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Review Paper on Optimal Location of Electric Vehicle Charging Station

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Abstract
Fossil fuel depletion and increase in global warming provides wide scope for alternative transport facilities. Electric vehicles (EV) novel features and development leads to increase in EV customers. Also the rapid promotions of EVs done by government in order ensure sustainability and clean environment leads to increase in need of charging facilities fulfilling the demand. The charging infrastructure must be located at appropriate location to reduce the congestion of charging stations (CS) at a particular place and scarcity at other place. The inappropriate location of CS can also have some adverse consequences on power grid. Thus the optimal placement of CS is most necessary for smooth and proper operation of system. In this paper, the review of research progress and the problems existing is done on optimal location of electric vehicle charging station (EVCS) with the aspect of objective variables, also the mathematical models and algorithm.
Keywords: *Charging station, electric vehicles, optimal location, algorithms*

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I. INTRODUCTION

The rise of average global sea level is accelerating from past few decades caused by melting of ice-sheets, climate change, glaciers, thermal expansion of seawater, etc. which are the consequences of rise in average temperature of earth's atmosphere commonly called global warming. One of the major cause for this is burning of fossil fuels [1]. One-fifth of all US emission is accounted to cars and trucks (vehicles), consisting 24 pounds of CO_2 and greenhouse gases for each gallon of gas [2]. To overcome this issue electric vehicle (EV) is a very good option as it has zero roadside emissions and small amount of overall emissions [3]. Although EV is beneficial and environment-friendly, there are some barriers for its mass adoption. One among its major barrier is EV driving range and lack of charging stations (CS) as compare to petrol and diesel stations [4]. EV charging is the only source of power for pure electric vehicles, while hybrid electric vehicles work on petrol as well as electric power. To increase the number of EV users, availability of adequate charging facilities is necessary. According to [5], inadequate charging facilities become barrier for 55% of people ready for switching from ICVs to EV in India. 150 CSs are present in India and the Govt. of India has setup a target of setting up 1 CS at each 3 km in cities and 1 CS at each 25 km on either sides of highways [6].

As the convenient and affordable charging infrastructure affect users purchasing decision, location of CS impacts effectively on promotion of EVs [7]. In residential sites, EV charging is observed during night and on weekends while that in commercial sites, maximum charging demand is observed during operating hours and depends on traffic patterns [8]. Operating models mostly consider investment cost and maintenance cost. In metropolitan cities, getting land for CS becomes difficult due to tight land supply [9]. Hence to use land wisely highly connected network of CS must be developed instead of random CS installation [10]. When the distribution system is introduced to a CS in its circuit, change in power flow can be observed. The power losses of the system are determined by the base load of system as well as by the position and capacity of CS [11]. Thus, while planning CS installation transportation and power grid requirements are considered as main aspects to be focused.

II. OBJECTIVES FOR OPTIMAL LOCATION OF CS

Various objectives are taken into consideration while planning for optimal location of EVCS. These consist of cost concepts, transportation concepts, power grid requirements, reliability, user-friendly, geospatial analysis, charging requirements, CS installers' point of view etc. They are also classified as for transport network, for distribution network and for both transport and distribution network as in Fig. 1. This is the main classification and considers few or all of the above concepts. As for transportation network it considers EV flow, distance of CS, cost benefits and no. of chargers at CS. For distribution network it considers power requirements of grid, voltage stability of grid, economic benefits and no. of chargers i.e. capacity of CS to charge at a time. And the combination of both network considers the elements of both aspects together.

