Development of An Optimal Location of Electric Vehicle Charging Stations in a Distribution Network

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ABSTRACT

The growing popularity of electric vehicles (EVs) offers sustainability initiatives and urban infrastructure both opportunities and obstacles. The creation of an effective, sustainably located, and strategically placed network of charging stations is essential to promoting the rise of EVs. The creation of an ideal site model for EV charging stations that are connected to renewable energy sources like solar and wind power is the main goal of this study. This study presents the development of an optimization scheme for determining the optimal location of electric vehicle (EV) charging stations in the IEEE 33-bus distribution network using the Moth Flame Optimization (MFO) algorithm. The proposed model aims to minimize total power losses, and improve voltage stability. The MFO algorithm is applied to identify optimal locations that balance network load and enhance system performance. Simulation results on the IEEE 33-bus system demonstrate the following quantifiable improvements: a reduction in total power losses by 17% compared to CPLEX algorithm placement strategies and improved voltage stability from the simulation results shown.

1. INTRODUCTION

The issue of fossil fuels and environmental pollution are the two primary causes of the growing popularity of electric automobiles. In addition to encouraging companies to set up charging stations, governments are pushing for the usage of EVs in every manner imaginable. Power system engineers face enormous hurdles because of the demand for EV charging [1]. This over took the generation of electricity. Most greenhouse gas emissions in the transportation sector are caused by light-duty vehicles, such as freight trucks (23.6%) and passenger cars (40.5%)[1]. To mitigate climate change, transportation electrification is becoming more and more crucial, particularly given that the greenhouse gas (GHG) intensity of electricity has decreased significantly in recent years because of moving to lower-carbon power generation sources and improving energy end-use efficiency [2]. Because of its reduced fuel emissions, electric vehicle (EV) technology has been gaining attraction, and it is projected that the number of EVs will rise rapidly. As a result, there is now a need for continuous infrastructure upgrades for charging. These needs to be utilized for both public and residential charging stations and be made for private, business, and public uses [3]. Five major worldwide phenomena are driving the explosive growth of electric vehicles (EVs) :(i) The exhaustion of fossil fuels and the subsequent increase in fuel costs; (ii)Increasing public understanding of climate change (iii) Technological advancements and the commercial viability of technology for renewable energy(iv) The creation of electronic control systems and electric motors that directly regulate EV propulsion; and (v) Advancements in technologies that support EVs, such as Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V).

Most nations are shifting to sustainable, dependable, economical, and environmentally friendly energy sources due to the pressure on fossil fuels. Since fossil fuels are a major source of CO_2 emissions, they pose a serious threat to the environment. Figure 1. displays the percentage contribution of CO_2 emissions by the following sectors: transportation, industry, residential, power and heat, and other sectors, according to the International Energy Agency, [4]. The aim of this work is to develop a scheme for the optimal location of electric vehicle charging stations in a distribution network using Moth flame optimization algorithm. MFO-based optimization framework provides a significant advancement in the strategic deployment of EV charging infrastructure, promoting both economic and operational benefits for modern power distribution systems.

The organization of this paper is as follows: Section 1 introduces the importances of electric vehicle, section 2 provides literature review of electric vehicle, Section 3 provides the method, section 4 discusses the challenging issues and prospect and finally section 5 present the conclusion.

