Wireless Charging Technology for Electric Vehicles

Yitian Jin
School of Physics and Electronic Engineering, Shanxi University, Taiyuan, China
202201103121@email.sxu.edu.cn

Abstract. Currently, global energy structure transformation and environmental protection concerns have drawn the attention of all sectors of society to electric vehicles. However, issues such as inadequate charging facilities, long charging times, and charging safety impede the popularization and promotion of electric cars. Against this backdrop, wireless charging technology, as an innovative charging method, is increasingly gaining public attention and showing enormous potential for development. Wireless charging technology employs the principles of electromagnetic induction and magnetic resonance to transmit electrical energy through the air, allowing electric vehicles to be charged without needing a physical connection, thereby increasing the convenience and safety of the charging process. After reading a lot of research, the author summarizes three common wireless charging methods, shows how this technology can be used in electric vehicle scenarios, and suggests ways to improve things based on current issues. The goal is to give the electric vehicle industry new ideas and solutions for its long-term growth.

Keywords: Wireless charging technology, Electric vehicle, Application scenario, Optimization suggestion.

1. Introduction

Governments are currently emphasizing the transformation of the global energy structure and environmental protection. As a new type of green transportation, electric vehicles are considered an essential alternative to traditional fuel vehicles due to their zero emissions, low noise, and excellent efficiency. However, the standard cable charging method for charging piles necessitates the connection of wire interfaces, which raises the potential safety dangers of leakage and short-circuiting between interfaces while also making the charging process more laborious [1]. Fortunately, wireless charging technology provides an opportunity to address the issue of wired charging for electric vehicles. In addition to that, the further merits of wireless charging technology are fully automatic, smart charging, time consumption, reliability, safety, user-friendliness, no human intervention, bidirectional power flow capability, and easy integration of Renewable Energy Sources [2].

This paper first summarizes the working principle of wireless charging technology, including magnetic coupling resonance mode, electromagnetic induction mode, and microwave radiation mode charging technology. It then comparatively analyses the advantages and drawbacks of these three charging modes, providing a reference for the selection and application of wireless charging. After that, the author discusses wireless charging technology application scenarios in the field of electric vehicles, such as parking wireless charging, station wireless charging, and dynamic wireless charging, demonstrating the great potential of wireless charging technology in improving the convenience of electric vehicle charging while lowering the cost of charging facility construction. However, wireless charging technology for electric vehicles continues to confront numerous hurdles in the application process. The author examines the problem regarding transmission efficiency, distance limitation, and compatibility, then describes appropriate solutions from the relevant literature. Finally, this study provides a summary and outlook on the development of wireless charging technology for electric vehicles, hoping to provide valuable references and insights to academics and practitioners in relevant domains.

2. Wireless Charging Technology Overview

2.1. Magnetic Coupling Resonant Wireless Charging Technology

Fig 1 shows the principal block diagram of the magnetic coupling resonant wireless charging system for electric vehicles, which comprises primarily two pieces: the transmitter and the receiver. The system receives industrial-frequency alternating current and converts it to stable direct current via a rectifier circuit. It then uses an inverter circuit to convert the direct current into high-frequency alternating current. At this point, the compensation topology on the transmitter side adjusts the transmitter coil's resonant frequency to match the inverter circuit's output frequency and achieves the resonant state. The high-frequency current in the transmitting coil creates a high-frequency-induced magnetic field, which converts electrical energy into magnetic energy. Faraday's law of electromagnetic induction produces an induced voltage when this magnetic field travels through the receiving coil, resulting in a high-frequency alternating induced current. The receiver-side compensation architecture matches the receiver coil's resonance frequency to the transmitter side's frequency to efficiently receive the electrical energy converted back from magnetic energy. Finally, the high-frequency alternating current at the receiving end is transformed into direct current through a rectifier circuit to charge the electric car battery [3].