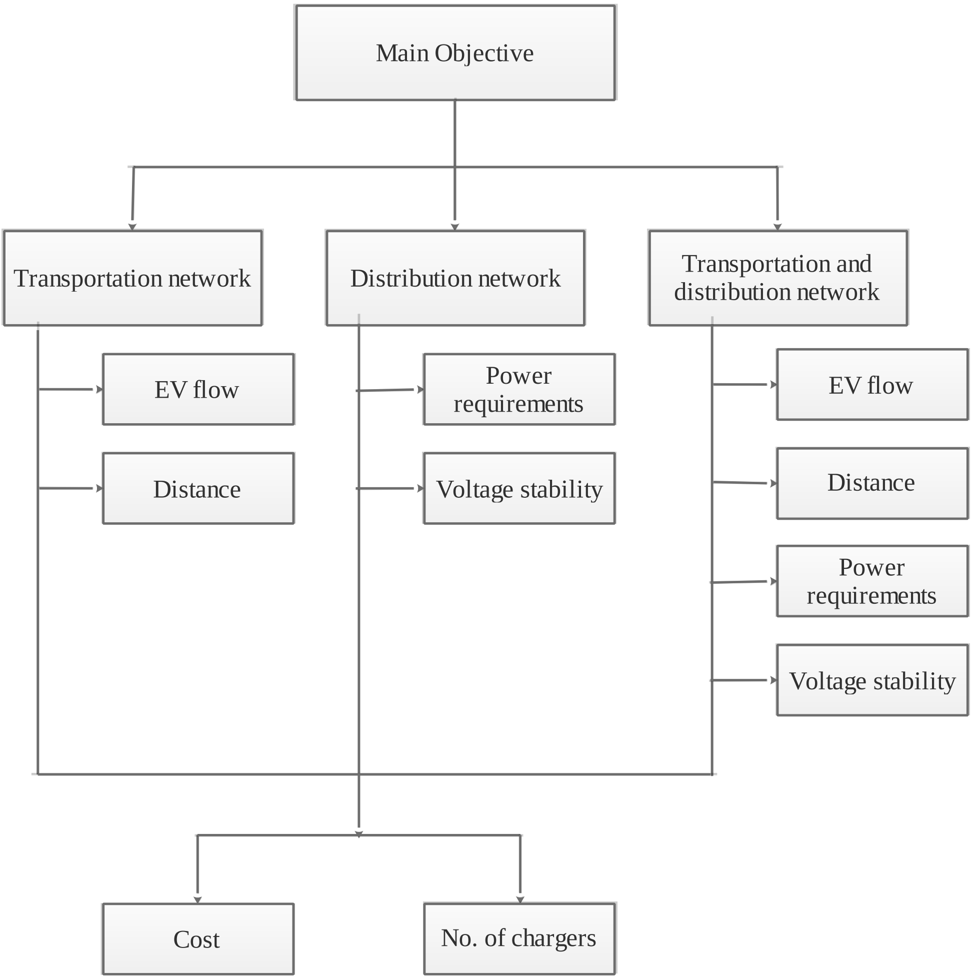

Fig. 1 Objective variables of optimal location of EV CS.

2.1 Cost Beneficial

To achieve better returns on the investment of CS author considers charging revenue minus building cost and maintenance cost of CS [12]. For achieving the goal of maximizing overall system profit, unit charging service charges are subtracted by operation cost in proportion to the capacity of CS and the fixed costs that include energy cost and infrastructure cost [13]. The location model aims to minimize total social costs, it considers construction cost also includes land cost; operation cost that includes worker wages, cost of maintenance, equipment depreciation cost and electricity purchase cost; and the wastage cost includes cost at time of charging, also direct and indirect cost [14]. The author plans minimization of total system cost that includes minimization of system travel cost and CS investment cost in [15]. The optimal location of FCS is obtained with minimal total cost, here the total cost includes development cost, electrification cost, traveling cost, and cost of energy loss of distribution network [16]. The author aims to minimize the total costs that contains cost of installation, cost of equipment depreciation, distance cost and waiting cost [17].

To minimize the overall cost of CS the author uses unit time and distance cost. The impacts of charging piles and service workers on profit of CS is analyzed [18]. The objective of [19] is to minimize the entire cost of CS, here the land cost and the installation cost limitations of CS are discussed thus aims to obtain maximum utility at minimum cost. The minimization of joint cost of construction cost, traveling cost of EV users and waiting time cost is considered while formulating objectives in [20]. To meet charging demand, optimum no. of slow and fast charging facility required is obtained by minimizing the cost of investment, cost of operation, and maintenance cost of the charging facilities [21]. The objective factors considered while finding optimal location of CS are cost of construction that involves cost of land, demolition, equipment, and project investment; and cost of operation and maintenance that involves electric charge, worker wages, economic expenses, taxes, etc. [22]. The cost of installation investment, maintenance and operating, travelling and power loss is reduced by implementing novel optimization technique in [23]. The author aims to minimize total cost that consists of construction cast and EV path deviation cost to satisfy users [4].