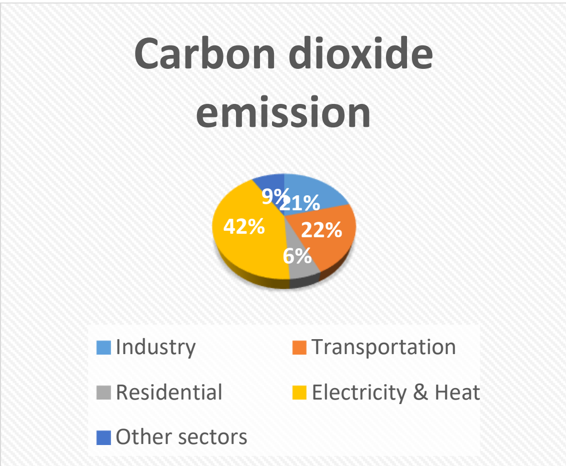

Figure 1: CO_2 emissions by different sector

2.0 Literature review

The literature review of related studies conducted by certain researchers are presented in this section which form a detail background of the study. [5] proposed a method for optimizing the location and size of electric vehicle charging stations to minimize combined operational and investment costs for both consumers and charging stations. Using the cumulative vehicle-hour data of Stockholm City, Sweden, the road network parameters were modelled with the Floyd shortest path algorithm to calculate efficient routes to stations. The optimization problem, aimed at minimizing integrated costs, was solved using Cplex software. Results demonstrated cost reductions but highlighted the need for a model that incorporates coordinated planning with distributed networks for further improvements. [6] introduced a novel grid-independent hybrid renewable energy system (HRES) sizing paradigm for rural areas, aiming to minimize energy costs while ensuring reliability. The system included PV arrays, wind turbines (WT), a diesel generator, a battery bank, power electronic converters, and a dummy load. A load management strategy prioritized WT power, supplemented by PV and battery storage, with excess energy charging the battery or feeding the dummy load.The optimization objectives were to minimize the loss of load probability (LOLP), dummy load, and energy cost, solved using the cuckoo search method. The model simulated energy balance for five Saudi Arabian locations on an hourly basis using MATLAB. Results showed the proposed simulation program (NPSP) outperformed GA and PSO in convergence rate. However, the study noted that relying solely on convergence rate as a success metric was insufficient, suggesting the need for additional reliability indices. [7] proposed a coordinated approach for allocating distributed generation resources (DGRs) and EV charging stations in distribution systems using a vehicle-to-grid interface. The model incorporated electric vehicle charging demands, electrical loads, and DGR outputs (gas-based micro-turbines and solar PV). The optimization aimed to minimize the annualized societal cost, with constraints and a second-order conic relaxation used to ensure model convexity. The approach was tested on a 31-bus distribution system in Jiangsu, China, using a mixed-integer second-order cone programming model implemented in MATLAB. Results were compared across three scenarios: uncoordinated charging (immediate charging on arrival), unidirectional vehicle-to-grid, and bidirectional vehicle-to-grid. Coordinated charging schemes (cases 2 and 3) achieved optimal siting and sizing of DGRs and EV charging stations while significantly minimizing annualized costs compared to the uncoordinated scheme (case 1).[8] developed a multi-objective optimization model for designing renewable energy-powered fast EV charging stations. The system integrated components like energy storage, PV panels, wind turbines, and grid backup, allowing energy purchase or sale based on the system's energy status. Using time-of-use (TOU) simulations, EV load demand was predicted, and the system components were modelled. The optimization aimed to minimize energy costs and pollution emissions, employing a hybrid multi-objective PSO and TOPSIS approach**.**[2] focuses on optimizing the placement of EV charging stations (EVCS) integrated with renewable energy sources like wind and PV systems, alongside energy storage systems (ESS), in a micro grid. A robust optimization model addresses uncertainties in EV charging demand and renewable energy output, incorporating road network and power grid data. The load fluctuation rate is introduced as a key metric to align energy supply with demand. However, the model assumes static road and grid infrastructure, neglecting potential future changes in traffic and urban dynamics.[9] develops an optimization model using Genetic Algorithms (GA) to determine the optimal number and locations of EVCS, aiming to minimize total deployment costs and enhance service quality by reducing travel distances to stations. While effective, GA risks premature convergence to local optima, potentially leading to suboptimal solutions in complex search spaces.[10]**,** a two-layer optimization approach integrates an urban road network with a 33-bus radial distribution network to simultaneously allocate EVCS and PV energy as distributed generation. This approach balances accessibility and grid stability by minimizing energy losses and voltage deviations. However, the method can become computationally intensive for larger networks with numerous EVCS and renewable sources. Several studies emphasize that the location of EV charging stations (CS) significantly affects voltage profiles, power losses, and load flows in the distribution network. Improperly sited stations can lead to power imbalances and voltage instability, especially during peak charging periods. Various optimization techniques have been proposed, such as Mixed-Integer Linear Programming (MILP), Particle Swarm Optimization (PSO), and Genetic Algorithms (GA), to ascertain the best location for charging stations while minimizing losses and improving voltage stability.The inclusion of renewable energy sources like as solar and wind has been explored to reduce reliance on conventional grid power for EV charging. Studies show that optimally incorporating renewable reduces carbon emissions and operational costs while also improving the energy sustainability of the system. However, the intermittent nature of renewable sources poses challenges to maintaining a reliable supply of energy, especially peak period. Hybrid systems combining renewable sources with grid power and energy storage are frequently recommended.

