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Review of Electric Vehicle Charging Station Placement Impact on Distribution System

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ABSTRACT-Currently, the limited availability of fossil fuels and the environmental concerns over greenhouse gas emissions have significantly influenced the shift from conventional vehicles to electric vehicles (EVs). The primary power source for an EV is its battery.A critical challenge in this system is recharging the EV batteries before they are depleted, hence Electric Vehicle charging stations(EVCS) are necessary. However, implementing EVs on a large scale presents numerous challenges, such as poor EVCS infrastructure, accessibility, determining optimal EVCS locations, and power losses. For EVCS placement several simulative, analytical, heuristic and hybrid optimization techniques are applied to get improved results. With an emphasis on power losses minimization, this paper analyses a review of the literature on several optimal techniques for EVCSplacement into the distribution network.

KEYWORDS: Electric vehicle, charging station, optimization

I. INTRODUCTION

In recent years, the steady progress in transportation has led to the growth of the automotive sector. Factors such as the potential to reduce CO2 emissions from gasoline-powered vehicles, economic feasibility, environmental concerns, renewable energy sources, and rising oil prices have made electric vehicles (EVs) an appealing option for modern urban transportation systems. The placement of electric vehicle (EV) charging stations plays a pivotal role in promoting the adoption of EVs[1]. The energy source of EVs are batteries which needs to charged repeatedly before complete depletion. Strategically located charging stations can mitigate range anxiety, a common concern among potential EV buyers. Ensuring that charging points are available at regular intervals along major highways, in urban centres, and at key destinations like shopping malls and workplaces can provide drivers with the confidence that they will not be stranded with a depleted battery. This accessibility is crucial for encouraging more people to transition from traditional internal combustion engine vehicles to electric ones. Another concern in EVCS placement is, it affects grid stability due to increased power demand and uncertain load conditions. If EVCS is not placed at optimal location it reduces voltage, increases power losses, harmonics, instability and voltage deviation in the distribution network and there are various techniques to solve these issues.This study provides the review of EVCS placement at optimal location simulation approaches used in various literatures with the focus on power loss and voltage deviationminimization of the network.

II. ELECTRIC VEHICLE CHARGING STATION

2.1 Overview of EVCS technology

Electric vehicle charging stations (EVCS) are essential components of the infrastructure supporting the adoption of electric vehicles (EVs). These stations provide the necessary power to recharge EV batteries. The voltage and frequency difference in certainparts of the world allows the manufacturers of the EVCSto manufacture them according to the grid requirementsof the respective country. There are 4 levels of chargingEVs from EVCS viz. Level 1, Level 2, DC Charging andSuperchargers[2].Level 1 chargers use a standard 120-volt outlet and are suitable for overnight charging at home. Level 2 chargers require a 240-volt outlet and can provide a full charge in a few hours. DC charging requires 50V DC which provides full charge in few minutes. Finally, superchargers have voltage of 400V DC and charges in few minutes.

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TABLE 1

Types of EV charging

Type	Input voltage	Input current	Charging time	Uses
Level 1	120 V	12-16 A	10-13 hours	Home/office
Level 2	240 V	15-80 A	3.5-7 hours	Private/ commercial
Level 3	200-920 V	Max 500 A	10-30 minutes	Public

2.2 Approaches for optimal location of EVCS

The available literature primarily defines that different approaches determine the problem formulation of optimal location of EVCS. In fact, these approaches are the DNO(Distribution Network Operator) approach, CSO(Charging Station Owner) approach, EV user approach and combination of given approaches. The investors of charging stations require to place the EVCSs to minimize the installation cost and maximize the profit by charging the EVs. On the other hand, the EVs drivers intend to place the CSs to minimize the traveling cost, charging time, waiting time, charging, access cost, etc, while the distribution network operator desire to place the CSs to minimize the impact at distribution system parameter. Thus, for optimal placement of EVCS all the approaches should be considered[3].

2.3 EV integration impacts on grid

The integration of small quantities of EVs into the distribution grid will not impact the grid. However moderate to high penetration of EVs into distribution grid has its effect.The placement of electric vehicle (EV) charging stations (EVCS) at optimal location significantly impacts both power distributor and consumer. Strategic placement can enhance grid stability and efficiency, while poor placement can lead to grid issues like load distribution, grid stability and reliability, peak demand management, power losses, load profile, voltage and frequency imbalances and harmonics. Ultimately, EVs have introduced both considerable challenges and benefits for the power infrastructure[4].

III. ELECTRIC VEHICLE CHARGING STATION PLACEMENT IN DISTRIBUTION SYSTEM

The various methodologies used to find the optimal location forEVCSplacementondistribution system are metaheuristic, hybrid, and artificial intelligence techniques. The solution to EVCS placement problem is obtained by optimization method. Many studies are conducted utilizing modelling techniques and appropriate software to determine the optimal location forEVCS placement in the distribution system.

3.1 Meta-heuristic techniques

Meta-heuristic optimization is concerned with the use of meta-heuristic algorithms to solve optimization problems. Effective search or optimization algorithms are necessary to obtain the optimal solution. Numerous optimization algorithms can be categorized in several ways based on their intent and requirements. Genetic Algorithm(GA), Particle Swarm Optimization(PSO), Grey Wolf Optimization(GWO), Gradient Based optimizer(GBO), Bacterial Foraging Optimization Algorithm(BFOA)and Harris Hawks Optimization(HHO) are some of the available search algorithms used to find the optimal placement of EVCS with the focus on maintaining the distribution network reliability, power loss and voltage stability.Literature reviews and illustrations of several of these techniques is reviewed in[5, 6, 7, 8, 9]

The goal of [5] is identify optimal locations for EVCSs integrated with photovoltaics within the network. Subsequently, the employment of individual GA and PSO algorithms to optimize EVCS placement focuses on minimizing power loss and enhancing voltage.