Table 1. Cost analysis for optimal location of CS

Author	Year	Cost type	Vehicle/ CS type
Xianqiang R., Huiming Z., Ruohan H., Yueming Q.	2019	Construction cost, operation cost and wastage cost	EV/CS
Caiyun B., Hailong L., Fredrik W., Anders A. Lu L., Zhixin Y.	2019	Charging revenue, building cost, maintenance cost	EV/CS
W. Dait, Y. Lit, X. Gan, G. Xie	2019	Charging cost, operation cost, fixed cost	EV/ FCS
D. Xiao, S. An, H. Cai, Ji. Wang, H. Cai	2020	installation cost, equipment depreciation cost, distance cost and waiting cost	EV/CS
Y. Chen, C. Cheng, S. Li, C. Yu	2018	Land cost, installation cost	EV/CS
R. Chen, X. Qian, Lixin M., S. Ukkusuri	2020	Construction cost, travelling cost, waiting time cost	EV/CS
H. S. Hayajneh, M. N. Bani Salim, S. Bashetty and X. Zhang	2019	investment cost, operating cost, maintenance cost	EV/ CS (SCS + FCS)
K. Kasturi M. R. Nayak	2018	investment cost, operational & maintenance cost, travelling cost, power loss cost	EV/CS
Cong Q. Tran , Dong Ngoduy, et.al	2020	Travel cost, installation cost	EV/CS
Nuttapol Chartsuk, Boonruang Marungsri	2019	development cost, electrification cost, traveling cost, energy loss cost	EV/ FCS
Han Wu, Dongxiao Niu	2017	construction cost, operation and maintenance cost	EV/CS
Fang Guoc , Jun Yanga, Jianyi Lu	2018	construction cost, EV path deviation cost	EV/CS

*FCS fast charging station, SCS slow charging station.

2.2 EV flow, traffic and driving constraint

The charging demand is calculated using daily traffic flow at different measurement points but these points are unevenly distributed hence small grid network is developed of entire area. The demand nodes are assumed which are centroid of every grid and average traffic flow is calculated giving the output of charging demand [12]. The objective is obtained based on the extended flow refueling location model (FRLM) with an unsure travel range to obtain the EV flow [24]. The distance from road section at which EV needs charging to the CS is considered to obtain wastage cost while charging and also considers direct and indirect cost [14]. A novel approach is used to calculate and reduce the transportation energy loss, as if FCS is far away from need of charging point of EV then access energy loss can occurs [25]. The author formulates function of flow decay with rates and threshold of range anxiety that aims to reduce range anxiety problem [4].

The vehicles driving range is considered while modeling for equilibrium choice of route with its driving range constraint and optimal location is set to maximize the path flows [26]. The distance satisfaction function is calculated determining if demand point is covered by distance or not this is from the demand point to CS and depends on distance here, if minimum distance maximum satisfaction and vice versa [27]. The modelling of route choice behavior of travelers allowing stops for charging is done to capture route congestion considering the traffic and the total travel time in minimized in [15]. The author aims to capture maximum traffic flow which helps in simulating charging demand of EVs with some restrictive factors like maximum travel distance while finding location for CS [11]. The aim is to overcome range anxiety and completion of long-distance trips so FRLM using long-distance travel data is used for appropriately obtaining locations for CS [28]. While modeling the demand flow of EV, EV charging patterns, SOC of EVs, EV arrival and departure time, reason of EV arrival, and walking distance, etc. factors are considered and the EV traffic flow is maximized depending on network decisions [29]. The impacts of drivers, vehicles, traffic flow etc. is simulated for meeting drivers' charging satisfaction, traffic efficiency and to eliminate drivers range anxiety [30].

