

Research on the Design of Electric Vehicle Charging Infrastructure from an Intelligent Management Perspective

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Abstract: Strengthening the design and intelligent management of electric vehicle (EV) charging infrastructure can optimize charging station configurations, improve charging efficiency, and enable remote monitoring and data analysis through intelligent management systems. This helps meet the growing demand for EV charging and promotes the development of a sustainable transportation system. This paper reviews the evolution of EV charging infrastructure, analyzes design principles under intelligent management, and discusses challenges and solutions in EV charging infrastructure design, aiming to enhance its safety and user-friendliness.

Keywords: electric vehicles; charging infrastructure; intelligent management system; structural design

1 Introduction

With the growing popularity of electric vehicles, charging infrastructure has become one of the key components in the new energy vehicle sector. This paper explores the development history of electric vehicle charging infrastructure, examines the application of intelligent management systems within this infrastructure, and analyzes the design principles, methods, as well as technical and managerial challenges faced. The aim is to better promote the development and application of electric vehicle charging facilities.

2 Development of Electric Vehicle Charging Infrastructure

In recent years, countries have introduced a series of policies to accelerate the development of electric vehicle charging infrastructure in response to the growing market demand for EVs. These policies include tax reductions, subsidies, and incentives that provide financial support for new energy vehicle companies to invest in charging facility construction, thereby promoting the expansion of charging stations and their coverage.

Throughout this process, charging technologies have seen continuous innovation and improvement. The introduction of advanced technologies such as fast charging and wireless charging has significantly enhanced charging speed and convenience, offering users a better charging experience [1]. As electric vehicles become more widespread, user demand for charging continues to rise, placing higher requirements on charging speed.

The application of intelligent management systems in electric vehicle (EV) charging infrastructure has made the charging process smarter and more flexible. Users can use mobile apps to check real-time availability, charging status, and pricing information at charging stations, enabling them to select the most suitable charging option based on their needs.

Meanwhile, intelligent management systems optimize charger utilization and enhance the overall operational efficiency of charging infrastructure, thereby improving user satisfaction and experience. This not only accelerates the development of charging networks but also delivers a more convenient and efficient charging experience for users. The advancement of EV charging infrastructure serves the growing EV market while laying a solid foundation for sustainable transportation. Looking ahead, as technology continues to evolve and demand increases, EV charging infrastructure will keep innovating and expanding, becoming a key pillar supporting the sustainable growth of the

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EV industry. Joint efforts from relevant authorities, new energy vehicle manufacturers, and industry stakeholders will further drive the development of charging infrastructure, propelling the EV sector toward a greener and smarter future.

3 Application of Intelligent Management in Electric Vehicle Charging Infrastructure

Intelligent management plays a crucial role in enhancing user experience and operational efficiency of electric vehicle charging infrastructure, not only making the charging process more convenient but also laying a solid foundation for the future development of electric vehicles.

Firstly, an intelligent monitoring system can not only monitor the operational status of charging infrastructure in real time, but also perform predictive maintenance using data analysis and machine learning technologies. For example, by analyzing historical data and equipment health conditions, the system can predict which charging stations are likely to fail and proactively schedule maintenance, preventing service disruptions caused by equipment malfunctions. This predictive maintenance significantly enhances the reliability and stability of charging infrastructure, ensuring users can conveniently charge their vehicles anytime and anywhere.

Secondly, an intelligent management system enables smart payment and dynamic pricing to meet diverse user needs. By analyzing users' charging behaviors and consumption patterns, the system can develop personalized pricing strategies—such as flexible rates based on charging time, energy consumption, or membership level. Through remote monitoring and data analytics, it can continuously track the status of charging infrastructure, energy usage, and user demand, enabling optimized scheduling and efficient operations. Additionally, the system supports real-time fault diagnosis and remote maintenance, further enhancing the reliability and availability of charging infrastructure.

Thirdly, intelligent payment systems can support various payment methods, including mobile payments and membership card payments, offering users a more convenient payment experience and enhancing their satisfaction and loyalty.

