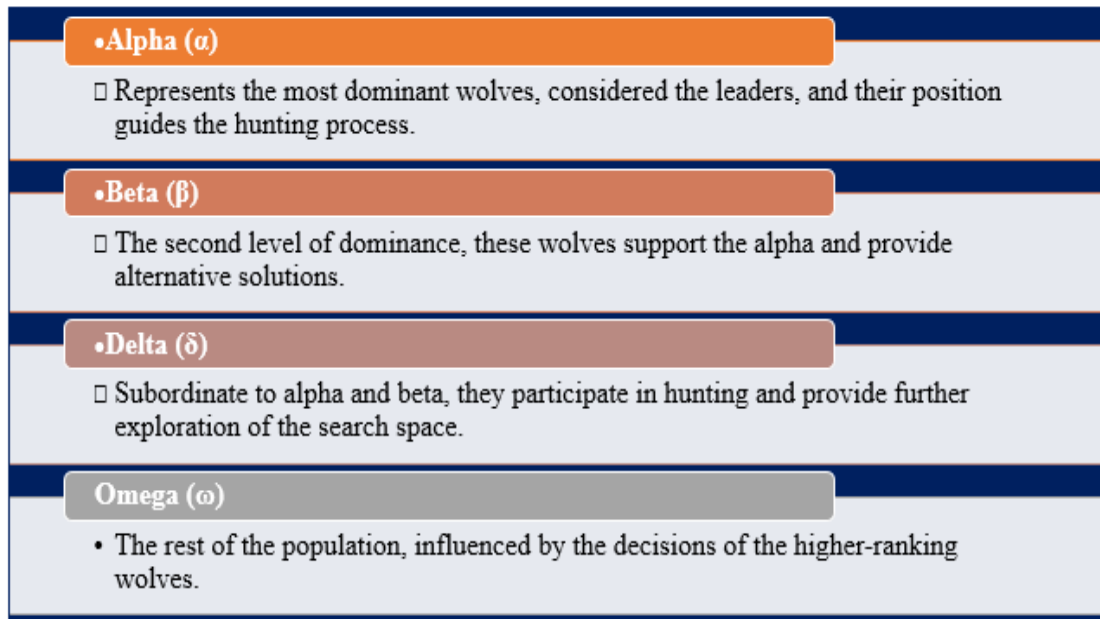


Fig. 1 Classification of Wolf Population

The Grey Wolf Optimizer initiates its search with a randomly generated population of solutions, representing the wolves. These wolves' positions are iteratively updated, guided by the positions of the alpha, beta, and delta wolves—mirroring the pursuit of prey, which symbolizes the optimal solution. This iterative hunt continues until a predefined stopping criterion is satisfied [12]. The GWO process is visually depicted in the flowchart presented in Fig. 2.

