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Analysis of the Advantages of the Battery Swapping Mode under the Vehicle-to-Grid Interaction

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Abstract:

As the world advocates the development of new energy, the holding quantity of electric vehicles continues to rise, so the vehicle-to-grid interaction has become one of the key topics of today's research. Researchers regard electric vehicles as an adjustable mobile energy storage device that interacts with the power grid for energy and information. However, there is still a research gap on whether the battery swapping mode is more suitable for vehicle-grid interaction than the battery charging mode. Therefore, this study will collect data to compare the economic, convenience, and technical aspects of battery swapping and charging. It is concluded that charging and battery swapping are not much different in terms of economic attractiveness to users, but their convenience is greatly improved. At the same time, battery swap stations, as distributed energy storage units, have a better peak shaving and valley filling function for vehicle-to-grid interaction. However, the size and compatibility of batteries and the universality of battery swapping modes still need further research.

Keywords: electric vehicle; vehicle-to-grid Interaction; charging; battery swapping.

1. Introduction

With the world policy vigorously promoting the new energy development, the International Energy Agency (IEA) data predicts that electric vehicle sales will exceed 40 million by 2030 [1]. In particular, the number of new energy vehicles in China continues to rise. By the end of 2023, the total number of new energy vehicles in China will reach 20.41 million [2]. Various problems have emerged with the large-scale promotion of new energy vehicles. The randomness of new energy electric vehicle charging will greatly increase the pressure on the power grid. At the same time, the high power of fast charging technology will also increase the peak-to-valley difference in load. Therefore, vehicle-to-grid interaction technology has emerged. It uses new energy vehicles as mobile batteries. During the peak load of the power grid, the battery power is fed back to the grid. During the low load of the power grid, the excess power is fed back to the battery, thereby reducing the pressure on the grid [3]. Based on infrastructure construction, charging stations also have the problem of a contradiction between supply and demand. There are too few public charging stations, and the utilization rate of private charging stations is low. Some communities are even unable to build charging stations [2]. Therefore, using the battery swapping mode can perfectly solve these problems. On March 27, China's Central Ministry of Finance announced a list of pilot counties for filling gaps in charging and swapping facilities in counties by 2025. 75 pilot counties are located in 26 provinces, and funding is provided to build no less than 60 battery swapping stations [4]. At the same time, CATL and Sinopec signed an industrial and capital cooperation framework agreement on April 2, and plan to build more than 500 battery swap stations within the year [5]. This study will briefly describe the concept of vehicle-to-grid interaction, compare the battery swapping mode with the charging mode, and summarize the commonalities between the battery swapping mode and vehicle-to-grid Interaction. Finally, whether the battery swapping mode is suitable for vehicle-grid interaction is determined.

2. Vehicle-to-Grid Interaction and Battery Swapping

2.1 Concept and Technical Architecture of Vehicle-to-Grid Interaction

The conventional simple power supply (V0G), the smart charging control through EV charge control and communication (V1G), and the bidirectional charge-discharge control (V2G) are the three stages of vehicle-to-grid interaction technology development. As shown in Figure 1, in vehicle-to-grid interaction, electric vehicles are defined as an adjustable mobile energy storage device that interacts with the power grid for energy and information [6].

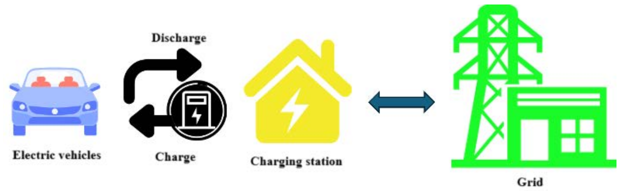

Fig. 1 Conceptual diagram of Vehicle-to-grid interaction

According to statistics, most households do not use their electric vehicles for more than 20 hours a day. In this case, the vehicle battery can be connected to the grid to provide an energy buffer. When the charging load of electric vehicles is connected to the power grid without reasonable control, the peak load of the power grid will increase significantly. This phenomenon increases the difficulty of stable operation of the power grid and increases the risk of power grid regulation. Therefore, to realize vehicle-to-grid interaction, electric vehicles must communicate with the power grid in real time, understand each other's status, and coordinate the charging and discharging strategies of a large number of electric vehicles connected to the power grid to achieve orderly charging and peak shaving and valley filling of the power grid load [3].