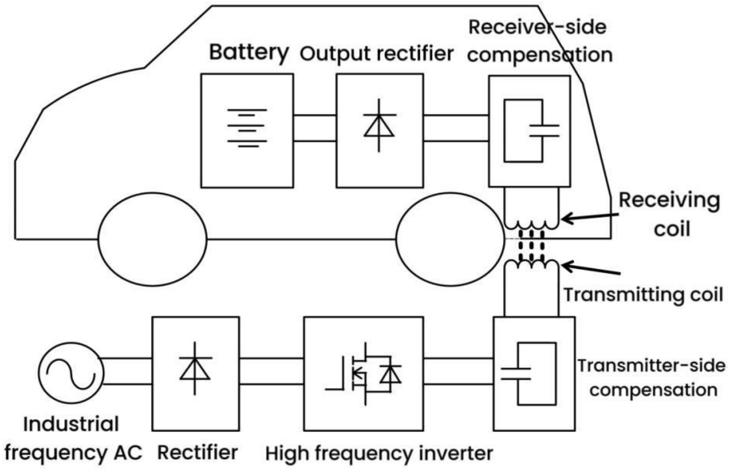

Figure 1. Magnetic coupling resonant wireless charging system for electric vehicles

2.2. Electromagnetic Induction Wireless Charging Technology

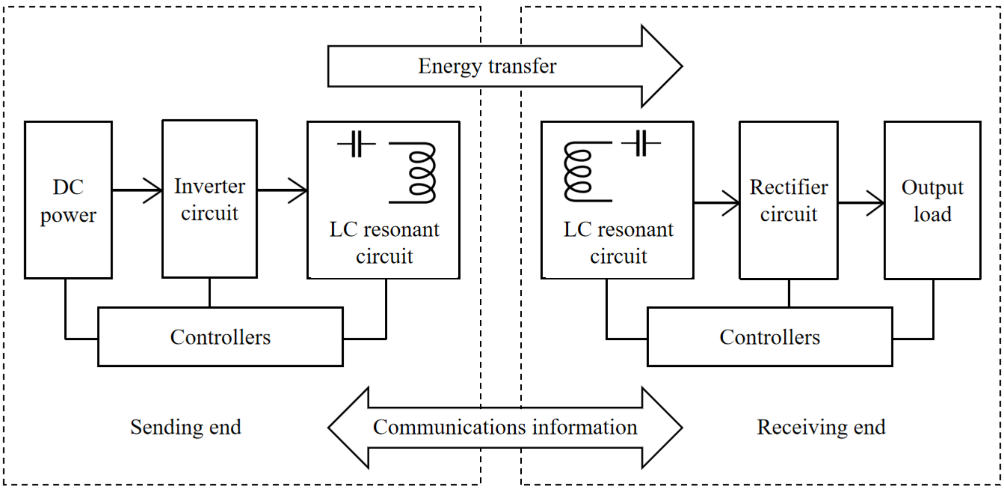

Figure 2. Electromagnetic induction wireless charging system

Fig 2 illustrates the primary circuit structure of the electromagnetic induction wireless charging system. After the DC power signal is input to the system at the sending end, it is converted into an AC signal by an inverter circuit, which is then converted into sinusoidal AC power by an LC resonant circuit consisting of a capacitor and a primary coil, resulting in an alternating magnetic field on the primary coil. The secondary coil at the receiving end generates electromotive force and current by electromagnetic induction, which is then converted by the LC resonant and rectifier circuits to deliver DC power to the output load [4]. The system achieves efficient wireless transfer of electrical energy by using independent hardware and software, as well as communication control for the two subsystems at the transmitter and receiving ends.

2.3. Microwave Radiation Wireless Charging Technology

Fig 3 depicts the architecture of the microwave radiation wireless charging system. When DC energy is applied, the microwave signal source at the transmitting end generates a milliwatt microwave signal, the power amplifier amplifies the small signal, and finally outputs a watt microwave signal, which is radiated into free space via the transmitting antenna by converting the fed high-power microwave signal into electromagnetic waves. At the receiving end, the receiving antenna captures the corresponding frequency band electromagnetic wave in the region and converts it back to the microwave signal in the circuit to be sent to the rectifier circuit, using the non-linear effect of the rectifier diode to efficiently convert the microwave energy into DC energy to provide a stable power supply for the loads [5].

