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Research on the Current Situation, Challenges and Development Trends in the Field of Electric Vehicle Charging

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Abstract:
This paper explores the challenges in the charging industry, particularly in the context of electric vehicles (EVs). It examines the current status of DC, AC, and wireless charging, revealing that DC fast-charging has a power range of 50-180kW, while ultra-fast charging exceeds 250-350kW. AC charging piles are crucial for daily energy replenishment, while wireless charging achieves efficiency close to wired charging but faces promotion obstacles. The study also highlights the diversified operation modes of charging facilities. Challenges include power grid impact, unbalanced layout, insufficient power access, and low return on investment. The paper proposes solutions and predicts development trends, predicting a shift towards high-power ultra-fast charging and intelligent Vehicle-to-Grid (V2G), upgrading infrastructure towards balance and intelligence, and shifting the market focus to "operation-centric" with capital concentration and diversified business models. This research aids in planning, policy-making, and enterprise operations in the charging field, contributing to EV promotion and carbon neutrality goals.

Keywords: Charging; Electric Vehicle; Power; Technology; Market

1. Introduction

The electric vehicle (EV) market has grown rapidly in recent years due to the pressing need for low-carbon transportation and the change in the global energy system. According to data from the International Energy Agency (IEA), global EV sales exceeded 14 million units in 2024, with the market penetration rate rising year by year [1]. However, the construction of charging infrastructure and the development of charging technology still lag behind the growth of vehicle ownership, becoming a key bottleneck restricting the further popularization of EVs. Current research mainly focuses on improving charging power, shortening charging time, optimizing the layout of charging piles, and promoting standard unification. Nevertheless, there remain significant research gaps in power grid load balancing, user experience optimization, and coordination with renewable energy [2].

This paper adopts a multi-dimensional analysis approach to study the “EV charging issue,” focusing on the comprehensive optimization of charging efficiency, grid-friendliness, and user convenience. The significance of this research lies in providing a scientific basis for future EV charging infrastructure planning and policy-making, promoting the coordinated development of charging technology and the power grid, and reducing reliance on traditional fossil energy. Meanwhile, through the study of user behavior and demands, strategies to optimize the public charging experience can be proposed to facilitate the large-scale promotion and application of EVs, thereby offering references for the achievement of carbon neutrality goals and the construction of smart energy systems.

2. Overview of Electric Vehicle Charging Technology

2.1 Current Situation of DC Charging

Charging power continues to be upgraded. Currently, the power of mainstream DC fast-charging piles generally reaches 50kW–180kW, while ultra-fast charging piles have achieved 250–350kW, with some pilot projects exceeding 600kW. Fast charging belongs to DC charging: the fast-charging power of mainstream new energy vehicles is mainly concentrated between 50kW and 150kW, and high-end models have exceeded 250kW through technological upgrades. At the same time, the on-vehicle side is transitioning from the 400V platform to the 800V high-voltage platform, enabling a faster charging speed that replenishes 300–400 kilometers of driving range in 10–15 minutes [3].

Technical maturity is also constantly improving. Liquid-cooled cables and liquid-cooled charging gun heads have become standard configurations for high-power fast charging, effectively solving heat generation and safety issues. After the upgrade of communication protocols, they can also support intelligent charging, dynamically adjusting power to balance battery life and power grid loading [4].

In terms of standards, the current situation shows diversity but a tendency toward integration. China adopts the GB/T standard and promotes the new national standard supporting higher power and two-way V2G. Europe and North America mainly use CCS2, while Japan still retains CHAdeMO. Tesla is also gradually opening its supercharging network. The world is moving toward interoperability and unified communication protocols to improve cross-brand and cross-regional compatibility [5].

Infrastructure construction is also advancing rapidly. China leads the world in the number of DC fast-charging piles. By May 2025, the total number of public charging piles in the country had reached 4.083 million, among which DC charging piles accounted for 46.4% (i.e., 1.895 million). Europe and North America are also accelerating the layout of ultra-fast charging networks on highways to meet the needs of long-distance travel [3].

