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Cost-Effective Strategy for the Deployment of Charging Stations for Electric Vehicles Using Flower Pollination Algorithm

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Abstract

The adoption of electric vehicles (EVs) is increasingly prevalent due to their advantages such as reduced emissions, lower noise pollution, decreased maintenance requirements, and efficient power consumption. Many modern countries are integrating EVs as part of their initiatives to enhance environmental sustainability and energy efficiency. However, the strategic placement of EV charging stations is crucial as it can impact voltage stability, peak load, power quality, and transformer lifespan within the power system. Thus, optimizing the location and sizing of EV charging stations is essential for cost-effective distribution system planning. This paper presents an approach for determining the optimal placement and sizing of charging stations using the Flower Pollination Algorithm. The proposed method is evaluated on a distribution power system, demonstrating its efficacy in optimizing charging station locations and sizes while minimizing operational costs. The results indicate that the Flower Pollination Algorithm outperforms the Artificial Bee Colony Algorithm in terms of cost efficiency and overall performance.

Keywords: Artificial Bee Colony Algorithm, Charging Station, Cost minimization, Electric Vehicle, Flower Pollination Algorithm.

Introduction

On a global scale, the automobile industry has grown into a major player in terms of both economic output and investment in research and development. The electric vehicle industry is always innovating by adding new technological features that benefit drivers, passengers, and the environment. In addition, and according to a report by the European Union, the transport sector is responsible for nearly 28% of the total carbon dioxide (CO2) emissions, while road transport is accountable for over 70% of the transport sector emissions (Sanguesa et al., 2021). Therefore, the authorities of most developed countries are encouraging the use of Electric Vehicles (EVs) to avoid the concentration of air pollutants, CO2, as well as other greenhouse gases. Furthermore, as stated in a report by the European Union, the transport industry is liable for around 28% of the overall CO2 emissions. Within the transport sector, road transportation alone is responsible for more than 70% of these emissions (Ayetor et al., 2021). Hence, the authorities in most developed nations are promoting the use of EVs as a means to mitigate the accumulation of air pollutants, including CO2, and other greenhouse gasses.

By 2050, it is projected that battery-based sustainable energy technology equipment will account for more than 60% of the market. In 2050, there will be more than 3 billion electric vehicles being used and a total of three terawatt-hours of battery storage. Batteries will have a crucial part in the emerging energy economy. In addition, they will emerge as the primary and most significant driving force behind the need for essential minerals, including lithium, nickel, and cobalt (Pirmana et al., 2023). EVs have recently emerged as a significant influence in Malaysia. Nevertheless, the absence of electric vehicle (EV) infrastructure, coupled with its significant reliance on fossil fuels, presents a formidable obstacle (Veza et al., 2022). The greatly increased electrification of the transport sector presents both opportunities and constraints. The primary advantages of EVs are their positive impact on the environment. EVs produce zero emissions, eliminating the need for fossil fuels. As a result, EVs are considered zero-emission vehicles (Forrest et al., 2020). Increasing the number of EVs in urban areas has the potential to enhance local air quality. EVs exhibit reduced noise levels compared to conventional vehicles, and their electric motors demonstrate exceptional efficiency. In addition, EVs have the capability to discharge power to the electric grid, which means they might possibly provide assistance for grid services (Leijon & Boström, 2022). In the majority of cases studied, EVs tend to have lower total emissions. The emissions associated with EVs, however, are influenced by the way energy is produced locally (Gustafsson et al., 2021). Conversely, one drawback of EVs is their current high cost due to the inclusion of batteries and the need for charging infrastructure. Hence, it is imperative to meticulously strategize the charging station infrastructure to enhance cost-effectiveness, identify the most advantageous locations, and optimize the charging rate.

