



## AN ENHANCED DISTRIBUTION SYSTEM PERFORMANCE WITH OPTIMIZATION TECHNIQUES FOR LOCATION OF ELECTRICAL VEHICLE CHARGING STATIONS

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### ABSTRACT

This study introduces a novel strategy for strategically placing of Electric Vehicle Charging Stations (EVCS) within a distribution power network towards minimizing power losses. The proposed methodology leverages the Grey Wolf Optimization (GWO) metaheuristic algorithm, enthused by the grey wolves hunting, 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 GWO algorithm's performance is evaluated in comparison to that of the prevalent Particle Swarm Optimization (PSO) methodology. The study analyzes system voltage levels in relation to the nominal voltage, ensuring compliance with operational limits. The results demonstrate the GWO algorithm's superiority in minimizing power losses and enhancing voltage profiles across the distribution network. 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 behavior, providing insights into the strategy's resilience to real-world variations. The proposed GWO-based optimization strategy offers a significant contribution to make power distribution infrastructure more dependable and efficient in order to handle the growing number of EVs. 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.



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### I. INTRODUCTION

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 attentive scheduling and supervision to guarantee system stability and efficiency [1], [2]. Uncoordinated EV charging may lead towards augmented power losses, voltage deviations, and potential overloads, jeopardizing the reliability of the supply network. Therefore, strategic placement of EV charging stations is crucial for mitigating these challenges and maximizing the benefits of EV integration [3-5]. The optimal placement of EVCSs is a complex optimization problem with multiple conflicting objectives [6], [7]. 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 [8], [9].

Traditional approaches to EVCS placement every so often bank on simplified assumptions and deterministic illustrations, which may not accurately reflect the dynamic and uncertain sort of real-world EV charging behavior. 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 [10-12]. In several branches of engineering, metaheuristic algorithms have become indispensable for tackling difficult optimization issues. These algorithms, inspired by natural processes such as biological evolution or animal behavior, offer several advantages over traditional methods. They excel at solving the complicated problem of EVCS placement optimization because they can access a larger solution space and avoid local optima [13]. Among these algorithms, the Grey Wolf Optimizer (GWO) has gained significant attention due to its effectiveness and simplicity [14].

The GWO algorithm takes its cues from wolf packs and their cooperative hunting tactics and social order. In its population-based search method, the algorithm considers all possible solutions to the optimization issue. Through iterative updates and information sharing among individuals, the algorithm converges towards the optimal solution [15]. 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 [16], [17]. This study proposes an optimal strategy for placing EVCSs within a power distribution system using the GWO algorithm. The objective is to keep voltage profiles within acceptable bounds while minimizing power losses. The IEEE-33 bus system, a broadly used benchmark for distribution system studies, is employed to validate the efficacy of the proposed methodology. There is a thorough comparison between the GWO-based method's performance and the outcomes produced by the PSO algorithm, a well-established optimization technique commonly used in power system analysis [18-20]. 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 behavior, providing insights into the robustness of the proposed strategy under real-world conditions. The following are some of the study's contributions:

- 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.

Here is, the rest of the paper is oriented: The proposed GWO algorithm and the system modelling technique are described in full in Section 3. In Section, the consequences of findings and comparisons from the simulation are detailed. The conclusion and its implications meant for forthcoming studies are summarized in Section 5.

## II. MATERIALS AND METHODS

### II.1 GREY WOLF OPTIMIZATION

This section elucidates the utilization of the Grey Wolf Optimization (GWO) algorithm to pinpoint the strategic location of EVCS within the power distribution network. The Grey Wolf Optimizer is a metaheuristic optimization technique mimicking the hierarchical hunting behavior of Grey Wolves. As illustrated in Figure 1, the algorithm categorizes the wolf population into four distinct groups [21].