Table 2. Traffic constraint analysis for optimal location of CS

Author	Year	Constraint type	Vehicle/ CS type
Caiyun B., Hailong L., Fredrik W., Anders A. Lu L., Zhixin Y.	2019	Converting traffic flow in charging revenue	EV/CS
Chungmok Leea , Jinil Han	2017	FRLM for obtaining travel range	EV/CS
Xianqiang Ren, Huiming Zhang, Ruohan Hu, Yueming Qiu	2019	Distance is converted to need of charging	EV/CS
Md. Mainul Islam, Hussain Shareef, Azah Mohamed	2018	Transportation loss, road density	EV/FCS
Fang Guoc, Jun Yanga, Jianyi Lu	2018	Users' range anxiety, distance deviations	EV/CS
Jia H., Hai Y., Tie-Qiao T., Hai-Jun H.	2018	EV's driving range	EV/CS
Yuxi Z., Zheyong Q., Pengbing G.,Shihao J.	2018	Distance satisfaction	EV/CS
Cong Q. Tran , Dong Ngoduy , Mehdi Keyvan-Ekbatani and David Watling	2020	Re-routing behaviors with driving ranges, travel time	EV/CS
Guozhong L., Li K., Zeyu L., Jing Q., Fenglei Z.	2019	Traffic flow	EV/ FCS
Yawei H., Kara M. K., Kenneth A. P.	2019	Long-distance travel data	EV/CS
Weiwei Kong, Yugong Luo, Guixuan Feng, Keqiang Li, Huei Peng	2019	Driver's charging satisfaction, traffic efficiency	EV/ FCS

*FCS fast charging station

2.3 Voltage and power requirements

When the distribution network is introduced with CS, power flow and power loss of network will change and the change is due to both base load of grid and the capacity and position of the CS. The objective is to minimize this change i.e. power loss within the network [11]. While selecting optimal location for CS, checking of power grid conditions is much important, as the load of power distribution network must be balanced that increases the security of power grids reducing damage of circuits. The author considers the power grid conditions and requirements while modeling for location [14]. The optimal locations with minimum distribution loss is obtained by computing daily distribution loss of all possible CS locations in micro-grid. This loss analysis is done with 3 cases like un-optimized power flow, optimal power flow with particle swarm optimization and optimal power flow with particle swarm optimization including integrated power management [31]. The impact of single CS and three CSs on distribution network is observed by analyzing the active and reactive loss, transmission line power flow and voltage deviation; and the optimal location maintaining stability conditions of distribution network is determined [32]. The grid power loss that consist of the power loss caused by fundamental voltage and current also the harmonic power loss occurred while fast charging of EVs are considered while selecting optimal location for FCS [25]. The safety of power grid is maintained putting power and voltage constraints and the branch node, resistance, voltage, power transmission, etc. gives operating conditions of power grid [30]. The power loss minimization and voltage deviation minimization of the power grid is observed, here the transmission line losses are reduced given by transmission line conductance, voltage magnitudes and phase angles, the bus voltage magnitude is maintained within certain range [33].

The examination of active power loss is finished with existing radial distribution bus and with optimum reconfiguration of system here, the impacts on system voltage profile is observed. Load flow analyzes is done to obtain voltage, current, real and reactive power losses of distribution system while finding optimal location of CS on distribution network [34]. The CS connection to distribution system causes power loss that is to minimize as that affects real power of the system and reactive power affects voltage stability. Voltage profile improvement is also necessary to maintain the smooth operation of distribution system [35]. The placement of CS at the optimal node of distribution system is obtained that maintains healthy voltage profile and minimum power loss as much possible with three case studies i.e. by placing one CS at three different places applying load balancing, voltage limit and current flow limit constraints [36]. To ensure system stability and ability to sufficiently supply power to load, the power flow of distribution system is essential. The CS in optimal location has less power loss and voltage within limits also the stability index within limits [37]. The placement of CS is at optimal node in the electrical power system. Voltage Source Converter is used to represent plug-in electric vehicles aims to minimize the system power loss [38].