Recent studies have focused on identifying the optimal locations and sizing for electric vehicle (EV) charging stations. For instance, (Liu et al., 2020) utilizes a fuzzy multi-criteria decision-making approach to determine potential sites for charging stations. This methodology is structured into three phases: the first phase establishes a comprehensive set of evaluation criteria; the second phase employs a fuzzy best–worst method to assign weights to subjective criteria; and the final phase applies a fuzzy gray relation analysis model to rank the alternatives. In another study, (Mao et al., 2019) proposes a location planning model for fast charging stations that takes into account the effects on critical power grid assets. Similarly, (Kathiravan & Rajnarayanan, 2023) introduces a novel Galaxy Gravity Optimization technique, which addresses the issue of EV charging station placement by integrating both electrical and road constraints. Additionally, presents the Archimedes Optimization Algorithm (AOA) for the strategic planning of EV charging stations, aiming to minimize system losses. A further refinement of this method is detailed in (Nurmuhammed et al., 2023), which introduces a modified AOA that incorporates adjustments using the Honey Badger Algorithm (HBA). This enhanced approach evaluates optimal charging station placement based on several indices, including power loss, voltage deviation, and voltage stability index (VSI). To compute the minimum cost associated with this placement, a Newton-Raphson based load flow analysis is employed.

The Flower Pollination Algorithm has recently garnered considerable attention and has been utilized to address a diverse array of optimization problems. In their study, (Odili et al., 2020) performed a diagnostic examination of the FPA to ascertain the most effective or almost perfect number of iterations required for solving optimization issues. Based on multiple empirical testing, the study shows that the Flower Pollination Algorithm is not only a fast technique but also produces positive results when the correct number of iterations and flower population are used. Furthermore, FPA has effectively addressed various issues, including the management of electrical machine controllers (Chiranjeevi et al., 2021), , the optimal adjustment of P and PI controllers within a variable speed drive VSD system control circuit (Nadweh et al., 2020), the reduction of phase current deviation among the phases in distribution power systems (Mahendran & Govindaraju, 2020) and the determination of the most suitable size for distributed generation in distribution power systems (Reddy et al., 2016). This study proposes the use of FPA to solve the problem of finding the ideal charging station for EVs in order to minimize the total cost. FPA has been chosen due to its superior ability to tackle a wide range of problems.

Test System

The proposed optimization approach was evaluated using the standard IEEE-33 bus distribution test system, which is widely used for various optimization tasks. This system is well-suited for testing the optimal placement and sizing of electric vehicle (EV) charging stations. The IEEE-33 bus system includes one slack bus and thirty-two load buses, with no buses initially carrying a load. For this study, Bus 1 was designated as the reference bus. The locations for potential charging station placements were randomly selected from Buses 2 to 33. The size of the charging station was treated as a load, and its real power consumption was subtracted from the bus data provided by IEEE. This setup allowed for a thorough examination of the effectiveness of the Flower Pollination Algorithm in optimizing the location and dimensions of EV charging stations within a distribution power system. Figure 1 displays the schematic diagram of the system, which consists of 7 zones. The location of the charging station is designated in each zone. Table 1 displays the available options for installing charging stations in each zone, along with their respective capacities.

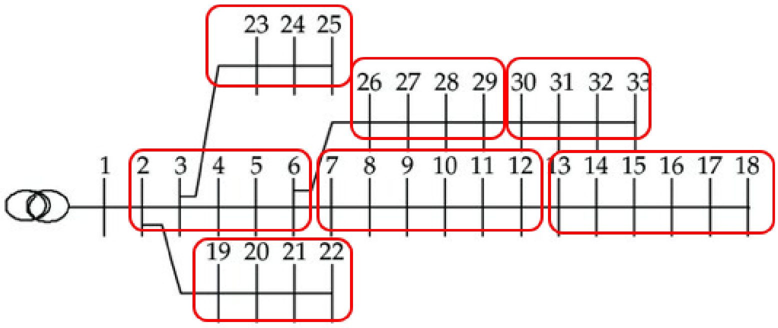

Figure 1: Schematic diagram of IEEE 33-bus distribution test system

Table 1
Location and Sizing of Charging Stations

Location	Possible Bus Location	Sizing limit (kW)	
		Min	Max
Charging Station 1	2, 3, 4, 5, 6	50	500
Charging Station 2	7, 8, 9, 10, 11, 12	50	500
Charging Station 3	13, 14, 15, 16, 17, 18	50	500
Charging Station 4	19, 20, 21, 22	50	500
Charging Station 5	23, 24, 25	50	500
Charging Station 6	26, 27, 28, 29	50	500
Charging Station 7	30, 31, 32, 33	50	500

