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Design of Mobile Charging Stations for Future Electric Vehicles

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Abstract: Regarding the charging issue of electric vehicles, this paper analyzes the current challenges, related business models, and the potential implementation of future mobile charging stations from a design perspective. Taking the feasibility of future mobile charging stations as a framework, this study conducts design research on future charging issues. A conceptualization of mobile charging stations is proposed to explore new approaches to electric vehicle charging. With battery swapping technology as a starting point, improvement solutions and their feasibility for electric vehicle charging facilities are explored to alleviate the charging concerns of current electric vehicle users.

In recent years, the new energy vehicle industry in China has been continuously developing, transitioning from the strategic planning phase to the introduction phase, and currently entering the early stage of growth. Along with technological advancements, the market size has gradually expanded, and the industry landscape has been diversifying, with an accelerated pace of infrastructure development for electric vehicle charging equipment and subsequent market service models [1].

Charging equipment is the most crucial supporting device for electric vehicles, and charging-related concerns have been a persistent issue for electric vehicle users. Traditional electric vehicle charging requires a waiting time of 6 to 10 hours. With the development of fast direct current (DC) charging and the emergence of battery swapping stations, the charging time has been reduced. However, user anxieties about charging and battery range limitations still exist, as many users lack access to fixed parking charging stations.

1. Introduction

1.1 Current issues in electric vehicle charging

Electric vehicles commonly face challenges such as slow charging speeds, limited charging infrastructure, and limited battery life. Users of electric vehicles are anxious about charging duration and charging locations. The main reason for this anxiety is that China's new energy vehicle industry is still in the early stage of growth, and the supporting infrastructure for electric vehicles is not yet fully developed. Addressing user concerns about charging facilities can not only improve the convenience of charging but also enhance the acceptance of electric vehicles among the public.

Based on the current background of new energy vehicle development and trends in battery swapping policies, this paper proposes a concept of mobile charging stations to explore new approaches to electric vehicle charging. With battery swapping technology as a focal point, improvement solutions and their feasibility for charging infrastructure are explored to alleviate the charging concerns of current electric vehicle users.

1.2 Innovations

Based on the available information, battery swapping technology is already a relatively mature solution, but factors such as implementation costs, resource consumption, and location considerations need further exploration. Therefore, this article presents three innovations regarding the concept of mobile charging stations.

(1) Innovative charging mode: In the traditional fixed charging pile model, electric vehicle owners need to locate relevant charging stations. In the mobile charging mode, the roles of vehicle owners and charging stations can be reversed, with charging stations actively searching for vehicles, making the charging process more convenient and efficient.

(2) Innovation in battery energy exchange technology for mobile charging stations: The drawback of mobile charging is that the charging time is comparable to that of fixed charging stations. Therefore, mobile charging stations face two challenges during operation: (a) how to provide rapid energy replenishment to vehicles and (b) how to recharge the station after its battery is depleted. Battery swapping has inherent advantages over traditional charging methods, with a battery swap taking only 2 minutes and 46 seconds, offering efficiency and convenience surpassing that of refueling a conventional gasoline vehicle at a gas station. However, the initial investment for a battery swapping station can range from 3 million to 10 million RMB. For instance, Beijing Automotive New Energy Corporation, which has adopted battery swapping, stated that each station requires a minimum of 28 batteries, with each battery priced at 115,000 RMB, resulting in a storage cost of 3.22 million RMB per swapping station. The traditional construction of battery swapping stations often incurs significant costs, while mobile charging stations reduce the size and construction costs of electric vehicle charging stations. They utilize modular energy storage systems or battery pack systems to provide energy replenishment to electric vehicles, thereby improving the energy supply efficiency and charging efficiency of mobile charging stations.

(3) Innovation in business models: Innovative business models are crucial for the development of the new energy vehicle industry [2]. In cases where mobile charging stations face insufficient energy supply, they can adopt a decentralized approach to seek nearby cooperative businesses for battery swapping, thereby maximizing resource allocation and benefits.

2. Mobile Charging Station Case Studies

2.1 NIO's BaaS Policy

NIO, an automotive company in China, has implemented the Battery as a Service (BaaS) policy [3]. This policy utilizes NIO vehicles' swappable battery design and the existing nationwide network of battery swapping stations to provide NIO users with battery services that are rechargeable, swappable, upgradable, and separate from the vehicle. Under this policy, the vehicles belong to the users, while the batteries are owned by a "Battery Asset Management Company." Users can lease the batteries and gain the right to use them without worrying about battery depreciation, alleviating battery anxiety. This enables users to enjoy upgraded batteries and a better recharging experience, as shown in Figures 1. After opting for NIO's BaaS battery rental service, users only need to rent or upgrade batteries according to their individual needs, without the need to

purchase batteries. For certain vehicle models, the design of the chassis is compatible with the battery swapping stations, allowing users to complete a battery swap in just 5 minutes. NIO's battery-as-a-service business model has laid the foundation for battery sharing and circulation mechanisms.