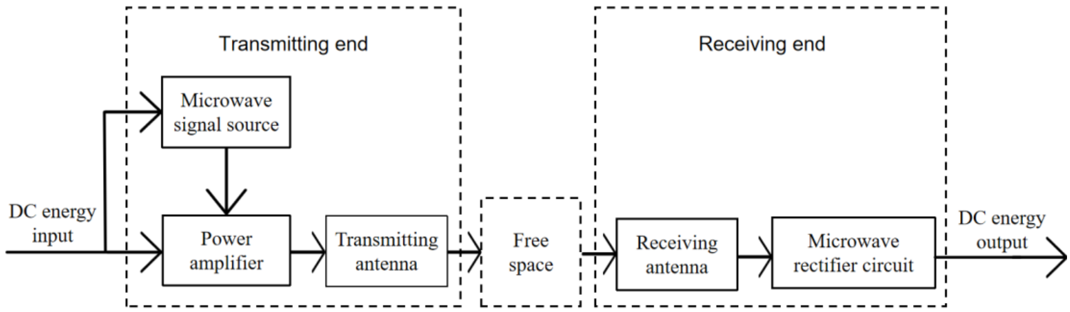

Figure 3. Microwave radiation wireless charging system

2.4. Pros and Cons of Three Wireless Charging Options

Magnetic coupling Resonant wireless charging technique offers a longer transmission distance, emits less electromagnetic radiation, and can be used for one-to-many transmission while maintaining high transmission efficiency over longer distances. This method has a high tolerance for relative position and angle changes between the coupling mechanisms. Still, the coupling mechanism quality factor and resonance frequency matching requirements are high, precise tuning is required, and the transmission efficiency may be affected when metal objects are in the transmission path [6].

The electromagnetic induction wireless charging technology is simple in design, inexpensive, and has exceptionally high transmission efficiency over short distances. However, because this technique employs separate loose-coupled transformers, magnetic leakage is more severe, resulting in an exponential decline in transmission power and efficiency as transmission distance increases, making it only suitable for short-distance power transmission [7]. Furthermore, the two coils on the transmitter and receiver sides must be precisely aligned while charging, which limits their flexibility.

Microwave radiation wireless charging technique not only controls the direction of transmission without the requirement for precise alignment, but it also has a long transmission distance of tens of meters or more due to the intense microwave penetration. However, due to the slower speed of microwave energy transmission and the narrower wave range, the output power is lower, and the transmission efficiency is less than 40% [6]. At the same time, microwave radiative power transmission produces significant electromagnetic pollution, which may hurt human health.

The three wireless charging technologies described in the preceding section can achieve the traditional sense of wireless energy transmission. Still, a comparison reveals that each has benefits and drawbacks regarding transmission efficiency, distance, safety. In practical implementation, practitioners should thoroughly understand its technical characteristics and select the proper wireless charging technique in different places to get the best power transmission effect. Table 1 presents a comprehensive comparison of the three wireless charging techniques discussed above.

Table 1. Comparison of Three Wireless Charging Methods

Wireless Charging Method	Transmission Distance	Advantages	Drawbacks	Applications
Magnetic coupling resonance mode	Medium distance: Several centimeters to several meters	Highly effective transfer of hundreds of watts of power within a few meters; great penetration capabilities, and low electromagnetic interference	Greater requirements for matching the quality factor and resonant frequency of the coupling mechanism	Charging electric vehicles and household appliances; in vitro power supply for medical products
Electromagnetic induction mode	Short distances: Several millimeters to several centimeters	Simple structure, low cost; extremely high transmission efficiency over short distances; mature technical study	Short transmission range, usually at the centimetre level; less flexible	Charging of small electrical devices such as smartphones, computers, and electric toothbrushes
Microwave radiation mode	Long distance: Tens of meters and more	Large transmission lengths and spatial freedom	Requires higher power transmitting and receiving equipment; low transmission efficiency, high energy loss; significant electromagnetic contamination, low biosecurity	Energy transfer between space satellites; smart home sector

As shown in Table 1, the magnetic coupling resonant wireless charging method has the following advantages: moderate transmission distance, good anti-interference ability, high transmission power, etc. It can carry hundreds of watts of power over short distances with excellent efficiency, making it ideal for use in electric vehicle wireless charging systems.

3. Application Scenarios

When investigating the use of wireless charging technology for introducing electric vehicles, it is critical to consider various factors such as charging method, economic investment, safety, and security, particularly in deploying charging facilities. In light of this, this chapter will concentrate on the specific application scenarios and operating aspects of wireless charging technology for electric vehicles.

