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A Review of Studies on Charging Station Site Selection

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Abstract

With the acceleration of the global energy transition and the rapid growth in the number of electric vehicles, the rational deployment of charging infrastructure has become a key bottleneck constraining the further development of the electric vehicle industry. As a complex systemic endeavor, the site selection for charging stations not only affects user experience and operational efficiency but also impacts the energy supply efficiency of transportation systems and the stable operation of urban power grids. This paper aims to provide a systematic review of recent research progress on the issue of charging station site selection.

Keywords

Charging Station; Site Selection; Overview.

1. Introduction

As global warming and resource issues become increasingly severe, General Secretary Xi Jinping has stated: "Achieving carbon peaking and carbon neutrality is an intrinsic requirement for implementing the new development philosophy, building a new development paradigm, and promoting high-quality development; it is a major strategic decision made by the Party Central Committee in coordinating the overall domestic and international situations." The Central Committee's recommendations for the 14th Five-Year Plan propose a strategy for the 2035 goals: "to widely establish green production and lifestyles, and to ensure that carbon emissions stabilize and gradually decline after peaking." Electric vehicles, powered by clean energy, can effectively reduce carbon emissions and alleviate environmental issues, making them widely embraced by countries around the world. China boasts the world's largest market for new energy vehicles. As of September 2024, the total number of electric vehicle charging facilities in China reached 11.433 million, while the number of new energy vehicles in operation reached 28.09 million. On the other hand, according to Xinhua News Agency, as of September 2024, China's current vehicle-to-charger ratio stands at 2.46:1, which still falls short of the Ministry of Industry and Information Technology's target of achieving a 1:1 ratio by 2030. This project aims to optimize the site selection plan for urban electric vehicle charging stations, improve urban transportation levels, allocate resources rationally, and achieve cost reduction and efficiency gains. Therefore, the selection of locations for charging stations remains a topic of significant research interest. This paper will provide a review of the literature on this issue.

2. Site Selection Model

2.1. Point-of-Demand Site Selection Model

The point-demand model assumes that demand originates from users located near facility sites, who typically converge at a specific facility site to receive services, such as residential areas, shopping centers, and workplaces. Typical examples of the point-demand model include the P-median model, the P-center model, the maximum coverage model, and the set coverage model. Objectives include minimizing the distance from the facility site to the demand points,

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minimizing facility construction costs, or maximizing demand coverage. The P-median model was first proposed by Hakimi[1] to determine the optimal locations for P charging stations given a fixed layout, such that the sum of the products of the distances between the charging stations and demand points and the respective demand levels is minimized. In contrast, the P-center model aims to minimize the maximum distance between demand points and charging stations. Jia Long et al. [2]considered the mutual influence among different charging stations and proposed an improved P-center model, which minimizes the sum of the products of the distances between all charging stations and demand points and the respective charging demands. This effectively meets the charging needs of different types of EVs in urban areas; however, it does not account for factors such as EV driving routes, charging preferences, and road congestion.

Coverage models can be divided into two categories: maximum coverage models and set coverage models. Set coverage models aim to cover the maximum demand at the minimum cost. Wang et al. [3]utilized a hybrid integer programming method to determine charging station locations based on set-coverage and vehicle refueling principles, achieving maximum demand coverage while minimizing costs. The limitation of the set-coverage model lies in assigning equal weights to all demand points and ignoring the finite nature of resources. Consequently, Church et al. [4]proposed the maximum-coverage model, which aims to cover as many demand points as possible given a finite number of charging stations and service radii.

2.2. Site Selection Model for Traffic Demand

When studying the site selection of energy-supply facilities, since the primary consideration is often to ensure that vehicles have the opportunity to recharge in a timely manner during their trips, another category of models based on route demand-also known as flow-based models-has been extensively studied. In these models, demand is generated by trips and is served as vehicles pass through facility locations. Classic models include the FCLM (Flow Capturing Location Model) and the FRLM (Flow Refueling Location Model). Hodgson[5] first proposed the well-known Flow Capturing Location Model (FCLM) in 1990. Given the demand paths and the number of charging stations, this model aims to maximize the captured demand through site selection; however, it does not account for the limited service capacity of individual charging stations in real-world scenarios. Consequently, researchers have modified the FCLM model. Kuby et al.[6] incorporated vehicle mileage constraints to propose the Flow Refueling Location Model (FRLM). In addition, some researchers have incorporated stochastic charging demand into the FCLM and FRLM models. Tan et al. [7]extended the FCLM model into a two-stage stochastic optimization problem: the first stage determines the optimal location of charging stations based on all scenarios, while the second stage maximizes the traffic that charging facilities can serve under each scenario. Yildiz et al.[8] addressed both site selection and capacity planning in a stochastic traffic diversion model while accounting for deviation paths, and proposed a branch-and-bound method to solve the complex model. Zhou et al. [10] developed an FRLM model with capacity constraints and employed distribution-robust optimization for charging station site selection.

2.3. Multi-objective Site Selection Model

To address the imbalance between supply and demand for electric vehicle charging infrastructure, Zhang et al. developed a multi-objective model aimed at maximizing demand coverage and minimizing construction and operational costs. They designed a hybrid solution strategy combining the ant colony algorithm and the genetic algorithm, and validated the effectiveness of the model and algorithm through case studies. Cao et al[9], based on queueing theory, established a multi-objective site selection optimization model with user charging rejection rate, charging station utilization rate, and operator investment costs as objectives, and proposed an improved multi-objective particle swarm optimization algorithm for solving the

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problem. Liu[10]et al., in their study of electric bus charging station site selection, constructed a multi-objective optimization model aimed at maximizing economic benefits and balancing regional utilization rates. They designed a multi-nested genetic algorithm for solving the problem and validated the effectiveness of the model and algorithm through case studies. Farhadi [11]et al. constructed a multi-objective optimization site selection model aimed at maximizing the satisfaction of charging demand and minimizing costs, and proposed a data-driven method to solve the model. Yan[12]et al. constructed a multi-objective site selection optimization model based on three aspects: grid vulnerability metrics, active power losses, and rated energy storage capacity, and proposed an improved multi-objective particle swarm algorithm to solve the model. Wang[13]et al., addressing the issue of urban charging stations failing to meet user demand, constructed a multi-objective optimization model aimed at reducing construction costs, increasing utilization rates, and satisfying user needs. They proposed a multi-objective improved particle swarm algorithm to optimize the site selection of charging stations as well as the ratio of fast-to-slow charging stations within them.

3. Summary

In summary, while there has been a body of research on charging station site selection optimization both domestically and internationally, most studies have focused on a single type of demand. Few studies have systematically explored multi-objective site selection optimization that integrates both point and flow demands. In reality, charging demand manifests as both point and flow demands; therefore, a single point-demand or flow-demand model does not accurately reflect actual conditions. Consequently, future research could integrate the set-coverage model with the cut-off model to develop a site selection optimization model that combines point and flow demands.

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