2.2 Current Situation of AC Charging

AC charging piles play an important role in the charging field of new energy vehicles. In terms of power level and charging speed: the power of mainstream single-phase AC piles is mostly in the range of 3.3–7kW, and the power of three-phase AC piles can reach 11–22kW. Their charging speed is relatively slow, usually taking 6–10 hours to fully charge. However, this slow-charging method is suitable for home or office use at night, and is widely applied in scenarios such as residential areas, office parks, and public parking lots, serving as the main means of daily energy replenishment for EVs [6].

From the perspective of technical maturity: AC charging piles feature simple structure, low cost, and convenient installation, with little impact on the power grid. Moreover, the technology of On-Board Charger (OBC) is continuously upgraded, enabling higher power and more efficient energy conversion to effectively reduce energy loss. Currently, AC charging piles have achieved a high penetration rate and are commonly equipped in urban communities and public parking lots in China [4].

Regarding compatibility and standards, Europe and North America primarily employ Type 1/Type 2 interfaces, which broadly enable Plug-and-Charge, whereas China adopts the GB/T AC charging interface as the national standard, which is compatible with the majority of car types. In the meantime, communication protocols are continuously improved to facilitate intelligent billing, load control, and charging power adjustment [5].

In terms of industry and market status, more than 70% of China’s charging piles are AC, and as of 2024, there will be over 6 million units owned, more than three times as many as DC. The foundation of the urban charging net-

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work in Europe is AC piles, particularly the 11kW three-phase piles that are extensively used in residential areas. Additionally, more and more operators provide Plug-and-Charge and mobile payment services, significantly improving the user experience [6].

2.3 Current Situation of Wireless Charging Technology

Wireless charging technology for EVs is an innovative charging method. It mainly transmits energy from the ground transmitter to the on-vehicle receiver based on the principle of electromagnetic induction or magnetic resonance coupling, realizing non-contact charging. Its charging power is generally 3.3–11kW, and some pilot projects have achieved a power of 20kW or above. In terms of form, it includes fixed wireless charging, which enables charging when the car is parked, and dynamic wireless charging, which enables charging while driving.

In terms of industry and demonstration projects: in the passenger car field, brands such as BMW, Mercedes-Benz, and Hyundai have launched optional or pilot wireless charging schemes, mainly targeting high-end models and taxi fleets; in the field of public transport and logistics vehicles, some cities have deployed fixed wireless charging stations, suitable for short-term parking scenarios; South Korea, Germany, and China have all conducted dynamic wireless charging road tests to verify technical feasibility [7].

Currently, wireless charging technology has achieved an energy transmission efficiency of 85–90%, close to the level of wired charging. Although it has high requirements for vehicle parking positions, the new-generation system can automatically align, improving user convenience. It also supports two-way charging (V2G) and has the potential to participate in power grid peak regulation [8].

In terms of standards and compatibility: the International Electrotechnical Commission (IEC) has released the IEC 61980 series of wireless charging standards, and China has also formulated the GB/T 38775 series of standards, covering system safety, communication protocols, and interoperability. However, there are still technical barriers among different manufacturers in the market, and interoperability needs further improvement.

Wireless charging has significant advantages: it requires no plugging or unplugging, making it convenient and fast—especially suitable for high-frequency use scenarios such as taxis and public transport. It can reduce wear on charging guns and cables, improve safety, and can also be combined with autonomous driving and unmanned parking to achieve fully automated energy replenishment. Nevertheless, the industry still confronts several challenges. High construction costs and a low penetration rate are significant hurdles. Additionally, there is a need for optimization in efficiency, heat dissipation, and electromagnetic compatibility, especially for high-power wireless charging. Furthermore, full compatibility between the on-vehicle side and ground side is difficult to achieve due to insufficient standardization and large-scale application [8].