Table 3. Grid constraint analysis for optimal location of CS

Author	Year	Constraint type	Vehicle/ CS type
G. Liu, L. Kang, Z. Luan, J. Qiu, F. Zheng	2019	Power loss	PEV/FCS
Xianqiang Ren, Huiming Zhang, Ruohan Hu, Yueming Qiu	2019	Power grid conditions	EV/CS
K. Gupta, R. A. Narayanankutty, K. Sundaramoorthy, A. Sankar	2020	Distribution loss	EV/CS
Tripti Kunj, Dr. Kirti Pal	2020	Stability conditions	EV/CS
Md. Mainul Islam, Hussain Shareef, Azah Mohamed	2018	Grid power loss	EV/FCS
Weiwei Kong, Yugong Luo, Guixuan Feng, Keqiang Li, Huei Peng	2019	Safety of power grid	EV/FCS
Changxu Jiang, Zhaoxia Jing, Tianyao Ji, Qinghua Wu	2018	Power loss, voltage deviation	PET/CS
Moupuri Satish Kumar Reddy, K.Selvajyothi	2019	Real power loss, voltage profile	EV/CS
A. Awasthi, K. Venkitusamy, S. Padmanaban, et.al.	2017	Voltage profile and quality, power loss	EV/CS
Arnab Pal, Aniruddha Bhattacharya, Ajoy Kumar Chakraborty	2019	Voltage profile, power loss	EV/FCS
Terapong Boonraksa and Boonruang Marungsri	2018	Power loss, voltage limits, stability index	EV/FCS
K. Yenchamchalit, Y. Kongjeen, K. Bhumkittipich, N. Mithulananthan	2018	System power loss	PEV/CS

*FCS fast charging station, PEV plug-in electric vehicle, PET plug-in electric taxies

III. MATHEMATICAL MODELS AND ALGORITHM

Considering to optimal placement of CS, the objective function is multivariable and complex, the optimization deals with minimization and maximization of a function subjecting equality and/or inequality constraints. The classic and evolutionary optimization algorithms are utilized by researchers for finding solution of problem that is briefly given below:

3.1 Genetic Algorithm

The complex location problems are most promisingly solved by heuristic algorithm method. Genetic algorithm (GA) have been seeking considerable attention over past recent years due to its novel optimization technique on the bases of its simplicity, ease of operation, minimum requirements, large search space and their global perspectives. GA has been successfully applied for variety of problems including location problems. GA solution is utilized for location model to reduce the social cost [14]. The EV transportation energy losses are minimized with help of GA that chooses best CS locations at its first stage of programming [21]. The objective function of minimization of power loss and maximization of captured traffic flow in distribution and transport networks resp. is solved using GA [11]. The main objective of work is to minimize power loss and optimize voltage profiles for power system. Here for four cases four different algorithms are used in which two of them are GA and hybrid GA. The output showed that hybrid GA provides best location solution [39]. GA is applied to optimize the problem to calculate necessary number of CS and then best position of CS from them to satisfy EV user demands [40].

3.2 Particle Swarm Optimization (PSO)

PSO overcomes the drawbacks of gradient based solvers by providing solutions to highly non-linear problems, it offers with the number of particles in a swarm and solution to the problem is provided through every particle. PSO provides highly efficient solutions as compare to other techniques, it is easy to implement and has fast convergence as compared to GA. PSO provides highly efficient solutions as compare to other techniques, it is easy to implement and has fast convergence as compared to GA. PSO is used with different scenarios to carry out distribution loss analysis in [31]. The optimization of active power loss and voltage profile improvement is done with help of PSO along with reconfiguration of radial distribution system [34]. The determination of optimal location of Plug-in Electric Vehicles (PEV) CS in the electrical power system is done by using PSO method [38]. The suitable location of charging facilities for electric bus is obtained in battery replacement mode with regional charging demand by solving model with PSO algorithm [41]. PSO is used for obtaining optimal capacity of CS for unbalanced radial distribution system along with location of CS [42].