[6] describes a novel metaheuristic algorithm named GBO was used in this work for solving the charger placement problem with the goal of maintaining the distribution network reliability, power loss and voltage stability.

[7]The paper established a charging station location optimization model based on genetic algorithm and social total cost model, and calculates the total operating cost of charging stations under various distribution conditions.

In order to reduce real power loss and provide a stable voltage profile, the charging station has to be placed as efficiently as possible. The [9] paper examines and elucidates the influence of electric vehicle charging stations (EVCS) on the balanced radial distribution network (BRDN) using particle swarm optimization (PSO).

3.2 Hybrid technologies

Hybrid algorithms play a prominent role in improving the search capability of algorithm. Hybridization aims to combine the advantages of each algorithm to form a hybrid algorithm, while simultaneously trying to minimize any substantial disadvantage. In general, the outcome of hybridization can usually make some improvements in terms of either computational speed or accuracy.

[10] describes a hybrid algorithm which inherited the best features of both GA and PSO was used considering the initial investment cost anddistribution grid powerquality as another parameter in the objective function for optimal placement of EVCS.

In [11], a hybrid bacterial foraging optimization algorithm and particle swarm optimization (BFOA-PSO) technique is proposed for the optimal placement of EVCSs into the distribution network with high penetration of randomly distributed rooftop PV systems. The optimization problem is formulated as a multi-objective problem minimizing active and reactive power losses, average voltage deviation index, and maximizing voltage stability index.

The distribution network reliability, voltage stability and power loss can be improved by Hybrid between Genetic Algorithm and Particle Swarm Optimization (HGAPSO) for solving the charger placement problem as recommended in [12].

3.3 Artificial intelligence techniques

AI optimization algorithms are computational methods that aim to find the best solution among a set of possible solutions to a specific problem. These problems often involve maximizing or minimizing a certain objective, subject to a set of constraints.

The EVCS integration causes increased network active power loss, a degradation in voltage profile, and decreased voltage stability margin.[13] An artificial intelligence (AI) approach, the hybrid of grey wolf optimization and particle swarm optimization, i.e., HGWOPSO, to investigate the suitable nodes for EVCS and DGs in a balanced distribution system.

[14]suggests a novel approach for deploying the fast-charging station(FCS) with minimum investment and power loss in the distribution system while maintaining voltage stability andpower quality. An improved version of the Improved Bald Eagle Search Algorithm(IBESA) is presented for placing FCSs with randomly placed solar-based distribution generation in the distribution system.

TABLE 2
EVCS placement optimization techniques on power loss and voltage stability

Sl. No	Approach	Algorithm	Objective	Test system	Reference
1	Meta-Heuristic	GA and PSO	minimizing power loss and enhancing voltage	IEEE 33 bus	[5]
2	Meta-Heuristic	GBO	Improve reliability and voltage stability, and reduce power loss	IEEE 33 bus	[6]
3	Meta-Heuristic	GA	Power loss reduction and cost evaluation	Irish territory of 200Kms	[7]
4	Meta-Heuristic	PSO and HHO	voltage stability, reliability, and power losses analysis	IEEE 33 bus	[1]
5	Meta-Heuristic	PSO	reduce real power loss and provide a stable voltage profile	IEEE 69 bus	[9]
6	Hybrid	GA - PSO	cost anddistribution grid powerquality analysis	Radial distribution network	[10]
7	Hybrid	BFOA-PSO	Reduce power losses and improve voltage profile and stability	IEEE 69 bus	[11]

			index		
8	Hybrid	GA - PSO	voltage deviation and real power loss analysis in the system	20 kV distribution system with 18 substations	[12]
9	Artificial Intelligence	GWO-PSO	Reduce power losses and improve voltage profile and stability index	IEEE 33 and 69 bus	[13]
10	Artificial Intelligence	IBES	voltage stability andpower quality	Network distribution	[14]

3.4 Outcomes of review on various techniques

This paper illustrates the importance of optimal placement of EVCS in the distribution system. EVCS placement at optimal location plays a major role in EVs adaptability. In distributors approach the power parameters and hence it has to be analysed. It has been found that different optimization approaches were utilized to determine the best solution for EVCSs placement.Furthermore, various researchers have considered different approaches for optimal location EVCS Table 2 offers a comparative overview of different optimization approaches defined in EVCS placement problems in thiscontext.These methods are dependent on the choice of objective functions, constraints, solution mechanisms.The two prime techniques used by researchers for problem-solving are GA and PSO. The main parameters which are analysed are voltage, power quality, power loss, reliability impact of the distribution system. Large and complicated systems are a good fit for meta-heuristic methods. The optimal solution is more effective and trustworthy when it is a mix of two or more optimization techniques.Artificial intelligence techniques are the most recent techniques and it is capable to get comparatively accurate solution.

IV. CONCLUSION

Electric vehicle charging station research is vital, yet it is still in its early phases. The location of the electric vehicle charging station might affect the distribution network's parameters, as well as the investor's attitude due to investment and profit. Furthermore, the position of EVCS influences the EV user's decision to charge. Therefore, research articles on optimal locations for charging stations are examined under different approaches. In distributors approach aims at minimizing active and reactive power losses, increasing voltage profile and stability indexes. Various algorithms are applied for optimal solutions based on the problem formulation. GA and PSO are the most frequently used method. The ultimate aim is to reduce losses and improve the efficiency of the system.

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