Proceedings of the 4th International Conference on Mathematical Physics and Computational Simulation
DOI: 10.54254/2753-8818/2026.33781

Analysis of the Current Status and Future Trends of Wireless Charging Technology for New Energy Vehicles

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Abstract. In the context of the promotion of the global "double carbon" goal and the rapid development of the new energy vehicle industry, wireless charging technology, as an important support to solve the pain points of traditional wired charging and promote industrial upgrading, has attracted widespread attention. Firstly, this paper systematically combs the basic principles, circuit structure and mainstream technology route of wireless charging technology for new energy vehicles. On this basis, the development level of technology at home and abroad is compared, the industrial application status of the technology is further analyzed, and the existing technology and industrial bottlenecks are deeply analyzed. Then, the future development trend of technology is clarified, and the multi-level optimization strategy is proposed. Finally, it summarizes the research conclusions, gives industry development suggestions, and points out the research deficiencies and future research directions, providing theoretical and practical reference for the research and development, promotion and high-quality development of new energy vehicle wireless charging technology.

Keywords: New energy vehicles, Wireless charging, Technical route, Development status, Future trends

1. Introduction

With the promotion of the global "double carbon" goal, new energy vehicles have become the core carrier of energy conservation and emission reduction in the field of transportation. The market scale continues to expand, but the charging problem has always restricted its large-scale popularization. Traditional wired charging has some pain points, such as "one pile is hard to find", inconvenient plugging and plugging, and easy loss of the interface. With the convenience and safety of non-contact charging, wireless power transmission (WPT) technology has gradually become an important technical direction to solve the charging dilemma and promote the upgrading of the new energy vehicle industry.

Based on the development needs of the new energy vehicle industry [1], this study systematically analyzes the basic principles, development status and existing bottlenecks of wireless charging technology, identifies future development trends and proposes optimization strategies, which can not only enrich the theoretical research of wireless charging technology, but also provide practical reference for industrial technology research and development, industrial layout and policy

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DOI: 10.54254/2753-8818/2026.33781

formulation, help the large-scale application of wireless charging technology, and promote the high-quality development of the new energy vehicle industry, which has important theoretical significance and practical value.

This study focuses on the wireless charging technology for new energy vehicles. It systematically reviews the basic principles, circuit structures and mainstream technical routes of the technology, compares and analyzes the technological development levels, industrial application status and core bottlenecks at home and abroad, explores the future development trends, and proposes targeted optimization strategies. Finally, it draws research conclusions, puts forward industry development suggestions and prospects future research directions. This research clarifies the development context of wireless charging technology for new energy vehicles, solves key technical and industrial pain points, improves the supporting charging infrastructure for new energy vehicles, and promotes the transformation of charging methods toward convenience, intelligence and safety. It provides a reference for industrial technology R&D, industrial layout and policy formulation, and accelerates the high-quality development of the new energy vehicle industry and the construction of a green travel system.

2. Basic principle and development status of wireless charging for new energy vehicles

2.1. Theoretical basis

The core of wireless charging of new energy vehicles is to realize the non-contact transmission of electric energy from charging facilities to vehicle batteries with the help of energy conversion and transmission of electromagnetic fields. The essence is to convert the power grid energy into a wireless transmission energy form, which is stored in the battery after being converted at the vehicle receiving end. The whole process follows three core physical principles of electromagnetic induction, magnetic coupling resonance and microwave transmission, providing theoretical support for technology implementation. Wireless charging of new energy vehicles has higher technical requirements for system performance, which mainly includes four aspects: first, the power level. Due to the need to shorten the charging time to improve the user experience, the charging system needs to have a large power output, usually ranging from several kilowatts to several tens of kilowatts; The second is the charging distance. The vertical charging distance should reach 15~45 cm, and the horizontal offset should be greater than 15 cm, so as to reduce the difficulty of vehicle parking alignment; The third is the charging efficiency.

The overall charging efficiency from the power grid to the vehicle battery needs to be greater than 85% in order to meet the actual application needs and have the promotion value; Fourth, insulation performance. High power output will be accompanied by high voltage. Good insulation performance is the key to ensure the stable and safe operation of the charging system under extreme weather conditions.