2.4 Current Situation of Charging Facilities (Operation Mode)

The profit models and business logics of the current new energy vehicle charging industry show a diversified development trend. Charging service fees are the core source of income, usually charged by electricity quantity (yuan/kWh). In some regions, charging standards are adjusted in combination with peak-valley electricity price differences to balance supply and demand. Membership systems or subscription systems have also become important profit methods. Automobile enterprises effectively improve user stickiness and repurchase rates by launching preferential charging packages or free charging quotas. At the same time, the industry continues to expand the scope of value-added services, covering parking, battery swapping, in-vehicle entertainment, advertising, and energy storage peak-shaving income, further enriching the income structure. In addition, energy management business is gradually emerging: by integrating photovoltaic (PV) systems, energy storage systems, and Vehicle-to-Grid (V2G) technology, it realizes power peak-load shifting, provides auxiliary services for the power grid, and obtains additional income therefrom.

In terms of technology and operation trends, the capabilities of intelligent scheduling and load management are continuously upgraded. Charging platforms can dynamically allocate charging power according to the real-time loading of the power grid and user charging demands, avoiding the impact of peak electricity consumption periods on the power grid. The degree of interconnection is constantly deepened. Charging pile platforms are gradually realizing cross-platform QR code scanning charging, Plug-and-Charge function, and unified payment systems, greatly lowering the user threshold. The integration of energy storage and charging has become an important development direction. Configuring energy storage equipment in areas with insufficient power grid capacity can not only smooth the fluctuation of charging load but also reduce electricity costs during operation. Big data operation also plays a key role: by analyzing user charging behavior data, operators optimize the location and layout of charging piles and implement dynamic pricing strategies, effectively improving the utilization rate and operation efficiency of charging piles.

3. Challenges

3.1 Technical Level

New energy vehicle charging faces several challenges, including the power grid impact caused by high-power charging. This can lead to excessive peak power grid loading and insufficient local power distribution capacity, threatening power supply safety. Solutions include intelligent load management, dynamic power allocation algorithms, distributed energy storage coordination, and Vehicle-to-Grid (V2G) technology. Intelligent load management adjusts charging power to maintain stable grid operation, while distributed energy storage coordination reduces power supply pressure. V2G technology allows EVs to feed back electricity to the grid when idle, optimizing power grid loading.

The balance between charging speed and battery life is also crucial. Excessively high charging rates will accelerate the attenuation of lithium batteries, affecting driving range and the service life of the entire vehicle. The solutions include intelligent charging strategies, which dynamically adjust the current curve based on battery status to reduce damage to the battery. Optimization of battery thermal management improves heat dissipation efficiency to reduce battery damage caused by high temperatures. Research and development of new battery technologies (such as solid-state batteries) can fundamentally solve the contradiction between fast battery charging and service life.

Low utilization rate of charging facilities and unreasonable location selection are also industry pain points. In some areas, charging piles have a high idleness rate, while there is a serious queuing phenomenon in high-demand areas, resulting in low ROI. The solutions include site selection based on big data, using traffic flow and historical charging data for scientific layout to improve the rationality of charging piles. Dynamic pricing mechanisms: encouraging users to charge during off-peak hours to improve facility utilization.

In the promotion of wireless charging, efficiency, standard compatibility, and construction cost remain obstacles. The solutions include improving electromagnetic coupling efficiency and developing automatic alignment systems to enhance vehicle parking accuracy. Promoting the integration of international and domestic standards to ensure the interoperability of vehicles and charging systems of different brands.

Regarding user experience and payment convenience, the experience varies across different operator platforms. The solutions include plug-and-Charge technology based on the ISO 15118 protocol: simplifying the charging process. Building an one-stop platform: integrating data from different operators to allow users to complete pile searching, navigation, and payment through a single APP.

3.2 Infrastructure Level

Although significant progress has been made in the construction of charging pile infrastructure, there are still a series of issues. Firstly, there is an unbalanced layout of infrastructure. In core urban areas, the density of charging piles is high but utilization is oversaturated; while the construction of pile networks in suburban areas and along highways is insufficient. The solutions include conducting scientific site selection based on big data analysis and implementing a hierarchical layout strategy to meet charging demands in different scenarios.