Development of Flower Pollination Algorithm for cost minimization

Flower pollination optimization is a novel optimization algorithm that draws inspiration from the process of flower pollination. Many meta-heuristic algorithms are based on the fundamental principles of natural phenomena, taking inspiration from the behaviors of plants and animals in nature. The Flower Pollination Algorithm (FPA) replicates the natural process of pollination, which is utilized by 80% of plants for reproduction (Hu et al., 2024). There are two types of pollination that occur in FPA, namely biotic and abiotic. Approximately 10% of the plant species fall under the classification of a-biotic, whilst the remaining 90% of plants are classified as biotic. In the process of global pollination, known as biotic pollination, pollinators including bats, birds, and animals serve as transporters of pollen. In abiotic pollination, sometimes referred to as local pollination, pollination occurs through the processes of water diffusion and wind-blown dispersal (Mateen et al., 2023). Table 2 presents the parameters of FPO used in this paper. The flowchart of FPA for determining the optimal planning of EVs charging stations is presented in Figure 2.

Table 2
The parameter of the Flower Pollination Optimization

Parameter	Value
Number of Iteration	100
Population size, n	20
Probability switch, p	0.8

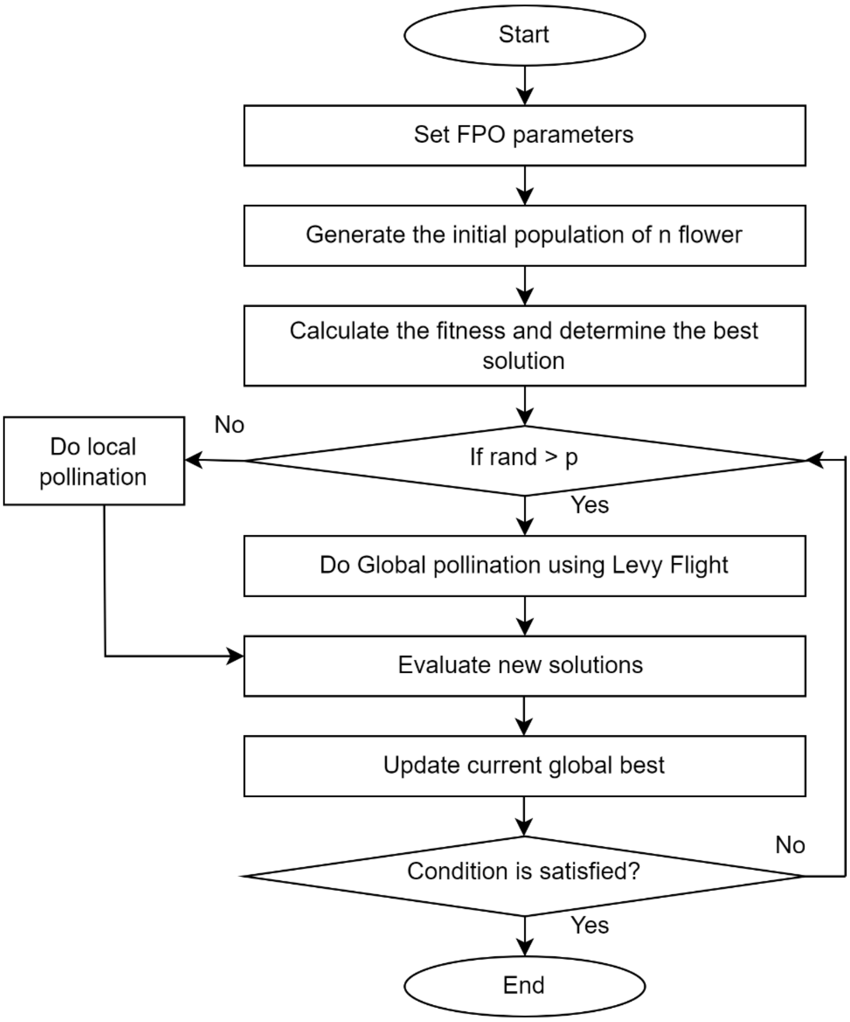

Figure 2: Flowchart of FPA

Results and Discussion

Three case studies are being considered to analyze the most efficient location and size for the electric vehicle charging station. Case 1 represents the initial load of the power system, prior to the inclusion of any charging stations. Case 2 refers to the arbitrary positioning of charging stations inside the power grid. Case 3 involves the strategic positioning of charging stations using the FPA algorithm. The outcomes for the most advantageous placement and dimensions of the charging station for all scenarios are displayed in Table 3.