2.2 Current Status of Battery Swapping Technology

2.2.1 Internation

The global commercial exploration of battery swapping technology began in the early 2010s. As an industry pioneer, Israeli company Better Place built the first commercial battery swapping station (BSS) in Israel and Denmark in 2011. Tesla then deployed a BSS pilot project on Interstate 5 in California in 2013. But both of these iconic projects ultimately failed. Better Place went bankrupt in 2013, and Tesla ceased operations in 2015 due to insufficient market demand. Four key factors led to the setbacks of early international attempts. First, the market foundation is weak. In 2013, the global electric vehicle ownership was only 220,000, less than 5% of the market size in 2019, which made it difficult to support the operation of battery swapping facilities. Second, the penetration rate of private charging piles in American households is high, and users are more inclined to use cheap electricity at night for charging. Third, consumers generally use electric vehicles as a means of short-distance travel, and still rely on fuel vehicles for long-distance travel. Fourth, battery swapping technology is immature. Early battery swapping systems had defects in key links such as battery standardization, cost sharing, and power scheduling [7].

2.2.2 China

In recent years, China's battery swapping mode has made breakthroughs. NIO launched BSS in 2018, and by March 2021, it had deployed 190 battery swapping stations. Its second-generation stations provide an average of 312 services per day. Aulton focuses on commercial areas such as taxis, and its partner car companies have deployed more than 300 BSSs. Compared with early attempts abroad, BSS has three success factors in China. First, the target user base is huge. The holding quantity of electric vehicles reached 4.92 million in 2020 in China. Second, the living environment has a high density. Most residents in the city center do not have private parking spaces and rely on public charging and swapping services. Third, battery swapping technology is gradually maturing. NIO has launched

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innovative services such as battery leasing, discounted battery swapping, and upgrades [7].

2.3 Principle and Operation Model of Battery Swapping Technology

As mentioned above, the battery swapping mode has greater development prospects in China. In China, NIO is the leader in battery swapping technology, so most of the following will be summarized and analyzed using NIO as an example.

As shown in Figure 2, chassis battery swapping technology combines the power battery with the chassis. The robotic arm quickly and accurately finds the vehicle's power battery buckle, quickly removes it, and replaces it with a new one. No human intervention is required in the entire process. The chassis battery swapping method can realize the automatic removal and installation of the power battery, ensuring accurate positioning and high reliability [8].

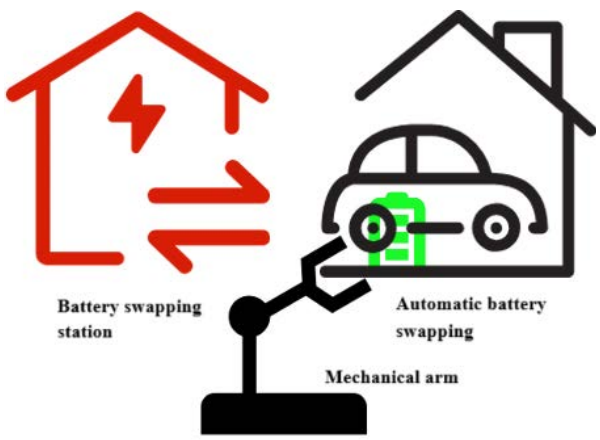

Fig. 2 Conceptual diagram of battery swapping

The battery swapping station is operated in the Battery as a Service (BaaS) mode. In this model, car companies sell batteries to asset management companies, which then rent the batteries to consumers. This can reduce the battery cost of the entire vehicle, thereby greatly lowering the threshold for car purchases. Since the management company manages the battery, they can take more scientific actions to charge it, thereby improving the value retention rate of electric vehicles and extending the battery life [2].

3. Comparison between Battery Swapping Mode and Charging

The essence of vehicle-grid interaction is to use low-cost electricity to attract users to charge their cars during low-power periods. Therefore, I will compare the economy and convenience of battery swapping and charging to highlight their technical advantages.

3.1 Economic Comparison

Self-charging cost calculation formula as follow:

$C = (d_V / d_B)* S_B * P$ (1)

Where C means Self-charging cost, d_V means Vehicle mileage, d_B means Battery mileage, S_B means Battery capacity, P means Electricity Prices.

