

Review of Electric Vehicle Charging Systems and Key Technologies

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ABSTRACT

This paper provides a systematic review of the latest research advances in electric vehicle charging systems and their key technologies, focusing on two core domains: super-fast charging equipment and power batteries. Analysis is conducted from perspectives including technical parameters, performance metrics, and industrial applications. By comparing the technological achievements of representative domestic and international enterprises (such as Huawei, CATL, Tesla, and StoreDot), the challenges currently facing fast charging technology are summarised. Recommendations for the charging infrastructure layout and the coordinative optimisation of power grid have been put forward to advance the further development of electric vehicle charging systems.

KEYWORDS

Electric vehicles; Charging systems; Super-fast charging; Power batteries

1 Research background

In recent years, electric vehicles have accelerated their replacement of traditional fuel-powered vehicles due to advantages such as zero emissions and high energy efficiency, becoming the mainstream direction for global automotive industry development. According to the International Energy Agency's latest report "Global EV Outlook 2025"^[1], Chart 1^[2] indicates that the global electric vehicle sales exceed 17 million units in 2024, growing by more than 25%. It is also predicted that the market size of electric vehicles will grow exponentially in the next five years. Except for 2/3W, the number of electric vehicle fleets of all models will reach 250 million, which is four times that of the end of 2024. The annual growth rate is projected to reach 25%. This rapid development trend places higher demands on supporting charging infrastructure, while innovation in charging technology has become a key factor in driving industry advancement and widespread adoption.

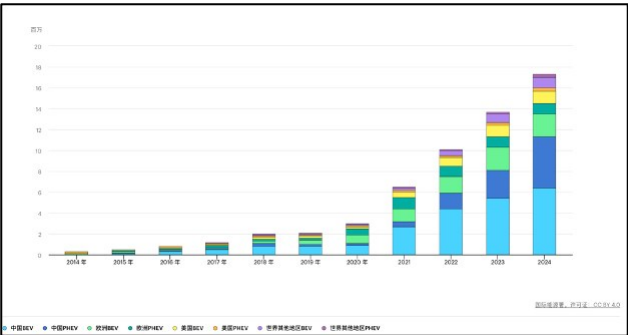


Figure 1 Global electric vehicle sales (2014-2024)

The current electric vehicle charging system faces two major challenges: firstly, consumer demand for faster charging is growing, yet high-power charging inevitably impacts grid stability, particularly during peak electricity consumption periods. Secondly, the lack of uniform technical standards among different manufacturers hinders the interoperability of charging facilities.

Research into key technologies for electric vehicle charging systems holds significant practical importance and urgency. Charging infrastructure forms the foundation for the electric vehicle industry's development. Meanwhile, technological breakthroughs can enhance the travel experience and alleviate range anxiety. This research also contributes to advancing the adoption of new energy vehicles, positively impacting carbon emission reduction targets. Therefore, undertaking research into key technologies for electric vehicle charging systems is highly necessary.

2 Research significance

This research holds significant theoretical and practical value for advancing electric vehicle charging systems.

Theoretically, by systematically reviewing the latest technological developments in super-fast charging equipment and power batteries globally, and establishing a comprehensive evaluation framework for charging equipment, it addresses the existing gaps in comparative studies across different technical pathways regarding efficiency, cost, and compatibility. This provides foundational support for theoretical innovation in electric vehicle charging technology and offers a reference basis for subsequent academic research.

In terms of practical value, this research focuses on the technical characteristics of various charging system architectures. The findings can be applied to the planning and construction of charging infrastructure. By examining key issues such as charging facility layout, grid-coordinated dispatch, and the standardisation of technical specifications, it can provide valuable insights for formulating relevant industrial policies. This will promote the coordinated development of charging technology with power batteries and grid systems.

3 Current state of super-fast charging equipment technology

3.1 Domestic advancements in super-fast charging equipment technology

Within the super-fast charging equipment sector, Huawei Technologies Co., Ltd. has introduced the industry's first fully liquid-cooled megawatt-class super-fast charging solution. This solution employs an innovative liquid-cooled thermal management design, with technical specifications indicating a maximum system output power of 1.5 megawatts and support for dual-gun 2400-ampere high-current output. It can replenish 20 kWh of energy per minute. For heavy-duty trucks equipped with 300 kWh battery packs, this enables a complete charge from empty to full within 15 minutes. Compared to conventional fast-charging stations, this system achieves approximately four times the charging rate ^[3].

For the passenger vehicle market, the system is compatible with all models and boasts a lifespan exceeding ten years – two to three times that of conventional air-cooled systems in the industry ^[4]. Furthermore, it is particularly noteworthy that the system maintains normal operation under extreme temperature conditions, including low temperatures of -30°C and high temperatures up to 60°C ^[5]. This broad environmental adaptability significantly enhances its application value across diverse climatic regions. From a technological development perspective, the innovation of this system lies not only in improved performance parameters but also in providing the industry with a feasible solution.