Fourthly, some advanced charging infrastructures have adopted blockchain technology to enhance security and transparency. Blockchain can improve the intelligent management of

charging facilities[2], ensuring the security and immutability of charging data, preventing malicious tampering, and safeguarding users' rights. At the same time, by leveraging blockchain, real-time sharing and exchange of charging data can be achieved, promoting interoperability among charging infrastructures and improving the overall efficiency and stability of the charging network. Additionally, some charging infrastructures utilize virtual reality (VR) technology to enhance user experience. Through VR, users can enjoy immersive experiences during charging—such as viewing scenic landscapes or participating in virtual social activities—making the process more enjoyable and engaging. Moreover, VR technology can provide real-time charging information and usage guidance, helping users complete charging operations more conveniently and thereby increasing user satisfaction and loyalty.

The application of intelligent management in electric vehicle charging infrastructure is continuously innovating and evolving, offering users a more convenient, efficient, and enjoyable charging experience while providing strong support for the efficient operation and management of charging facilities. With ongoing scientific and technological advancements,

intelligent management is expected to play an increasingly important role in the future, driving the electric vehicle charging industry toward greater intelligence and sustainable development.

4 Design Principles for Electric Vehicle Charging Infrastructure under Intelligent Management

4.1 Charging Infrastructure Structural Design

When designing the structure of electric vehicle charging infrastructure, designers should follow certain fundamental principles to enhance the intelligent management level of the charging infrastructure.

Firstly, Ensure the safety and reliability of charging infrastructure. In structural design, it is essential to consider

the infrastructure's resistance to risks and vibrations, as well as the rational layout of critical components such as cables and charging stations, thereby enhancing overall stability. For instance, in regions frequently affected by natural disasters, designers must incorporate disaster prevention and mitigation requirements, utilizing advanced materials and structural designs to improve the infrastructure's resilience during emergencies such as severe weather or earthquakes, ensuring that charging facilities continue to operate normally even under extreme conditions [3].

Secondly, fully consider the convenience and usability of charging infrastructure. Rational spatial planning and well-designed signage can help users locate charging stations more easily, while clear usage instructions enable quick and intuitive operation. For example, some commercial areas integrate navigation systems into their charging facility designs, providing users with precise guidance and making the entire charging process more convenient.

Thirdly, the durability of charging infrastructure should be enhanced. For example, using corrosion-resistant materials and advanced dust-proof encapsulation technologies can extend the service life of charging infrastructure and reduce maintenance costs.

Fourthly, optimize the layout of charging infrastructure and adopt modular design. In the arrangement of key components such as cables and chargers, thoughtful design can minimize the risk of cable tangling and damage. At the same time, modular design in the structural planning of charging infrastructure enables easier maintenance and upgrades.

Finally, fully consider environmental factors. In the structural design of charging infrastructure, renewable materials, energy-saving designs, and intelligent energy management systems should be fully incorporated to reduce[4] environmental impact and align with the principles of sustainable development.

4.2 Design of Intelligent Management System for Charging Infrastructure

The importance of intelligent management systems in charging infrastructure is becoming increasingly evident.

Firstly, in the design of intelligent management systems, emphasis should be placed on enhancing real-time data monitoring and analytical capabilities to promptly grasp the operational status, charging conditions, and health of charging infrastructure. For instance, advanced intelligent management systems leverage big data analytics to monitor electricity usage trends in real time, predict peak periods, and flexibly adjust charging strategies to optimize equipment utilization and reduce energy consumption. By conducting in-depth analysis of user charging behaviors, the system can also provide personalized recommendations—such as suggesting optimal charging times or displaying real-time availability of charging stations—enabling users to plan their charging trips more intelligently.

Secondly, user experience should be prioritized. Designers should create user-friendly interfaces and streamlined operation processes to enhance user satisfaction. For instance, the functionality of intelligent management systems can be expanded, enabling users to remotely charge their vehicles, make real-time payments, and check charging history via smartphone apps—making the entire charging process more convenient [5]. Through mobile applications, users can check the real-time status of charging stations anytime and anywhere, select suitable charging points, and even remotely start or stop charging sessions, significantly improving flexibility and convenience.