According to the references [9, 10], NIO's standard battery pack is 75 kWh, and the rental service fee for the standard battery pack is 728 yuan/month. If users choose the Baas solution to purchase a car, the car price will be reduced by 70,000 yuan. According to the NIO ET5 vehicle mileage calculator on NIO's official website, using a standard range battery pack, when the outside temperature is 25 degrees Celsius, the NIO ET5 China Light-duty Vehicle Test Cycle (CLTC) comprehensive driving mileage is 560km [11]. Taking the residential nighttime electricity price of 0.3 yuan/kWh and the average annual mileage of vehicles in Ningbo in 2023 of 11,000 kilometers as an example [12], it can be calculated by formula (1) that the annual charging cost is at least 442 yuan. If consumers choose BaaS, the 70,000 yuan reduction in car price is enough to subsidize the 8-year battery pack rental service fee. At the same time, consumers do not need to consider the construction cost of charging piles.

3.2 Convenience Comparison

Table 1 shows the classification of charging modes, including slow charging, conventional charging, and fast charging. Different charging modes of electric vehicles vary greatly in charging time and charging power.

Table 1. Electric vehicle charging modes [13]

Charging mode	Rated voltage (V)	Rated current (A)	Application
Slow	220AC	16	Residence
Normal	220AC	32	Shopping malls, parking lots, etc.
Fast	400/750DC	125/250/400	Highway service areas, charging stations, etc.

The slow charging mode has the advantages of small charging current, small charging power, long charging time, and relatively small impact on the power grid. The fast charging mode has the advantages of short charging time, but due to the high charging power, it will accelerate battery damage and have a greater impact on the power grid [13]. Even with fast charging, which has a relatively short charging time, it still takes at least 15 minutes to charge the battery to 80% [14]. However, battery swapping only takes 3 to 5 minutes to replace a battery, which is almost the same as refueling. This greatly shortens the time required to replenish energy, reduces the waiting time for car owners, and significantly increases the utilization rate of electric vehicles [14]. It is more convenient for car owners who do not have the conditions to install home charging piles.

3.3 Technical Advantages

Although fast charging technology has improved the convenience of using new energy vehicles, the high temperature caused by fast charging will accelerate the decomposition of the electrolyte, the aging of the electrode materials, and the damage to the battery structure, resulting in a rapid decrease in battery capacity [13]. In the battery rental service, the battery swapping station is responsible for the unified battery management. It will perform self-inspection every time it charges, and use intelligent temperature control and trickle charging strategies to extend the battery life, reduce safety risks, and reduce the cost issues that new energy vehicle owners worry about due to overcharging and discharging of the battery [15].

The battery swapping system saves more battery resources than the conventional model and complies with the circular economy concept by achieving echelon utilization and effective recycling through centralized battery management. Battery swap stations show a special energy synergy value in the development of new power systems [15].

The battery swapping station performs „peak shaving and valley filling“ as a distributed energy storage device. It has little effect on the electricity grid and a tiny load peak-to-valley differential. It has the ability to reverse power delivery during high usage and charge during periods of low demand. With effective power resource allocation and increased power system stability, this highly controllable regulation mechanism can guarantee that users can swap batteries as usual. Battery swapping stations‘ adaptable peak-load shifting and frequency-regulating capabilities will become a crucial tool for absorbing wind and solar power as the amount of installed new energy capacity grows [15].

4. Conclusion

Through research, this article finds that in terms of economic efficiency, the prices of charging and battery replacement are not much different in terms of attractiveness to users, but purchasing battery rental services can save the construction cost of home charging piles. In terms of convenience, users do not need to consider whether old residential communities can install private charging piles. At the same time, it greatly reduces the time cost of charging and solves the problem of electric vehicle range anxiety. In terms of technical advantages, under the battery leasing model, centralized management of batteries makes them safer and longer-lasting. As distributed energy storage, it fits the peak-shaving and valley-filling function of vehicle-to-grid interaction.

The main contribution of this article is to make more people understand the advantages of battery swapping over charging in vehicle-to-grid interaction and to develop a preference for battery swapping. When more users choose the battery leasing model, it will help reduce the peak-to-valley difference in charging load, increase power storage, and reduce the pressure on grid capacity expansion.

Current research does not study the battery size and compatibility of current electric vehicles. Currently, there are not many car companies that use battery swapping. Future research should study the promotion and cooperation between different car companies, as well as how to unify battery standards to make battery swapping more convenient for different electric vehicles. With policy support, the number of battery swapping stations will be increased, making battery swapping stations more dense and the battery swapping mode more universal.

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