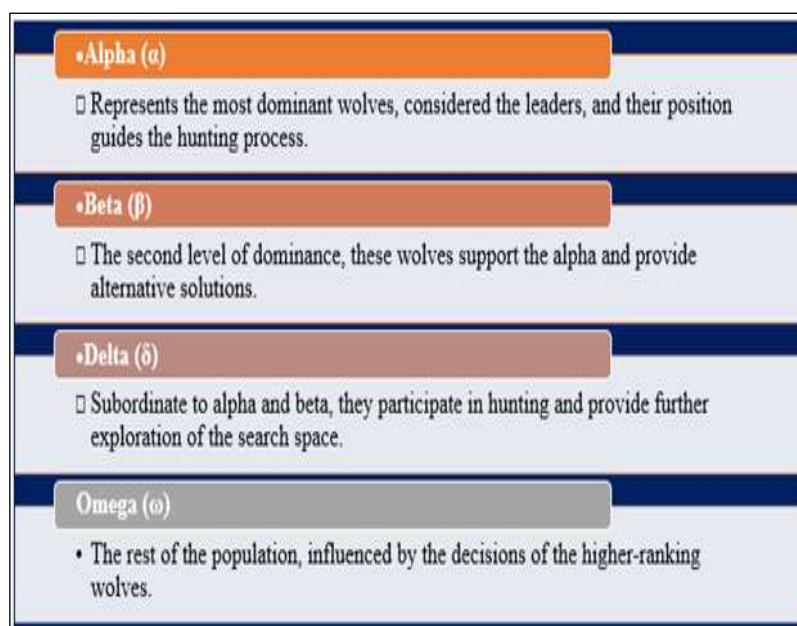


Figure 1: Classification of Wolf Population.  
Source: Authors, (2025).

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 spots of the Alpha, Beta, and Delta wolves—mirroring the pursuit of prey, which symbolizes the optimal solution. This iterative hunt continues up to a predefined end criterion is contented [22]. The GWO progression is visually depicted in the following flowchart in Figure 2.



Figure 2: GWO Flow Chart.  
Source: Authors, (2025).

## II.2 TEST CASE SYSTEM

The IEEE-33 bus test system is employed in this study as given away in Figure 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 [23]. A fixed system load, derived from standard IEEE-33 bus data, is assumed. EV charging stations are modelled as additional loads at designated buses. Newton-Raphson Power flow analysis method determines system losses and voltage profiles for various charging station placement configurations [24], [25].

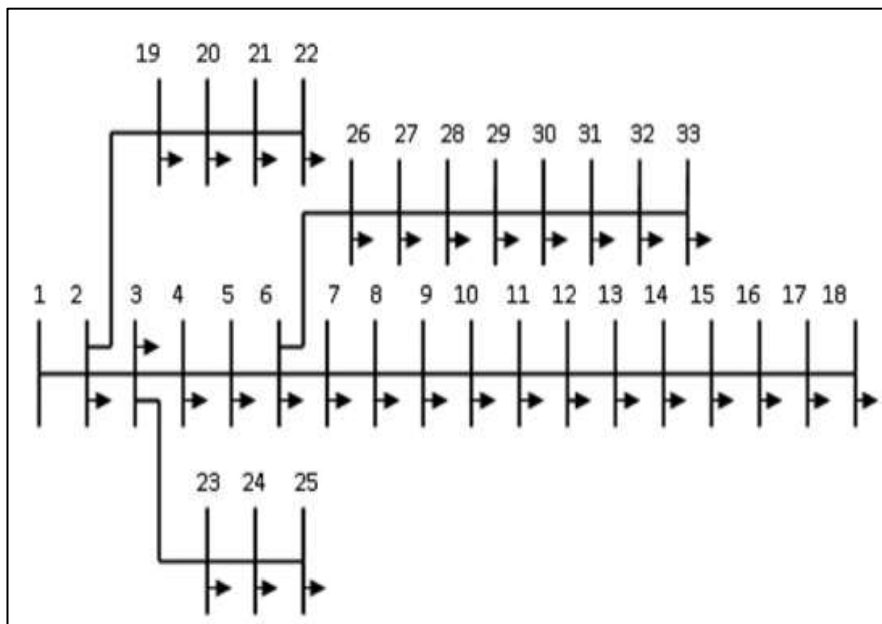


Figure 3: IEEE-33 Bus System.  
Source: Authors, (2025).

IV. RESULTS AND DISCUSSIONS

IV.1 SYSTEM VOLTAGES PROFILE

A complete assessment of the simulation results produced by using the suggested GWO-based method for the IEEE-33 Bus test system's optimum EV charging station placement is provided in this part. The calculated loss sensitivity factor (LSF) for this system are shown in Figure 4.