2.2 Jiedian Charging Treasure Case Study

(1) Mobile Usage of Charging Treasure: For example, the Jiedian Charging Treasure. This portable charger can be taken by users and returned elsewhere after recharging. The advantage of this operation model is its similarity to the deposit policy of shared bicycles. Since the charging treasure is lent out, users are required to pay a certain amount of deposit, which is equivalent to the individual price of a single charging treasure. Therefore, the risk is relatively small compared to shared bicycles.

(2) Mobile Usage of Charging Treasure in Fixed Scenes: After borrowing the charging treasure, users can continue their activities in the vicinity and return it to the original location after use. Compared to returning it to a different location, this model has lower risk and smaller operating costs since it eliminates the need for inter-regional allocation of charging treasures. However, it may not provide the highest level of convenience for users.

(3) Fixed Usage of Charging Treasure in Fixed Scenes: Shared charging treasures are placed on tables in locations such as cafes and restaurants, allowing users to charge instantly without paying a deposit. This model has the advantage of rapid deployment, relatively low costs, minimal product depreciation, and lower risks [4].

Therefore, the design of mobile charging stations in this article will also consider the long-distance usage in fixed scenes and the possibility of moving between different locations. This involves calculating the optimal operating range and distance for a single mobile charging station based on the size of the city and the scope of its mobility.

2.3 Electric Bicycle Swapping Station Case Study

For delivery personnel in the food delivery and courier industries, the range of electric bicycles is crucial. Most existing lead-acid battery electric bicycles on the market have a range of around 50-60 km and a continuous operating time of approximately 2 hours, requiring more than 8 hours for recharging. Such limitations do not meet the practical needs of delivery riders. To address the pain points of charging and range, an efficient and convenient battery swapping model has emerged. The introduction of battery swapping can greatly solve the issue of slow charging for electric bicycle users and may become the mainstream trend for electric bicycle charging in the future. Under this model, users can match with nearby swapping stations to replace their depleted batteries and pay a certain fee. Merchants are responsible for operating the swapping stations, while the battery management company takes care of battery maintenance.

2.4 Summary

Through a series of investigations into the business models of charging treasure operators, a deeper exploration of the allocation between mobile charging stations' regions is conducted.

Figure 1: NIO Battery Swapping Station

3. Mobile Charging Station Design

3.1 Exterior Design

Electric vehicles and mobile charging stations operate on a principle similar to aerial refueling of aircraft, enabling extended vehicle range. Electric vehicles can not only charge at roadside stations but also provide on-the-go charging similar to aerial refueling. In terms of exterior design, the battery packs are evenly distributed inside the storage tanks, and the battery replacement is performed through internal rotation. In terms of size, based on research on current parking space standards, parallel parking spaces in urban areas require a safety distance of 0.5-0.75 meters, and the width of the safety opening area should be 0.5-1 meter. Therefore, the exterior design aims to keep the vehicle width within 1 meter, making it compact and flexible for charging between parked vehicles and saving space.

3.2 Internal Structure Design

The battery packs are distributed inside the vehicle body. For the design of the mobile charging station in this case, the battery pack size is 690145362mm, and there are 4 packs in total. Calculating the battery pack's range: For a certain brand of electric vehicle, the total number of batteries in the battery pack is 7,104 cells of the 18650 model (with a diameter of 18mm and a height of 65mm). The range of this vehicle is 420km, and its capacity is 85kWh at 400V DC. There is a new model of battery called "4680" in development, with a diameter of 46mm and a height of 80mm. It is reported that the capacity of this "4680" battery is 8.8 times that of the 18650 model. If this "4680" battery is used in the battery pack of this design (180 cells of "4680" batteries), the calculated range of one battery pack is approximately 93.5km. Therefore, the total range provided by 4 battery packs for an electric vehicle is 374km. Currently, the range of most electric vehicles in the market is 150-300km, so the 374km range battery packs can charge two vehicles simultaneously or, after charging one vehicle, be moved to another location to charge other vehicles. Fine algorithms can be used to achieve optimal resource allocation.

Additionally, the bottom of the mobile charging station will also be equipped with its own built-in battery. Due to its smaller size, the range of this battery will be set to 50km. In this case, the five sets of battery packs in the mobile charging station support each other. When the charging portion of the battery packs is depleted, the dedicated battery packs in the mobile portion can provide power to the charging portion while retaining their own mobility. Conversely, when the dedicated battery packs in the mobile portion are depleted, the charging portion's battery packs can supply energy to them.[5]

The battery packs will be equipped with a Battery Management System (BMS). The BMS serves as the link between the electric vehicle and the battery pack, enabling rapid and real-time monitoring of the battery's operating status (state of charge, operating condition, health status). Effective battery management ensures that the battery packs operate in their optimal state.

4. Conclusion

This article is based on the flourishing trend of pure electric vehicles and addresses the concerns of electric vehicle users regarding charging. It explores new forms of charging for future electric vehicles through the design of a mobile charging station system. By combining battery asset companies with individual roadside operators, a decentralized operational model is implemented. The mobile charging station serves as a platform where users can make reservations through their mobile phones. The charging system prioritizes the deployment of the nearest mobile charging station, providing users with a new charging experience that is convenient, efficient, and available anytime, anywhere. This approach reduces user anxiety regarding charging locations and times for electric vehicles. Improvements in the basic infrastructure for electric vehicle charging will increase public acceptance and trust in electric vehicles.

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