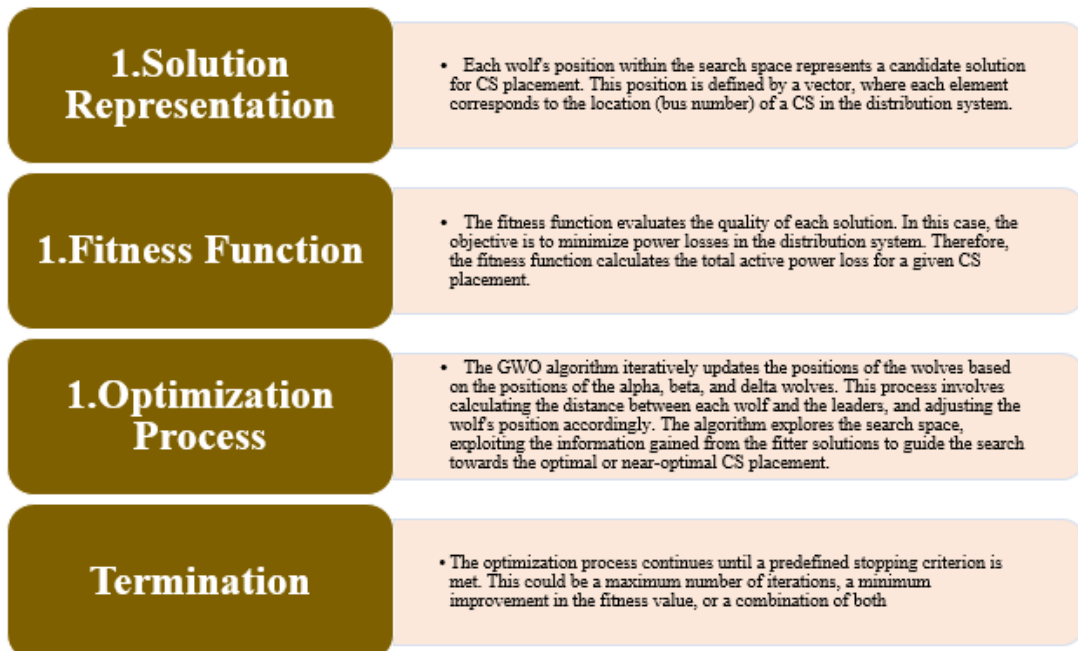


Fig. 2 GWO Flowchart

This approach utilizes the exploration and exploitation capabilities of the GWO algorithm to determine the optimal charging station placements within the distribution system, minimizing power losses and improving overall system performance.

Test Case:

The study employs the IEEE 33 bus test system as shown in Fig. 3 to validate the proposed GWO-based optimal charging station placement strategy. This system, with its characteristic radial structure typical of distribution networks, serves as a benchmark for evaluating distribution system planning and optimization algorithms [13]. A fixed system load, derived from standard IEEE 33 bus data, is assumed. EV charging stations are modelled as additional loads at designated buses. Power flow analysis, using the Newton-Raphson method, determines system losses and voltage profiles for various charging station placement configurations [14], [15].