Table 3
Results of optimal EVs charging stations using FPA

Case Study	Location	Sizing (kW)	Ploss (MW)	Vmin (p.u)	Cost ($)
Case 1			0.1684	0.9207	0
Case 2	2	500	0.4317	0.8752	172,680
	7	500			
	13	500			
	19	500			
	23	500			
	26	500			
	30	500			
Case 3	4	57.88	0.2144	0.9063	85,760
	11	112.68			
	18	115.35			
	20	50			
	25	75.36			
	27	81.16			
	32	68.27			

The results presented in Table 3 show the outcomes of using the FPA to determine the optimal location and sizing of EVs charging stations. The primary objective is cost minimization while maintaining voltage stability and minimizing power loss (Ploss). The three cases (Case 1, Case 2, and Case 3) demonstrate different configurations and their respective impacts on various performance metrics. Case 1 represents the system without any added EV charging stations. It is used as baseline scenario. Case 2 involves placing large-sized (500 kW) EVs charging stations at seven different locations. This case results in the highest power loss (0.4317 MW) and the lowest minimum voltage (0.8752 p.u.), indicating significant stress on the system. The cost is substantial at $172,680, reflecting the high infrastructure investment required for the large-sized charging stations. This case represents an aggressive deployment strategy, which might not be optimal due to its negative impact on voltage stability and higher power loss. Case 3 features a more diverse sizing of charging stations, ranging from 50 kW to 115.35 kW, distributed across seven locations. This case strikes a balance between power loss (0.2144 MW) and minimum voltage (0.9063 p.u.), resulting in moderate impacts on the system. The cost is $85,760, which is significantly lower than that of Case 2. This configuration suggests a more optimized placement strategy, reducing both power loss and infrastructure cost while maintaining acceptable voltage levels.

Figure 3 illustrates the voltage (in per unit, p.u.) across different bus numbers for three distinct case studies (Case 1, Case 2 and Case 3). These cases likely represent different scenarios or configurations for the optimal placement of EVs charging stations using the FPA. Case 1 represents the original network without any EVs charging stations. It is represented using a green line. This case shows the highest voltage profile among the three cases across most of the bus numbers. Case 2, which represents the distribution network with randomly installation of EVs charging stations demonstrates the lowest voltage profile among the three cases. There is a more significant drop in voltage, falling below 0.90 p.u. between bus numbers 5 and 15. This suggests that the placement of EV charging stations in this configuration has a more pronounced impact on the voltage stability, resulting in lower voltage levels at various buses. The voltage profile for Case 3 which is represented as blue circle shows the voltage profile obtained for optimal location and sizing of EVs charging stations using FPO. The voltage profile in this case is generally between those of Case 1 and Case 2. The voltage drops below 0.94 p.u. between bus numbers 5 and 20, with the lowest points slightly above those of Case 2. This indicates that the optimal placement of EV charging stations in this configuration offers a compromise between the other two cases, with moderately improved voltage stability.