2.2. Circuit structure

The wireless charging system mainly consists of a transmitting end and a receiving end, which work together to complete energy transmission and conversion. The transmitting end is installed on a fixed charging facility, and the core components include a power converter, a transmitting coil, a control module, and a driving circuit. It is responsible for converting AC power into alternating current suitable for wireless transmission and generating an alternating magnetic field; The receiving end is installed on the car chassis and consists of a receiving coil, rectification and filtering circuit,

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and energy management module. It is responsible for receiving magnetic field energy and converting it into stable DC power to charge the battery. In addition, the system is equipped with high-sensitivity sensors and intelligent control algorithms for real-time monitoring of charging status, adjusting power output, and ensuring the efficiency and safety of the charging process.

2.3. Application of mainstream technology routes

2.3.1. Electromagnetic induction technology

Electromagnetic induction charging is a wireless charging technology that utilizes the interaction of electromagnetic fields for energy transmission. Typically, the transmitting end is installed on the ground and the receiving end is fixed to the car chassis. The transmitting part mainly consists of rectification and filtering circuit, high-frequency inverter circuit, signal control circuit, primary side compensation circuit, and transmitting coil [2]; The receiving part consists of a receiving coil, rectification circuit, power regulation circuit, signal control circuit, and car battery. The workflow is as follows: the transmitting end obtains electrical energy from the power grid, rectifies and inverts it to obtain high-frequency alternating current, and under the regulation of the signal control circuit, this current is injected into the primary side transmitting coil through a compensation circuit, thereby generating high-frequency alternating magnetic flux in the adjacent space; When the receiving coil is close to the transmitting coil, the induced electromotive force is obtained by inductive coupling of high-frequency alternating magnetic flux. Under the action of the control circuit, it is rectified, filtered, and power adjusted before finally charging the car battery. This technology also has the characteristics of wireless transmission and easy hardware standardization. Its core advantages lie in its mature development and low hardware cost. Currently, it is mainly used in static wireless charging scenarios, such as parking lots and fixed parking spaces in residential areas. It is the most widely commercialized wireless charging technology, and some new household energy vehicles have already been equipped with this type of wireless charging function. However, this technology has obvious limitations. Due to the inverse relationship between transmission efficiency and transmission distance, transmission efficiency decreases with increasing transmission distance, and the transmission distance itself is relatively short (usually in centimeters); At the same time, in this charging mode, the transmitting and receiving coils must be accurately positioned, and an error of more than a few centimeters will affect the induction effect, thereby affecting the charging efficiency and stability.

2.3.2. Magnetic coupled resonance technology

Resonant coupling charging is a wireless charging technology that utilizes magnetic field interactions for energy transfer. The transmission part of this technology mainly consists of an oscillator, power amplification circuit, impedance matching circuit, signal control circuit, and transmission coil; The receiving part mainly consists of a receiving coil, a rectifier circuit, a regulating circuit, a signal control circuit, and a car battery. Its working principle is: after the transmitting end obtains electrical energy from the grid, it generates high-frequency oscillating current through an oscillator, which is amplified by a power amplification circuit and debugged by an impedance matching circuit to form a non radiative magnetic field around the transmitting coil, realizing the conversion of electrical energy to magnetic field; When the natural frequency of the receiving coil on the electric vehicle side is consistent with the frequency of the received electromagnetic wave, the strongest oscillating current will be generated in the receiving circuit,

DOI: 10.54254/2753-8818/2026.33781

completing the conversion of the magnetic field to electrical energy [3]. Then, the current is rectified, filtered, and regulated by the circuit to charge the onboard battery. Compared with electromagnetic induction charging technology, resonant coupling charging technology has the advantages of longer transmission distance and higher power [4]. However, due to the need to maintain a specific distance between devices and the time-consuming debugging process, it is more difficult to implement and the system cost is relatively higher [5]. This technology is mainly applied in scenarios that require certain charging distance and flexibility, such as large parking lots, commercial parks, etc. Currently, the commercial application scale is smaller than electromagnetic induction technology and is mainly in the pilot promotion stage.