3.0 Methodology

Moth Flame Optimization (MFO) is used to determine where electric vehicle charging stations should be placed in a distribution network that integrates renewable energy systems. It entails a blend of coding, power system analysis, and optimization procedures. Figure 2 illustrates the flowchart depicting the implementation of this proposed technique.

The main objective is to minimize power loss and improve voltage profile using equations (1)

$$P_{loss}(t) = \sum_{br=1}^{N_{br}} (I_{br}(t))^2 \, xR_{br} \tag{1}$$

The optimization issue considers the following operational constraints for the distribution system with a deployed DG unit. The power injection constraints:

$$\sum_{i=l}^{n} P_{DG} = P_{load} + P_{losses} \tag{2}$$

Total Power Balanced Constraint:

$$\sum_{i=l}^{n} P_{EVCs} + P_{substation} = P_{load} + P_{losses} \tag{3}$$

voltage deviation using equation (4)

$$\Delta V_i = V_{i,with\ EVCS} - V_{i,without\ EVCS} \tag{4}$$

IEEE 33 Bus Distribution Network

An IEEE standard 33 bus radial distribution system as shown in Figure 3 is implemented in MATLAB/Simulink. bus data were taken from the standard IEEE 33 bus distribution system and converted into $p.u$ system by taking base voltage=400Kv and base power=100 MVA.

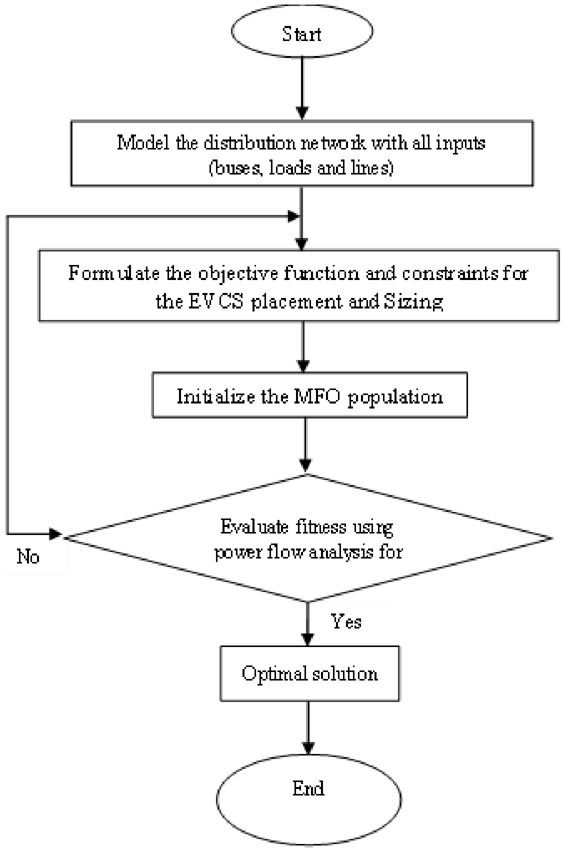

Figure 2: Flow chart of Proposed method

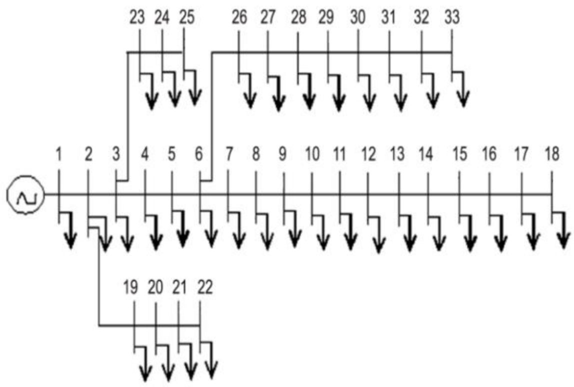

Figure 3: Single line diagram of IEEE 33 bus distribution network

4.0 Results and Discussion

This section presents the results of the study, highlighting the key findings and trends that emerged from the simulation results carried out in MATLAB/Simulink software.