3.1. Parking Wireless Charging

Compared to traditional wired charging, parking wireless charging technology eliminates the need to remove the plug from the charging post and insert it into the car's charging port, and the charging process can begin automatically when the car owner parks the vehicle in a parking space with a wireless charging device. Furthermore, wireless charging has no exposed ports, so there is no risk of electric shock or short circuits, and it is not hindered by rain, snow, or other adverse weather. Because a series of transmitter-converter circuits, including the transmitter coil, may be built underground, there is no need to install extra charging stations on the ground, which enhances land use and neighborhood aesthetics [8]. At the same time, parking wireless charging technology has outstanding compatibility and flexibility, allowing it to adjust to many surroundings in vehicle charging needs, such as house garages, public car parks, business districts, considerably expanding the usage of electric vehicles [9].

3.2. Station Wireless Charging

As new energy vehicles gain popularity, buses and taxis are increasingly transitioning from petrol or diesel to electric power, and the deployment of wireless charging stations is appropriate for these commercial vehicles that require frequent charging and quick shift changes [10]. Station wireless charging technology uses electromagnetic fields to wirelessly charge electric vehicles at bus stops, taxi waiting areas, and other fixed sites, allowing them to recharge during short layovers while continuing to operate. Station wireless charging technology improves the operational operations of electric vehicles, lowering urban carbon emissions and increasing air quality. Furthermore, deploying this technology encourages the intelligent upgrading of the city's charging infrastructure, consistent with innovative city development [9]. Wireless charging at stations will be promoted as technology advances and costs fall.

3.3. Dynamic Wireless Charging

Dynamic wireless charging technology effectively combines wireless communication, real-time control, and positioning sensing technology, using charging tracks or coils buried beneath the road surface and coils installed beneath the vehicle chassis for magnetic coupling to charge electric vehicles while driving, which can fundamentally solve the problem of insufficient battery energy storage and affect the vehicle's range [11]. Furthermore, wireless replenishment of electric energy during driving can reduce the power battery capacity allocation of electric vehicles by up to 20% and the battery size by two-thirds, lowering the cost of onboard batteries and significantly reducing the overall weight of the car [12]. Implementing dynamic wireless charging technology will reduce the need for charging base stations in cities and be appropriate for highways and urban public transportation networks.

4. Technology Optimization

Wireless charging technology in the electric vehicle sector has become an essential trend, and its broad development prospects have sparked significant interest. Although important academic and practical achievements have been accomplished at home and abroad to promote this technology, its overall performance is still potential for improvement. In-depth research and continual advancement of wireless charging technology for electric vehicles will be the primary driving force that propels the industry forward.

4.1. Transmission Efficiency

Compared to wired charging technology, wireless charging technology relies on electromagnetic fields or electromagnetic waves to achieve energy transmission, and this process is unavoidably accompanied by energy loss, which reduces total charging efficiency. Wireless charging technology's energy transmission loss is primarily caused by coupling loss between the transmitter and receiver, energy transmission loss of the air medium, and radiation loss of electromagnetic waves [1]. To improve the energy transfer efficiency of wireless charging technology, Adeel Zaheer's team at the University of Auckland designed a bipolar coupling structure that effectively reduces interference between neighboring coils by adjusting the overlap area between the coils so that the mutual inductance value is roughly equal to zero [13]. Showa Corporation of Japan developed a magnetic coupling mechanism with a twin H-type core and tested it at Nara City and Haneda Airport. During the tests, the system produced up to 30kW of power at a frequency of 22kHz and a longitudinal spacing of 14cm while maintaining an operating efficiency of 92% [14].

4.2. Distance Limitation

Wireless charging technology for electric vehicles is limited in practical implementation due to the distance between the transmitter and receiver, which affects the charging range. As the charging distance increases, the energy of the electromagnetic wave rapidly weakens, resulting in a considerable loss in charging efficiency at long distances, and even charging cannot be completed. Furthermore, longer charging distances increase the system's safety risks, such as the potential negative impact of electromagnetic waves on the surrounding environment and human health during propagation, so safety concerns must be prioritized in designing and implementing wireless charging systems. Yanjie Li's team at Beijing University of Aeronautics and Astronautics (BUAA) proposed a parameter optimization process based on a square coil structure, intending to minimize the outer diameter and realize the coupling coefficient not less than 0.10, eventually successfully designed a wireless charging system coupling structure with a transmission distance of up to 300mm [15].