2.3.3. Microwave transmission technology

The microwave transmission technology's core is to use a microwave generator to generate microwave energy, and then transmit the microwave through a transmitting antenna; The receiving antenna on the vehicle receives microwaves and converts them into electrical energy for use by the vehicle. The biggest advantage of this technology is its long transmission distance, which enables long-distance wireless charging [6]. Theoretically, it can be applied to dynamic wireless charging scenarios to solve the charging needs during vehicle operation. However, at present, this technology has problems such as low energy conversion efficiency and the possibility of electromagnetic radiation affecting the human body and surrounding environment. The technology is not yet mature and is still in the laboratory research and small-scale testing stage, and has not been commercially applied.

2.4. Comparison of domestic and international technological development levels

Foreign research started early and accumulated deep technical knowledge, and overall it is in a leading position. Enterprises and research institutions in countries such as Sweden, the United States, Japan, and Germany have made breakthroughs in high-power and high-efficiency wireless charging technology. In 2016, Tokyo Electric Power Company (TEPCO) collaborated with Mitsubishi Electric to develop a wireless charging system with a charging power of up to 20kW, which can shorten the charging time to about 15 minutes; Oak Ridge National Laboratory in the United States has achieved 100kW wireless charging with an efficiency of 96%; BMW, Volvo and other car companies have achieved mass production and application of wireless charging technology, with continuous improvement in compatibility and efficiency.

In recent years, technology has continued to iterate, achieving dual breakthroughs in high power and dynamism in the past five years. In 2024, Oak Ridge National Laboratory in the United States, in collaboration with Porsche, successfully demonstrated the world's first 270kW wireless charging system. It uses multi-phase electromagnetic coupling coils and rotating magnetic field technology, which can charge 50% of the vehicle in 10 minutes. The system efficiency exceeds 95%, and the power density and safety are significantly improved. In 2025, the world's first commercial dynamic wireless charging section will be built on the A10 highway in France, led by Electreon and VINCI Group. The buried induction coil on the road surface can stably output 200-300kW of power during vehicle operation, supporting energy replenishment for trucks, buses, and other vehicles while driving. The measured efficiency and reliability meet commercial standards. Germany and South Korea are simultaneously promoting a 200kW level wireless charging network for public transportation, and dynamic charging technology is gradually moving from laboratories to large-scale applications [7].

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Domestic research started relatively late but has developed rapidly, with universities and enterprises working together to gradually narrow the gap with foreign countries [8]. In 2019, the Vehicle and Power Engineering Research Institute of Tongji University proposed dual-mode conversion technology, which effectively improved the efficiency of magnetic resonance wireless charging; In 2021, Zhuhai Gree Electric Co., Ltd. developed a technology solution based on magnetic resonance wireless charging, with a charging efficiency of over 90% and a charging distance of up to 40cm. Universities such as Beijing Jiaotong University and Tongji University have obtained multiple patents in the core technology field, and some cities have launched pilot projects for wireless charging bus routes. However, there are still shortcomings in high-power, dynamic wireless charging, and localization of core components.

2.5. Current status of industrial applications

The current wireless charging industry presents a pattern of "static charging first, dynamic charging pilot" [9]. In the field of static charging, commercial applications are gradually becoming popular, and equipment has been installed in batches in public parking lots, residential parking spaces, and other scenarios. Some household new energy vehicles have wireless charging as standard; In the field of dynamic charging, pilot projects have been carried out both domestically and internationally on bus routes and closed test roads to verify the feasibility of the technology [10]. For example, in October 2018, the "three in one" electronic highway integrating photovoltaic highway, wireless charging, and autonomous driving technology was officially unveiled in Suzhou, providing important practical references for the large-scale application of wireless charging technology in the transportation field. However, due to the impact of cost and technological maturity, wireless charging technology has not yet achieved large-scale popularization, and the industry is in a transitional stage from the cultivation period to the growth period.

2.6. Current technological and industrial bottlenecks

At the technical level, there are still many bottlenecks in wireless charging for new energy vehicles. The overall charging efficiency is low [11], and various energy losses such as coupling loss, air dielectric loss, and electromagnetic radiation loss occur during energy transmission. Among them, the efficiency of inductive wireless charging decreases significantly with increasing transmission distance, and improving efficiency in dynamic charging scenarios is particularly difficult. At the same time, the industry has not yet formed a unified standard, and there is insufficient technical compatibility. Multiple standards such as Qi, Air Fuel, PMA, etc. are parallel, which makes it difficult for different brands of devices to be compatible. There are also problems such as power and interface mismatch. The technology related to dynamic charging is still immature, and key issues such as precise positioning, bidirectional communication, and energy transmission stability between vehicles and charging facilities have not been effectively resolved. The control of electromagnetic radiation and electromagnetic compatibility is difficult and poses certain safety hazards. Although enclosed intelligent parking lots can improve electromagnetic compatibility issues, their high cost limits their large-scale application. In addition, the limited transmission distance of electric energy further restricts the expansion of wireless charging application scenarios.