4.1 Optimal placement of Electric vehicle charging station

The developed algorithm was applied to the IEEE 33-bus systems. In Table 1, the results of the moth flame Algorithm and CPLEX algorithm were compared. As can be seen in Table 1, the proposed method has better performance in power loss reduction over the CPLEX algorithm. The CPLEX algorithm is based on a combination of mathematical programming technique. Figure 1 – Figure 4 shows the power loss with and without EVCS placement on the IEEE 33-bus test network system. From the illustrations in the figures, one to four EVCS units were installed on the IEEE 33-bus radial distribution network.

Table 1: IEEE 33-bus system comparative analysis

No. of EVCS	Method	Optimal Bus Location	DG Power (kW)	Power Loss (kW)	Percentage Improvement (%)	Power Loss (kVar)
1	MFO	6	2664	103		74
2	MFO	30, 13	1212, 873	83		57
3	MFO	14, 24, 30	780, 1075, 1120	69		50
4	MFO	31, 14, 24, 7	761, 622, 965, 863	65	17	45
	CPLEX	2, 14, 19, 26	800,720, 990, 950	78		65

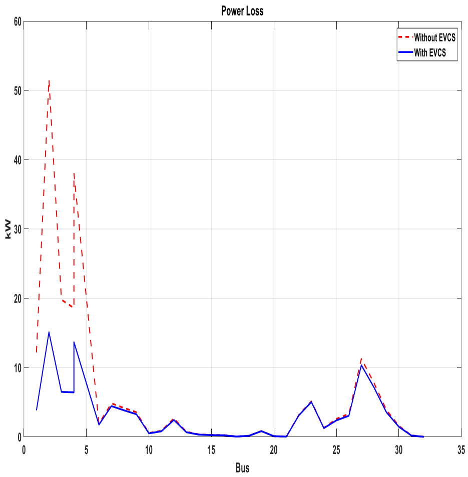

Figure 2: Power loss with single EVCS placement

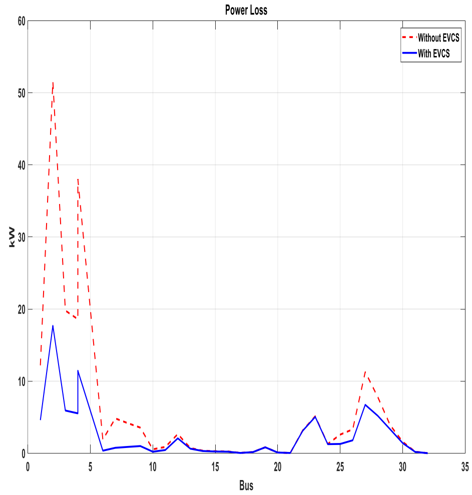

Figure 3: Power loss with two EVCS placement

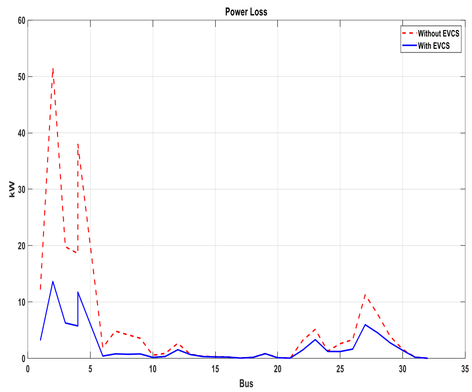

Figure 4: Power loss with three EVCS placement

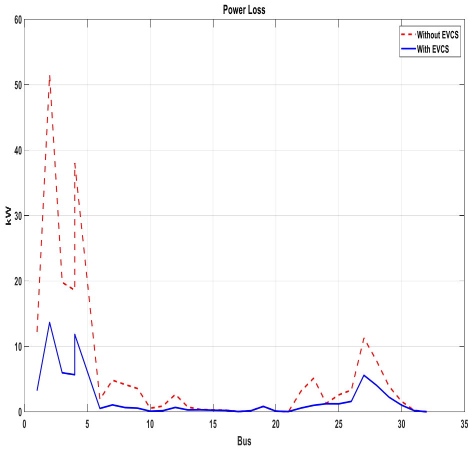

Figure 5: Power loss with four EVCS placement

4.2 Voltage profile of Electric vehicle charging station

From Figure 6 to Figure 9 it can be seen that the voltage profile of the proposed technique over performed that of the CPLEX algorithm. Figure 6 shows the voltage profile with a single electric vehicle charging station (EVCS) placement on the IEEE-33 bus radial distribution network. Figure 7 to Figure 9 shows the voltage profile of two, three and four EVCS placement respectively.