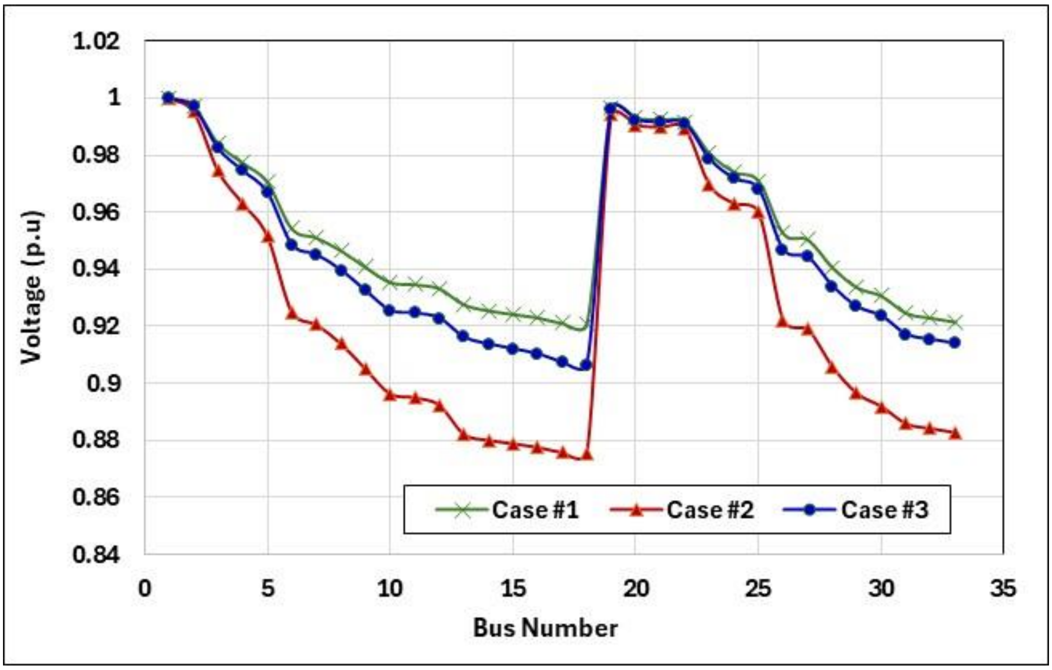

Figure 3: Results of voltage profile for all cases

Similar analysis is carried out using Artificial Bee Colony algorithm (ABC). Table 4 provides a comparative study between the FPA and the ABC for Case 3. The comparison focuses on three key performance metrics: power loss (Ploss), minimum voltage (Vmin), and cost**. FPA** results in a lower power loss compared to ABC which indicates that FPA is more efficient in reducing power loss, which is a critical factor in the performance of an electrical distribution system. Lower power loss means more efficient energy delivery and less wastage, which can contribute to overall system reliability and efficiency. In addition, **FPA** achieves a slightly higher minimum voltage compared to ABC. Higher minimum voltage levels are indicative of better voltage stability and reliability in the system. A minimum voltage closer to the nominal voltage ensures that all buses in the network receive adequate voltage levels, preventing potential undervoltage issues that could affect equipment performance and lifespan. In terms of cost minimization, **FPA** incurs a lower cost compared to ABC. The cost difference suggests that FPA is more cost-effective in determining the optimal placement and sizing of EV charging stations. Lower costs are advantageous for infrastructure investments, allowing for more efficient allocation of resources and potentially enabling more widespread deployment of charging stations.

Table 4
Comparative study between FPA and ABC for Case 3

	Ploss (MW)	Vmin (p.u)	Cost ($)
Flower Pollination Algorithm (FPA)	0.2140	0.9063	85,760
Artificial Bee Colony Algorithm (ABC).	0.2415	0.9020	96,600

Conclusion

This paper has presented the cost-effective strategy to allocate electric vehicles (EVs) charging stations using Flower Pollination Algorithm (FPO). Three case studies were considered; Case 1 represents the original network without any EVs charging stations. Case 1 serves as a benchmark for the optimal scenario with no additional costs but does not provide practical deployment details. Case 2 represents the installation of EVs charging stations at random locations. Case 2, although aggressive, demonstrates the pitfalls of uniform large-scale deployment. Finally, Case 3 represents the installation of EVs charging stations at optimal locations and optimal sizing. The results highlight the importance of strategic planning in the placement and sizing of EV charging stations. Case 3 emerges as the most balanced and cost-effective solution, offering moderate power loss and voltage stability at a reasonable cost. The FPA effectively identifies optimal configurations by considering cost minimization as the objective function. The impact on voltage stability and power loss were also discussed. The Flower Pollination Algorithm has identified different optimal placements of EV charging stations, with each case presenting unique impacts on the voltage profile. The ideal case would minimize voltage drops across all bus numbers while maintaining stability.

The comparative study highlights the superiority of the Flower Pollination Algorithm (FPA) over the Artificial Bee Colony algorithm (ABC) in the context of this analysis. FPA outperforms ABC in all three metrics (power loss minimization, voltage profile and cost minimization). Future work could focus on refining these configurations further and exploring additional constraints and real-world scenarios to enhance the robustness of the optimization approach. Further fine-tuning and additional constraints may be necessary to improve voltage stability, particularly in the regions with significant drops.

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