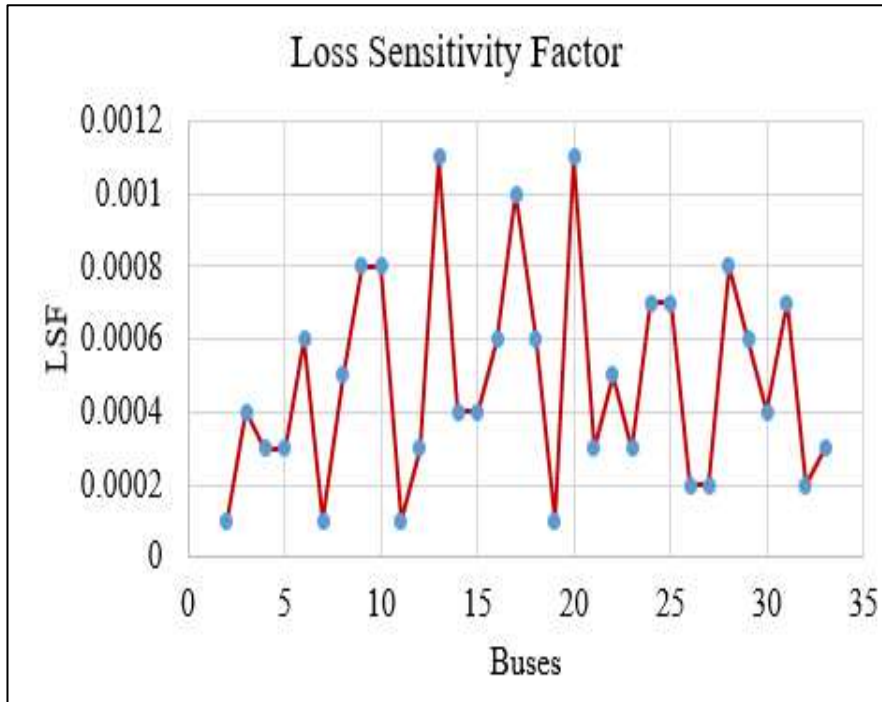


Figure 4: Calculated LSF for IEEE-33 Bus System.  
Source: Authors, (2025).

The Figure 5 below compares the system voltage against the nominal voltage of the IEEE-33 bus system under general operating conditions.

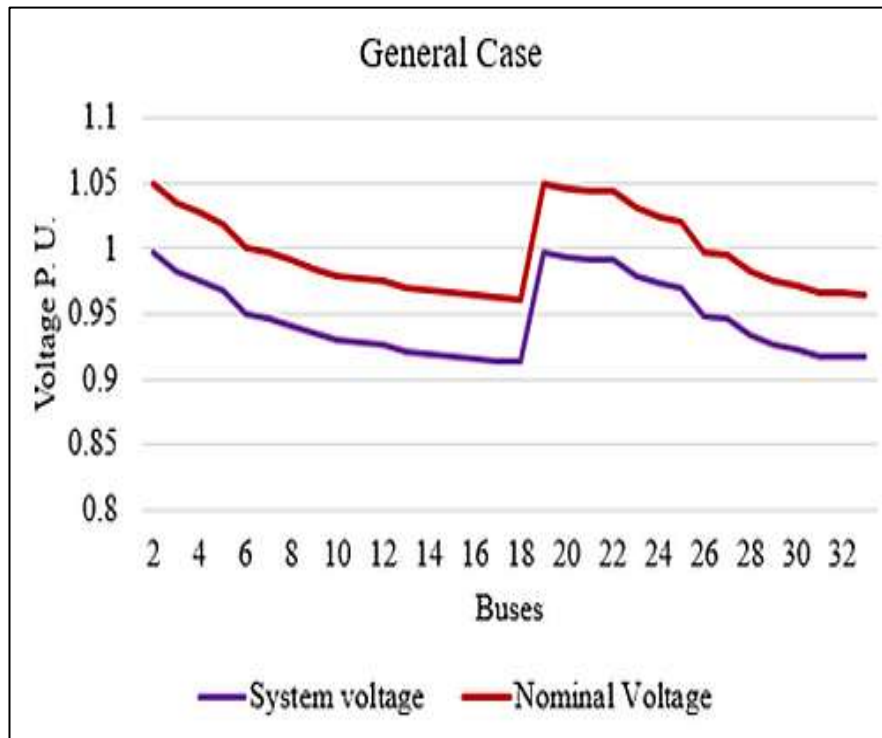


Figure 5: Voltages Profiles of the System – General Case.  
Source: Authors, (2025).