3.2 Technology advancements in overseas super-fast charging equipment

In the international field of fast-charging equipment technology, Autel Energy's MaxiCharger DC fast-charging system garnered significant attention at the 2025 CES exhibition ^[6]. This integrated charging solution employs an innovative technical architecture, delivering a maximum output power of 480 kilowatts and supporting simultaneous charging for four electric vehicles. Its outstanding compatibility design accommodates mainstream electric vehicle models, with operational data indicating a charging success rate exceeding 99%.

From a technical architecture perspective, the system employs a modular design. This structure enables multi-port coordination through intelligent power distribution algorithms. The payment system integrates multiple technical solutions including contactless payment, RFID identification, and plug-and-charge functionality. Notably, the system also supports seamless integration with renewable energy systems. It incorporates photovoltaic power generation and battery energy storage systems. This integration reflects a sustainable development design philosophy.

For operational management, the system incorporates an AI-based real-time monitoring platform that uses big data analytics to enable predictive maintenance. Achieving an overall availability rate more than 98%, it significantly enhances charging infrastructure operational efficiency. This technological innovation provides charging station operators with a reliable commercial solution and holds significant value for accelerating electric vehicle adoption.

As an industry leader in electric vehicle charging infrastructure, Tesla completed the first demonstration site of its V4 Supercharger in Harderwijk, Netherlands, in March 2023. This milestone marked the beginning of the commercialisation of next generation charging technology ^[7]. Subsequently, Tesla accelerated the worldwide deployment of its V4 Supercharger network, progressively expanding coverage across major EV markets including North America, Asia-Pacific and Europe.

According to the latest statistics, Tesla's global Supercharger network has exceeded 70,000 units ^[8]. The V4 Supercharger system delivers significant performance improvements. It increases charging efficiency by 25% when batteries are preheated. This system can replenish approximately 250 kilometres of range in just 15 minutes. The maximum power output reaches 325 kilowatts. These performance metrics are at the forefront of the industry.

From an industry development perspective, the rapid expansion of Tesla's V4 Supercharger network holds significant value. Its high-power characteristics markedly improve charging efficiency. It offers electric vehicle users a more convenient refuelling experience. Concurrently, its global deployment strategy effectively resolves infrastructure bottlenecks for long-distance travel. These advancements provide crucial reference points for technological development

across the entire electric vehicle industry.

4 Current state of power battery fast charging technology

4.1 Domestic advancements in power battery fast charging technology

Domestic enterprises have recently made breakthroughs in power battery fast charging technology. CATL introduced its second-generation Shenxing super-fast charging battery in April 2025. This product stands as the world's first lithium iron phosphate battery simultaneously achieving an 800-kilometre range and a 12C charging rate. It meets internationally advanced standards across multiple key performance indicators ^[9]. Test results demonstrate that under standard temperature conditions of 26°C, the battery can replenish 520 kilometres of range within just five minutes. Even under low-temperature conditions of -10°C, charging from 5% to 80% takes only takes 15 minutes. The product maintains a stable charging power output of 830 kilowatts even when fully depleted. This performance effectively addresses the challenge of rapid energy replenishment under extreme conditions.

On 8 January 2025, Honeycomb Energy Technology Co., Ltd held its fifth battery technology launch event. The company showcased its latest series of power battery products, which achieve significant breakthroughs in extreme environment adaptability and fast charging technology ^[10]. The company's off-road-specific battery achieves an ultra-wide operating temperature range from -43°C to 60°C. Under extreme cold conditions of -40°C, the battery's discharge energy and output power increase by 50% and 40% respectively. Through the adoption of innovative dual-medium integrated cooling technology, the system maintains stable power output even in high-temperature environments up to 40°C. Furthermore, at -20° C, the battery can still deliver a 5C instantaneous high-power discharge capability, which demonstrates its exceptional low-temperature performance.

Honeycomb Energy's Short Blade battery product also excels in fast-charging performance. Supporting a 6C charging rate with an energy density of 185 Wh/kg, it achieves a 10% to 80% charge replenishment in just 8.5 minutes during practical application. Through innovative electrode interface optimisation technology and a self-healing electrolyte formulation, this battery reaches a cycle life exceeding 5,000 cycles. When integrated with an advanced management system, its total service life extends to 15 years or 600,000 kilometres. These characteristics provide substantial support for the long-term reliable operation of electric vehicles.

Additionally, the company provides customised battery solutions for diverse applications. The long-life version offers 95.7 kWh capacity and supports 3C charging. This version comes with a warranty covering 8 years or 1.5 million kilometres. The fast-charging version offers 91.4 kWh capacity and enables 4C charging. It achieves 70% charge replenishment within 14 minutes. The commercial-passenger hybrid battery pack, designed for hybrid vehicles, delivers 13 kWh capacity with a peak discharge power of 360 kW. Its cycle life exceeds 35,000 cycles. This configuration improves vehicle energy efficiency and reduces carbon emissions.