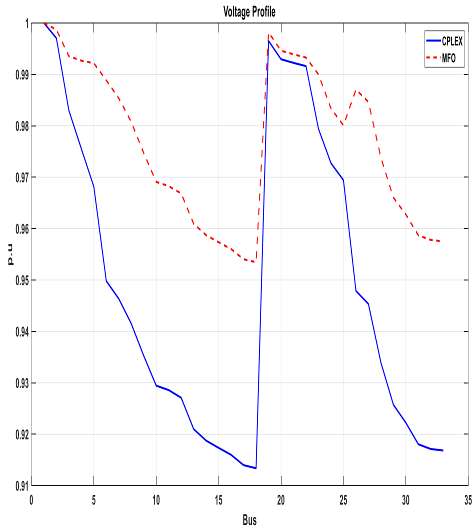

Figure 6: Voltage Profile with single EVCS placement

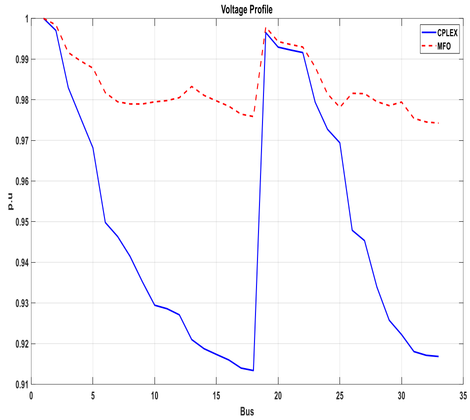

Figure 7: Voltage Profile with two EVCS placement

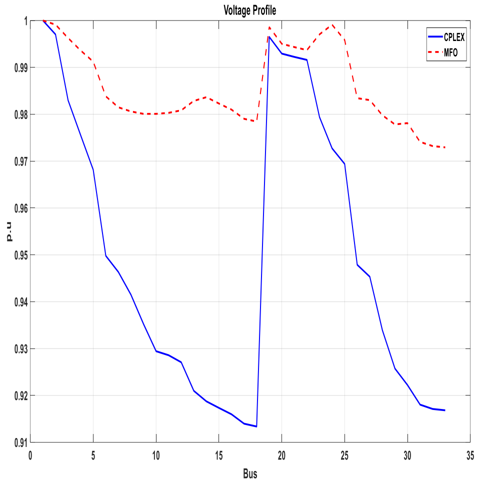

Figure 8: Voltage Profile with three EVCS placement

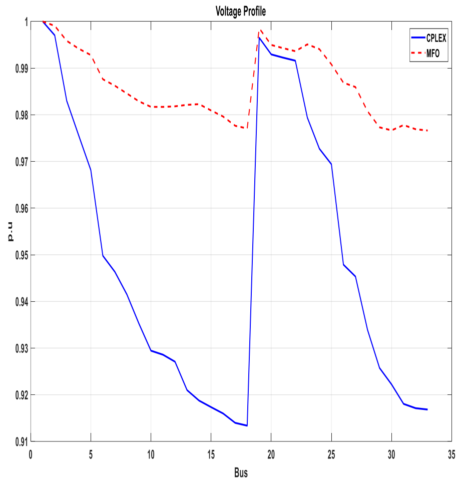

Figure 9: Voltage Profile with four EVCS placement

5.0 CONCLUSION

This study successfully presents a robust and efficient scheme for the optimal placement of electric vehicle (EV) charging stations within a distribution network using the Moth Flame Optimization (MFO) algorithm. The proposed approach effectively addresses key challenges such as voltage instability, and increased power losses caused by the growing integration of EVs. The MFO algorithm, was implemented to minimizes total power losses, and enhances voltage stability across the network. Simulation results confirm that the optimized placement of charging stations significantly improves the operational efficiency, reliability, and overall performance of the distribution system compared to conventional methods. The findings highlight the potential of the MFO-based optimization model as a practical and scalable solution for sustainable EV infrastructure development.

The following are the significant contribution:

1. Reduction in Power Losses:

The optimized placement of EV charging stations using the MFO algorithm resulted in a measurable reduction in total power losses within the distribution network by up to 17%, compared to CPLEX placement methods.

2. Improvement in Voltage Stability:

The proposed scheme significantly enhanced the voltage profile across the network, reducing voltage deviations from the simulation results

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