From the Figure 5, it can be seen that a consistent trend between the system's voltage and the nominal voltage expressed in Per Unit (P.U). For a more detailed voltage profile analysis, Figures 6 and 7 illustrate the system and nominal voltages obtained using the PSO and GWO optimization algorithms, respectively.

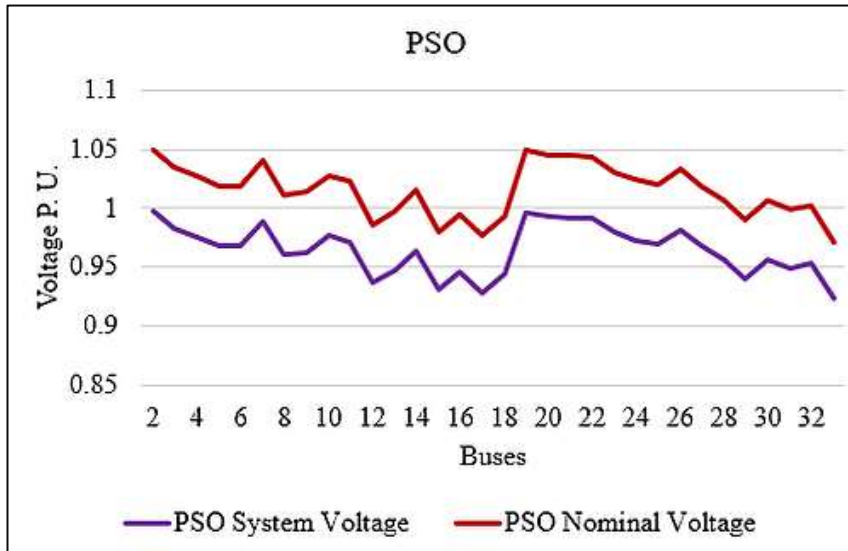


Figure 6: Voltages Profiles of the System with PSO.  
Source: Authors, (2025).

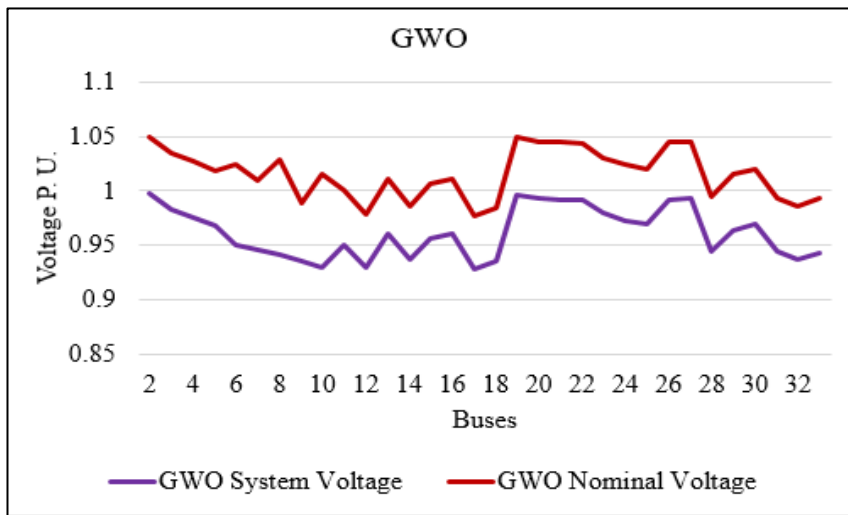


Figure 6: Voltages Profiles of the System with GWO.  
Source: Authors, (2025).

Figures 6 and 7 indicate that the GWO algorithm surpasses the PSO algorithm in optimizing the system voltage profile. Turning to the probabilistic aspect, Figure 8 shows the probability of EV presence at each bus in the IEEE-33 Bus system.