Table 1 Performance parameters comparison of domestic fast-charging batteries

	Shenxing Super-Fast Charging Battery	Honeycomb Energy Battery (Short Blade Battery)
Maximum Charging Rate	12C(world's first)	6C
Low-Temperature Charging Performance	15 minutes at -10°C(5%-80% SOC)	-
Charging time at ambient temperature	5 minutes(520km range)	8.5 minutes (10%-80% SOC)
Cycle life	-	15 years/600,000 kilometers

4.2 Advances in overseas power battery fast charging technology

StoreDot made substantial progress in power battery fast-charging technology in 2024. Collaborative real-vehicle tests with Polestar confirmed that its XFC-based 100in5 battery system can provide 100 miles of range after a 5-minute charge. The system achieves 70% state of charge within 10 minutes. This advancement offers a technical solution to alleviate range anxiety among electric vehicle users ^[11]. Performance testing indicates the battery system maintains stable capacity output after 2,000 rapid charge-discharge cycles. Its energy density reaches 325Wh/kg and 835Wh/L. The silicon-based 4695 cylindrical battery launched in early 2025 further enhances fast-charging capabilities ^[12].

Following its technological development roadmap, StoreDot has established phased targets for its "100inX" product series ^[13]: achieving 100 miles of range from a 4-minute charge by 2026, reducing this to 3 minutes by 2028, and reaching 2 minutes by 2032. StoreDot's batteries integrate organic-inorganic composite materials with intelligent optimisation algorithms. These technical features are supported by an advanced thermal management system.

StoreDot's technical solution has received recognition from several prominent automotive manufacturers, with six producers currently engaged in B-sample testing. Chart 3 illustrates the key performance metrics of this prototype ^[14]. According to the development roadmap, this technology is expected to achieve large-scale commercial application around 2027.

Table 2 100in5 battery: technical overview

100in5 B-Sample - 2024	
Anode material	Si
Specific energy (Wh/Kg)	300-340 *
Energy density (Wh/L)	860-920 *
Charge time 10-80% (mins.)	10
Cycle life consecutive fast charge 10-80%	>1000
Form factor	Pouch and prismatic
Expected capacity (Ah)	~150

*Net stack - electrodes, electrolyte and separator only; form-factor agnostic comparison

5 Analysis and discussion of key issues

5.1 Establishing a comprehensive evaluation system for charging equipment

Current electric vehicle charging equipment faces challenges due to inconsistent technical standards. This makes it difficult to achieve interoperability among charging facilities. To address this, a comprehensive evaluation framework for charging equipment must be established. This system should cover multiple dimensions, including charging efficiency, compatibility, service life and operating temperature range. It should also integrate convenient payment methods and intuitive user interfaces to enhance user experience. Establishing unified evaluation criteria will provide a scientific foundation basis for industry standardisation and user selection.

5.2 Optimisation of charging infrastructure coordinated with the power grid

The impact of high-power charging on grid stability, particularly during peak consumption periods, represents the second major challenge. Therefore, based on power system operational principles, proposing an optimized layout for charging infrastructure is essential. Specific measures include three key aspects: 1) Establishing intelligent dispatch systems that adjust charging strategies according to grid conditions to reduce load. 2) Promoting integrated photovoltaic-storage-charging infrastructure to utilizes renewable energy and energy storage systems to alleviate grid pressure. 3) Rationally planning charging facility layouts to prevent localised grid overloads. These measures enable the coordinated development of charging infrastructure and the power grid while ensuring stable grid operation.

6 Conclusions and outlook

This study systematically reviews recent advancements in electric vehicle charging systems and key technologies. The analysis focuses on technical characteristics and development trends within two core areas: super-fast charging equipment and power batteries. Research indicates that both domestic and international enterprises have achieved significant breakthroughs in super-fast charging technology and rapid charging performance for power batteries. Notable innovations such as Huawei's fully liquid-cooled megawatt-level ultra-fast charging solution, CATL's second-generation Shenxing super-fast charging battery and StoreDot's XFC-based 100in5 battery. These developments provide critical technical support for the widespread adoption of electric vehicles.

Nevertheless, charging systems confront two major challenges: the conflict between consumer demand for faster charging speeds the impact of high-power charging on grid stability, along with interoperability issues caused by inconsistent technical standards. To address these challenges, this paper proposes establishing a comprehensive evaluation system for charging equipment and optimising the coordinated operation between charging infrastructure and the power grid.

Future research should continue to focus on the synergistic development of super-fast charging technology and battery safety. Efforts must accelerate the standardisation of global charging protocols and deepen the integration of charging infrastructure with smart grids. Through continuous technological innovation and system optimisation, electric

vehicle charging systems will evolve towards greater efficiency, intelligence, and environmental sustainability. These advancements will contribute significantly to the achievement of global carbon reduction targets.

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