At the industrial level, the development of wireless charging is also constrained by multiple factors. Wireless charging systems require high-precision equipment such as transmitting coils, receiving coils, power amplifiers, and control devices. The hardware and construction costs are high, and the technical threshold is high, making it difficult to achieve large-scale promotion and

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application. The current layout of wireless charging infrastructure is not perfect, with only a few cities and key areas undergoing installation pilot projects, resulting in limited overall coverage. The degree of synergy in the industrial chain is not high, and the localization level of core components such as high-performance coils and power converters is relatively low. Some key technologies and core components still rely on imports [12]. At the market level, there is insufficient user awareness and acceptance, and consumers have concerns about the safety and actual charging efficiency of wireless charging, which to some extent affects the popularization and promotion of technology.

3. Trends and optimization of wireless charging technology for new energy vehicles

3.1. Future development trends

Based on the current technological situation and industry demand, wireless charging technology will develop in five directions in the future: first, high efficiency, striving to achieve or even surpass wired charging efficiency through technological optimization and the application of new materials; The second is low cost, which reduces hardware and operating costs through large-scale production and localization of core components [13]. The third is high compatibility, promoting standardization construction, and achieving compatibility with different brands, vehicle models, and with the power grid and intelligent transportation systems [14]. The fourth is dynamism, conquering core technologies, achieving automatic charging during driving, and solving range anxiety; The fifth is intelligence, which integrates with intelligent control technology to achieve automation and intelligent management of the entire charging process.

3.2. Technical optimization strategy

At the technical level, it is essential to optimize the coil structure and coupling design, and adopt high-efficiency new materials such as nanocrystals to reduce energy loss. Core technologies including precise positioning and transmission stability in dynamic charging should be developed to accelerate the commercial application of technical pilot programs. Meanwhile, the control of electromagnetic radiation needs to be strengthened, and the shielding design and monitoring technology should be optimized to ensure operational safety.

At the industrial level, investment in the research and development of core components should be increased to raise the localization rate and foster high-quality component manufacturers. The layout of charging infrastructure should be planned rationally to expand coverage, and its coordinated construction with power grids and intelligent transportation systems should be promoted. In addition, the operation mode should be optimized to cut down operation and maintenance costs and improve the economic efficiency of services.

At the standard level, joint efforts should be made with industrial stakeholders to formulate unified technical standards and specify relevant parameters and specifications. The testing and certification system should be improved to strictly control the quality of charging equipment. Furthermore, international cooperation needs to be enhanced to promote the alignment of domestic standards with international ones and strengthen international competitiveness.

4. Conclusion

This study systematically reviewed the basic principles and circuit structures of wireless charging technology for new energy vehicles, clarified the advantages and disadvantages of the three mainstream technology routes of electromagnetic induction, magnetic coupling resonance, and

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microwave transmission, and compared and analyzed the level of technological development, industrial application status, and existing bottlenecks at home and abroad. It was concluded that wireless charging technology is an important direction to solve the charging dilemma of new energy vehicles and promote industrial upgrading. Foreign technology accumulation is deep and leading, while domestic development is rapid but there are shortcomings in high-end technology research and development and core component localization. The coordinated optimization of technology, industry, and standards is the key to breaking through development bottlenecks. The development of this study enriches the theoretical system of wireless charging for new energy vehicles, providing scientific and practical reference for industry technology research and development, industrial layout, and policy formulation. It helps to promote the large-scale application of wireless charging technology, promote the high-quality development of the new energy vehicle industry, and support the implementation of the "dual carbon" goal. In the future, with the continuous breakthroughs in core technologies and the deepening of industry collaboration, wireless charging technology will gradually achieve large-scale popularization, injecting new vitality into the development of the new energy vehicle industry.

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