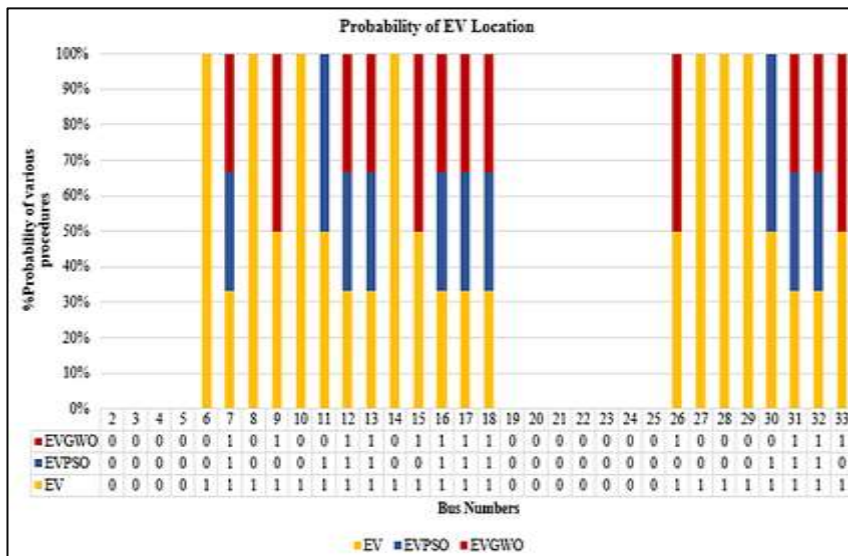


Figure 7: Probability of EV location.  
Source: Authors, (2025).

With Bus 1 designated as the slack bus, analysis of the results reveals the following EV placement outcomes:

- General Case: EVs are distributed across 21 buses: 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 26, 27, 28, 29, 30, 31, 32 and 33.
- PSO Optimization: EVs are strategically placed at 10 buses: 7, 11, 12, 13, 16, 17, 18, 30, 31 and 33.
- GWO Optimization: EVs are positioned at 12 buses: 8, 9, 12, 13, 15, 16, 17, 18, 26, 31, 32 and 33.

These are tabulated as in Table 1 below.

Table 1: Strategic Placement of EVCS.

Comparison of EVCS Placement				
Bus No.	General Case	PSO	GWO	
	6		7	8
	7		11	9
	8		12	12
	9		13	13
	10		16	15
	11		17	16
	12		18	17
	13		30	18
	14		31	26
	15		33	31
	16			32
	17			33
	18			
	26			
	27			
	28			
	29			
	30			
31				
32				
33				

Source: Authors, (2025).

In all scenarios, the proposed GWO based EVCS placement strategy consistently exhibits superior performance.

### V. CONCLUSIONS

This study introduced a strategic approach for optimizing EV charging station placement within a distribution system using the Grey Wolf Optimization algorithm. The primary objective was to minimize power losses and maximize the overall system performance. Rigorous evaluation on the IEEE-33 bus test system demonstrated the GWO algorithm's superior performance compared to the Particle Swarm Optimization algorithm in minimizing losses and improving voltage profiles. The GWO-based approach effectively pinpointed optimal charging station locations, leading to enhanced voltage stability and reduced losses, eventually paying off to an added effective and reliable distribution system. Furthermore, probabilistic analysis showcased the proposed strategy's robustness under uncertain EV charging patterns. The identified locations remained optimal under various EV demand scenarios, confirming the practicality and effectiveness of this approach for real-world applications.

### VI. AUTHOR'S CONTRIBUTION

**Conceptualization:** Sainadh Singh, Venkata Anjani Kumar G, Lenin Babu, Suresh Babu

**Methodology:** Sainadh Singh.

**Investigation:** Sainadh Singh.

**Discussion of results:** Sainadh Singh, Suresh Babu

**Writing – Original Draft:** Lenin Babu, Venkata Anjani Kumar G

**Writing – Review and Editing:** Lenin Babu, Venkata Anjani Kumar G

**Resources:** Lenin Babu, Venkata Anjani Kumar G

**Supervision:** Sainadh Singh, Venkata Anjani Kumar G, Lenin Babu, Suresh Babu

**Approval of the final text:** Sainadh Singh, Venkata Anjani Kumar G, Lenin Babu, Suresh Babu

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