3.3 Integer Programming

Few or each variable is treated as an integer in an integer programming problem technique. For different variables i.e. linear, non-linear and mixed integer, the integer programming is obtained at linear integer programming (LIP), non-linear integer programming (NIP), mixed integer programming (MIP), mixed integer linear programming (MILP), and mixed integer non-linear programming (MINLP). MILP model is utilized for achieving optimal location of CS, here the objective function is to maximizing the overall profits with some important constraints. Geographical Information System (GIS) is considered for gaining information related to traffic flow, charging possibilities etc. [12]. MILP is used to model the problem of optimal location and capacity of FCSs and renewable energy sources (RES) to be determined simultaneously considering the deviations and uncertainties of RES [42]. The author aims to model the problem of location of CS giving maximum profits with MILP [43]. A MINLP model is developed to the problem of sizing and optimal location of photovoltaic (PV) sources to be included in DC grid [44]. The problem of placement of CS with maximization of long-distance trip completion is formulated with MIP [28]. The cost minimization of investment, operating and maintenance of CS is obtained by linear programming to meet charging demands at the second stage of optimization [21].

3.4 Other Techniques

There are various techniques utilized other than above for optimal placement of CS some of those are mentioned here. Cross- entropy approach is formulated for different levels of EVs' penetration while placement of optimal location of FCS [15]. Monte Carlo method is used while optimal placing and sizing of FCS in a Muang district of Thailand considering minimum total cost [16]. The multi objective whale optimization algorithm is developed while finding optimal location for CS combined with PV and battery energy storage [23]. An optimization technique implemented for FCS placing is binary lightning search algorithm a recent introduced algorithm [25]. The multi-agent system and evidential reasoning approach is implemented for obtaining CS location for PETs [33]. The best CS location is achieved with the help of Artificial Bee Colony (ABC) algorithm [37]. The optimization of location is done using greedy heuristic and AHP methodology for grid power loss minimization and drivers' safety maximization [44].

3.5 Combined and/or Improved Techniques

A heuristic algorithm KSIGALNS algorithm is used with k-shortest path algorithm and iterative greedy algorithm to find the solution of minimizing the cost and best location for battery CS considering distance deviation problems and range anxiety [4]. For the placement of FCS, the Newton-Raphson method is used to prove the fixed-point equation has only one root and after that Ascent Heuristic algorithm is built to determine the optimal capacity and location of CS [13]. The optimal parameter is determined using Multi-Objective Particle Swarm Optimization (MOPSO) also the angle-based focus method is used to obtain the candidate location of CS and battery-exchange stations [19]. The author uses hybrid algorithm for improving voltage profile and quality of distribution system. Here hybrid algorithm of GA and improved PSO is proposed while optimal placement of CS, for better results this combination is also compared with conventional GA and PSO combination [35]. The optimization of Grey Wolf Optimization and Whale Optimization Algorithm is determined to find the solution for maintaining healthy voltage profile and minimum power loss while placement of CS at optimal node in radial distribution network [36]. For a sustainable development from social, economic and environmental perspectives, the triple bottom line principle is considered developing an intelligent multi-objective optimization approach consisting integration of improved MOPSO process with entropy weight method-based evaluation process while optimal placement of public CS [45]. In [46], improved Genetic Algorithm-Particle Swarm Optimization hybrid optimization algorithm is developed for solving multi-objective optimization problem resulting the location and capacity of RES and EVCS achieving reduction of power losses, maintaining the voltage fluctuations in limits, reducing cost of demand supply and charging cost and reduction of battery costs as possible.

IV. CONCLUSION

Electric vehicles offers negligible emissions providing sustainable and cleaner environmental solution, but the adoption is still at its initial stage. The adequate CS infrastructures are needed to replace the conventional transportations with EVs and smooth adoption of EVs. The CS must ensure proper traffic conditions with maintaining stability of network and the location of CS plays vital role in this part. Hence, selection of objectives considered while planning for optimal location of CS is important. In this review, the work presents different objectives, constraints and important factors required to be noted. The optimization techniques and mathematical formulation also plays a vital role while obtaining solution to reach to the accuracy of the solution. The work mainly focus to present a review on optimal location of EVCS problem. The nature of problem formulation and use of variety of solution finding optimization algorithms can be observed from the contribution of different researchers in this field.

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