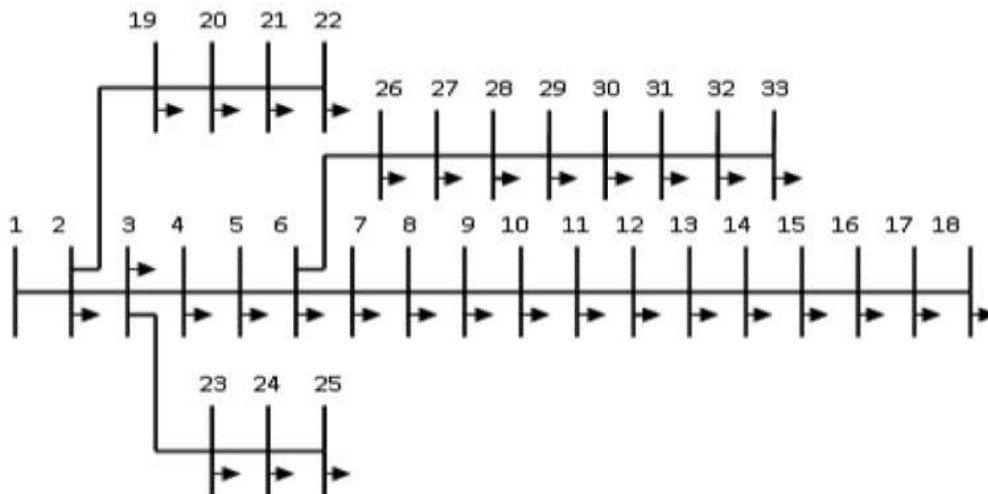


Fig. 3 IEEE 33 Bus System

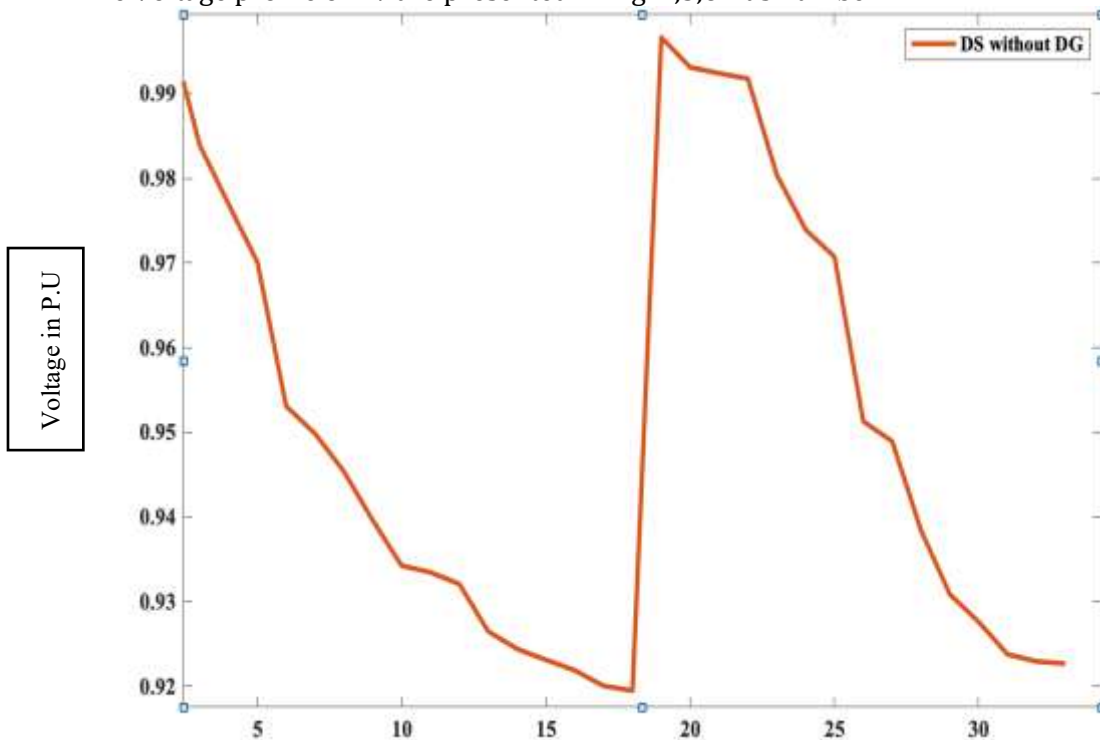
Results and Discussions:

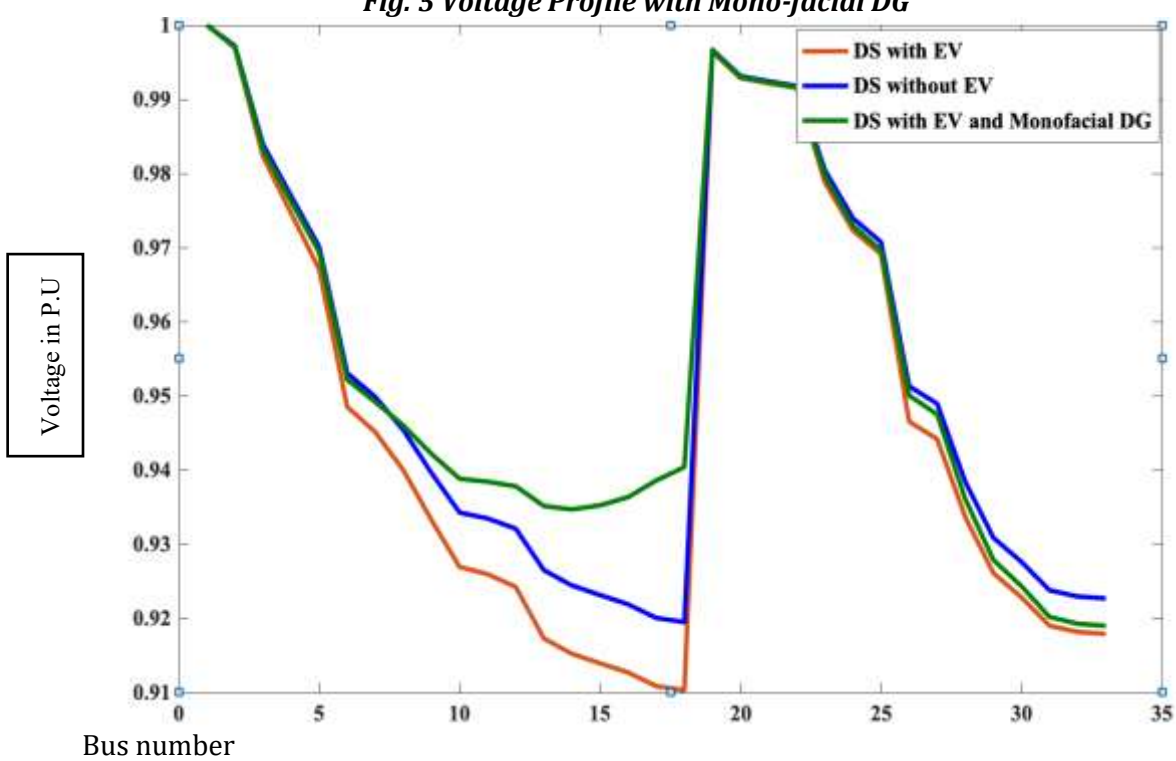
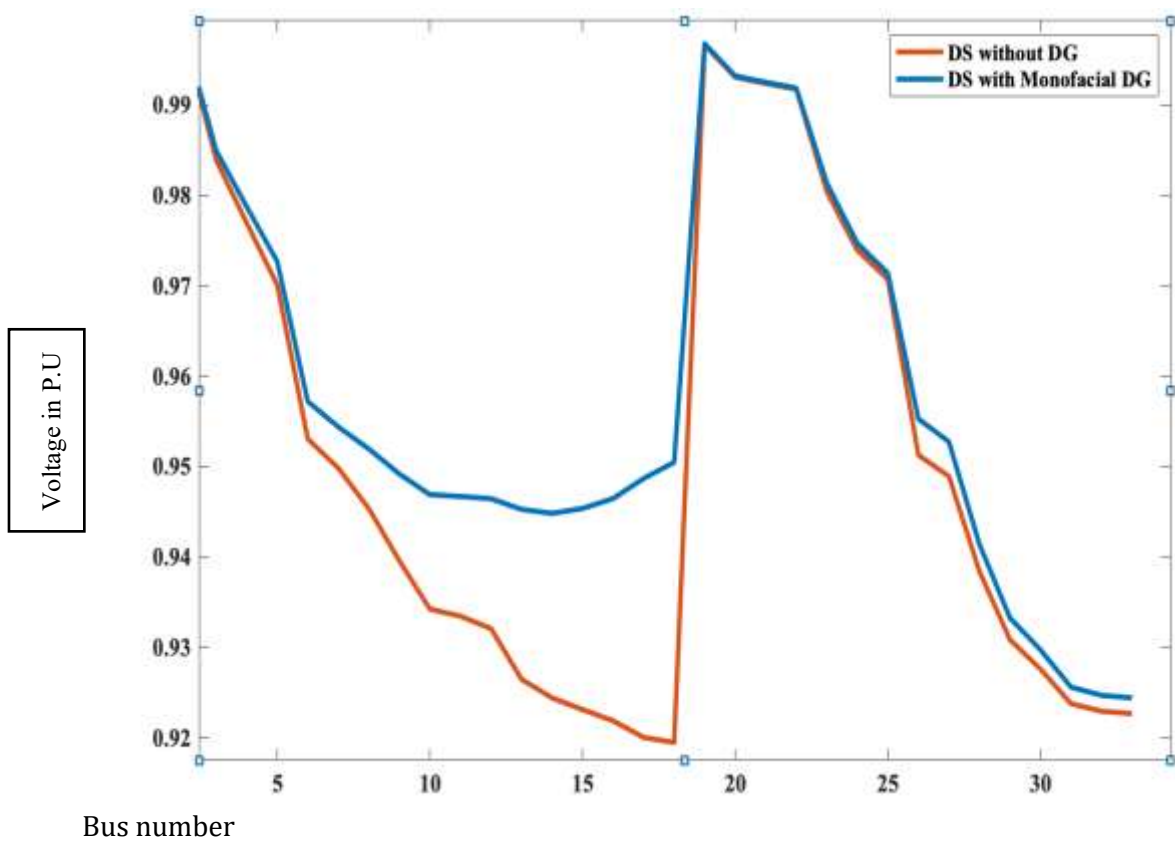
This section presents a comprehensive analysis of the simulation results obtained by applying the proposed GWO-based approach for optimal EV charging station placement on the IEEE 33 bus test system the distribution system losses with EV and without EV are tabulated as follows

Table 1 Distribution system losses

Condition	Losses
Distribution System Losses without DG	0.2118
Distribution System Losses with Mono-facial DG	0.1846
Distribution System Losses With EV	0.2496
Distribution System Losses With EV and Mono-facial DG	0.2166

The Voltage profile of EV are presented in Fig. 4,5,6 Bus number

**Fig. 4 Voltage Profile without DG**



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