Secondly, insufficient power access and capacity restrict the development of charging piles. The centralized access of high-power DC fast-charging piles will cause a great impact on the distribution network, and some stations have problems such as insufficient capacitance. The solutions include adopting an integrated scheme of charging stations and energy storage to alleviate power grid pressure and actively promoting the transformation of the distribution network to provide power guarantee for the stable operation of charging piles.

Operation and maintenance (O&M) and reliability issues also cannot be ignored. Currently, the failure rate of public charging piles is relatively high, affecting the user experi-

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ence. The solutions include using remote monitoring technology to grasp the status of charging piles in real time, and utilizing AI algorithms to predict faults and arrange maintenance in advance, as well as adopting a modular design to improve the availability of charging piles.

Furthermore, insufficient standardization and interoperability hinder the healthy development of the charging pile industry. There are barriers in payment, communication, etc., among different operators, requiring users to download multiple APPs. The solutions include promoting the implementation of unified communication protocols to support Plug-and-Charge and cross-platform interconnection, and enhancing the user experience.

Finally, insufficient integration of renewable energy and smart energy is also a current challenge. Most charging stations fail to make full use of renewable energy and lack energy management systems. The solutions include promoting the integrated PV-storage-charging model and building smart microgrids to realize flexible energy scheduling.

3.3 Market Level (Return on Investment)

The current new energy vehicle charging industry faces many challenges in terms of ROI, generally characterized by high investment and long cycles. The investment cost of DC fast-charging stations remains high, and the operation cycle usually takes 5 to 8 years to recover the cost. The industry has a single profit model, mainly relying on charging service fees and electricity price differences, and profits are easily affected by electricity price fluctuations and policy adjustments.

There are many factors affecting ROI. Site selection is a core factor, as the location of the station directly determines traffic flow and charging demand. The selection of pile types is also crucial: ultra-fast charging piles are suitable for long-distance scenarios, while slow-charging piles are suitable for daily charging scenarios. Electricity price strategies and policy environment are also key factors, which will affect the construction progress and operation costs.

To improve ROI, the industry needs to explore solutions from both technical and commercial aspects. Using big data analysis for scientific site selection to avoid "zombie piles." Guiding users to charge during off-peak hours through dynamic pricing mechanisms to improve utilization. Promoting the integrated PV-storage-charging model to reduce electricity expenditure during peak periods. Adopting a modular pile design to simplify maintenance processes and reduce O&M costs. Actively expanding value-added services to increase the profit space of individual stations and ensure a stable income source.

4. Conclusion

This paper examines the development of electric vehicle (EV) charging, focusing on three key dimensions: technology, infrastructure, and market. It analyzes the current status of DC, AC, and wireless charging technologies, highlighting their advancements and challenges. DC charging power is being upgraded, with ultra-fast piles reaching 50kW-180kW and 800V high-voltage platforms becoming popular. AC charging, with a power range of 3.3kW-22kW, is becoming the mainstay for daily energy replenishment in communities and office areas. Wireless charging, based on electromagnetic induction or magnetic resonance, has an efficiency increase of 85%-90%.

However, the charging industry faces challenges such as peak power grid loading, battery life contradiction, low utilization rates, and insufficient compatibility. Infrastructure layouts are unbalanced, power access capacity is limited, and renewable energy integration is low. The charging industry also has low ROI, a single profit model, and limited utilization rate.

To address these issues, the paper proposes dual technical and commercial solutions. Technically, high-power ultra-fast charging, intelligent V2G, wireless charging, and unmanned energy replenishment will become core directions. Infrastructure will be upgraded towards balanced layout, high power, intelligence, and multi-energy integration, with the operation focus shifting from construction-centric to operation-centric. The market will focus on leading enterprises, transform into a "charging + diversified services" composite type, and create comprehensive energy service stations.

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