4.3. Compatibility

The compatibility difficulty is especially evident when implementing wireless charging technologies for electric vehicles. The distinct production techniques used by different manufacturers, together with the co-existence of Qi, AirFuel, PMA, and other wireless charging standards on the market, make it easier for different wireless charging systems to interoperate, causing customer problems [1]. Furthermore, because different electric vehicles demand varied charging power requirements, the restricted power output of wireless charging devices may cause problems such as the inability to meet the charging requirements of specific vehicles or overheating during the charging process. To that aim, industry stakeholders should be encouraged to collaborate on developing a common wireless charging standard and improving the testing and certification process for wireless charging devices. Ensure that compatibility difficulties may be rectified while adhering to high safety standards, resulting in a more convenient and safe charging experience.

5. Conclusion

This study methodically discusses the working principles of three major wireless charging technologies: magnetic coupling resonant, electromagnetic induction, and microwave radiation. Then, after comparing and analyzing their advantages and limits, it is found that magnetic coupling resonance power transmission technology is most suited for use in the wireless charging field of electric vehicles. On this premise, the author proposes three applications of wireless charging technology for electric vehicles, demonstrating that the technology could provide users with a convenient and efficient charging experience. Finally, this study identifies three critical problems wireless charging technology encounters in practical applications. It proposes targeted optimization suggestions in conjunction with existing research results, providing a theoretical foundation and practical guidance for wireless charging technology's continued promotion and application in electric vehicles.

Advanced wireless charging technology for electric vehicles will significantly contribute to the EV industry's innovation and provide solid technical support for constructing a greener, more efficient, brighter mobility future. In the future, researchers must focus more on critical areas such as technology standardization, system compatibility, cost-benefit analysis, and safety laws to help boost the popularity and long-term development of electric vehicles. With technological advancements and rising market demand, wireless charging technology will likely become the preferred way of charging electric cars shortly, ushering in a new era in electric vehicle charging.

References

[1] Zheng Zhi Cong. Research on wireless charging technology for electric vehicles. Automotive Test Report, 2023, (14): 148-151.

[2] Manivannan B, Kathirvelu P, Balasubramanian R. A review on wireless charging methods–The prospects for future charging of EV. Renewable Energy Focus, 2023, 46: 68-87.

[3] Dong Yang. Steady-state output design and optimisation of magnetically coupled wireless charging system for electric vehicles. Chang'an University, 2023.

[4] Yang ZY. Design and implementation of electromagnetic induction wireless charging receiving end system. Southeast University, 2022.

[5] Xu Boqiang. Research on microwave wireless charging circuit technology. University of Electronic Science and Technology, 2019.

[6] YU Jinyong, DUAN Jiagang. Research and application of wireless charging technology for electric vehicles. Times Automobile, 2022, (01): 125-126.

[7] Wang, Chuan-Shen. Design and implementation of magnetic coupled wireless energy transmission system based on class E amplifier. Hangzhou University of Electronic Science and Technology, 2016.

[8] Liu Tao. Circuit study of magnetic coupling resonant wireless charging system for electric vehicles. Southwest University of Science and Technology, 2021.

[9] LI Jianfeng, CHEN Liangming. Research on wireless charging technology for electric vehicles. Automotive Test Report, 2024, (06): 143-145.

[10] LI Hongmei, ZHAO Luming, HU Yixian, et al. Research and application analysis of wireless charging technology for electric vehicles. Automotive Practical Technology, 2020, (10): 34-36+73.

[11] YAN Jichao, MO Bin, HUANG Peixin, et al. A review of key technology research on magnetic resonant wireless charging system for electric vehicles. Electromechanical Engineering Technology, 2024, 53 (03): 7-12.

[12] Li Ruixuan. Research on dynamic wireless charging system for electric vehicles based on anti-offset characteristics. Chang'an University, 2023.

[13] Zaheer A, Covic G A, Kacprzak D. A bipolar pad in a 10-kHz 300-W distributed IPT system for AGV applications. IEEE Transactions on Industrial Electronics, 2013, 61 (7): 3288-3301.

[14] Zaheer A, Covic G A, Kacprzak D. A bipolar pad in a 10-kHz 300-W distributed IPT system for AGV applications. IEEE Transactions on Industrial Electronics, 2013, 61 (7): 3288-3301.

[15] LI Yanjie, LI Feng, ZHOU Siqi, et al. Optimisation of wireless charging system for electric vehicles with large transmission distance. Journal of Beijing Institute of Technology, 2024, 50 (04): 405-416.