Thirdly, technological means should be fully utilized to achieve intelligent monitoring and flexible management of charging infrastructure. Through Internet of Things (IoT) technology, smart management systems can collect real-time data on various aspects of charging facilities—including power levels, equipment status, and charging speed—enabling comprehensive monitoring. This provides operators with real-time fault diagnosis and maintenance alerts, allowing them to promptly address issues and thereby enhance the reliability and availability of charging infrastructure.

Fourthly, the intelligent management system can continuously optimize its algorithms and functions through remote upgrades to adapt to evolving charging demands and technological

advancements. For example, as electric vehicle technology progresses, new charging interfaces or standards may emerge. Therefore, the intelligent management system should have strong scalability, enabling it to quickly adapt to

new charging standards and ensure compatibility and sustainable use of charging infrastructure in the future.

The design of intelligent management systems is crucial for improving the operational efficiency of charging infrastructure, optimizing user experience, and adapting to future development. By fully leveraging technological advantages, not only can the intelligence level of charging infrastructure be enhanced, but users can also enjoy more convenient and intelligent charging services, thereby promoting the sustainable development of the electric vehicle industry.

5 Challenges and Solutions in the Design of Electric Vehicle Charging Infrastructure under Intelligent Management

Currently, the design of electric vehicle charging infrastructure still faces multiple technical and management challenges.

In terms of technology, the development of fast-charging technology is a key focus, requiring solutions to address the impact of high-power charging on charging infrastructure and power grids, ensuring system stability and safety. To overcome this challenge, advanced battery management systems are essential to ensure effective heat dissipation during high-power charging, thereby extending battery lifespan and providing more reliable energy support for electric vehicles. Meanwhile, intelligent charging control technologies enable precise regulation of the charging process, improving efficiency and enabling grid coordination through smart management systems, reducing strain on the power grid and enhancing overall system reliability. Therefore, greater emphasis should be placed on applying intelligent charging control technologies to optimize the charging process, improve efficiency, and shorten charging times. Additionally, active research and development of high-power charging equipment are needed to enhance charging efficiency, reduce energy consumption, and ensure device safety.

In terms of management, the design of electric vehicle charging infrastructure faces challenges related to the standardization and regulation of charging station construction and operation. First, consistent standards for charging interfaces, payment systems, and operational management should be established. For example, some regions have already adopted international standards such as CCS, CHAdeMO, and GB/T to promote interoperability among charging infrastructures, ensuring users can access various types of charging equipment across different areas. Second, comprehensive policies and regulations should be developed to incentivize investment in charging infrastructure and encourage operator participation. Relevant authorities could introduce preferential measures such as tax incentives and reduced operating costs to attract more investors into the sector, stimulate the construction of additional charging stations, and support the healthy development of the electric vehicle industry. Third, relevant laws and regulations should be improved to regulate market practices, enabling charging infrastructure to better integrate with urban transportation and energy systems, thus achieving sustainable development of electric vehicle charging networks.

To address technical and management challenges, continuous innovation in the design of electric vehicle charging infrastructure is essential, incorporating advanced technologies and adhering to standards to ensure reliability, efficiency, and promote sustainable development across the industry. At the same time, industry stakeholders, relevant authorities, and standardization organizations must strengthen collaboration to advance global standard integration, facilitate the sharing and innovation of charging technologies, and further drive the development of electric vehicle charging infrastructure.

6 Conclusion

The development of electric vehicle charging infrastructure relies on advanced technologies and a well-designed intelligent management system. Proper design of charging infrastructure can enhance operational efficiency and user experience. In structural design, emphasis should be placed on safety and user-friendliness to ensure stable operation.

Regarding the intelligent management system, priority should be given to improving real-time data monitoring and

analysis capabilities, enabling continuous optimization of algorithms and functions through remote updates. From a user experience perspective, spatial planning at charging stations should follow ergonomic principles to ensure comfort and convenience during use. Clear signage and guidance information help users quickly locate charging equipment and understand the charging process. Navigation systems can provide precise route guidance in large parking lots or complex road networks, reducing the time users spend searching for charging points. Furthermore, to address technical and management challenges, it is essential to actively adopt advanced technologies and standardized practices,

effectively resolving existing issues in charging infrastructure design and promoting its sustainable development.

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