A Comparative Study on Wireless Charging for Electric Vehicles: Temperature Influence and Optimization

Guanyu Jin

Vimy Ridge Academy, Edmonton, T6C 1N8, Canada

g.jin1@share.epsb.ca

Abstract. With the rapid development of the electric vehicle (EV) industry, traditional wired charging methods have gradually exposed problems such as insufficient convenience, interface wear, and safety hazards. In order to meet users' demand for convenient and efficient charging methods, wireless charging technology has gradually become a research hotspot. This technology is not only expected to improve user experience, but also to promote the integrated development of future autonomous driving and intelligent transportation infrastructure. Against this background, this paper introduces the two mainstream technologies of wireless charging for electric vehicles: electromagnetic induction and magnetic resonance, and analyzes their respective principles, advantages and disadvantages, and current application status. At the same time, it explores the role of resonant circuit optimization, temperature variation influence, and soft switching technology (ZVS/ZCS) in improving transmission efficiency and system stability. Although there are still challenges such as short transmission distance and high cost at present, future advances in materials, control, and structural design are expected to promote the efficient and intelligent development of wireless charging.

Keywords: Wireless Charging, Electric Vehicles, Temperature Influence

1 Introduction

With the rapid development of new energy vehicles, electric vehicles have gradually entered the daily lives of the public and become an important direction for future transportation. At the same time, the charging efficiency, safety, and convenience of electric vehicles have also become the focus of public attention. Currently, how to achieve a more efficient and more intelligent mode of energy transmission is becoming a key goal in the development of charging technologies. Against this backdrop, wireless charging technology for electric vehicles, as an emerging and promising technology, has attracted widespread attention from both academia and industry.

At present, electric vehicles mainly rely on two traditional charging methods: the first is plug-in alternating current (AC) charging, which is suitable for home environments. Its advantages include low cost and simple equipment, but the charging

A. J. Moshayedi (ed.), *Proceedings of the 2025 2nd International Conference on Electrical Engineering and Intelligent Control (EEIC 2025)*, Advances in Engineering Research 279,
https://doi.org/10.2991/978-94-6463-864-6_82

speed is relatively slow; the second is direct current (DC) fast charging, which has higher charging efficiency and is suitable for public charging stations. Enterprises such as Tesla have also introduced supercharging technology, further shortening charging time. However, these traditional charging methods still have certain limitations: for example, the charging process requires manual plugging and unplugging, cables are prone to wear and damage, concentrated power grid load leads to instability, and the user experience still needs improvement.

Against this background, this paper is based on a practical review of electric vehicle charging technologies and summarizes the current state of academic research on wireless charging technology. Wireless charging technology mainly includes three methods: electromagnetic induction charging, electromagnetic resonance (nuclear resonance) charging, and microwave wireless charging. At present, the most widely used method is electromagnetic induction. This paper will systematically summarize and compare these three wireless charging methods, analyze their respective advantages and disadvantages, power transmission efficiency, and energy loss conditions, and explore how to improve the stability and efficiency of wireless charging. At the same time, it introduces two methods that influence the efficiency of resonant circuits: temperature and soft-switching technology. Finally, this paper will provide an outlook on the future development trends of wireless charging technology for electric vehicles.

2 Overview of Wireless Charging Technology

Wireless charging technology is an emerging method of charging, which can likewise be applied to the wireless charging technology of electric vehicles.

Wireless charging is mainly divided into two types: inductive charging and magnetic resonance charging. It's convenient and safe to use, with no risk of sparks or electric shocks. Also, it doesn't have problems like dust build-up, contact loss, or mechanical wear, so there's basically no need for extra maintenance. Moreover, it can work well in all kinds of harsh environments and weather conditions [1–4].

2.1 Electromagnetic induction

Electromagnetic induction is one of the core principles of wireless charging. Its working mechanism is based on Faraday's Law of Electromagnetic Induction [5]. When current flows through the primary coil, it generates an alternating magnetic field around it; this alternating magnetic field then acts on the nearby secondary coil, inducing an electromotive force within it, thereby generating current. Afterward, this current is regulated through a rectifier circuit and power management module, ultimately supplying power to the receiving device, realizing wireless transmission of electric energy. This process requires no physical contact and can complete energy transfer within a certain range.

In terms of advantages, electromagnetic induction has a high degree of automation and adaptability, suitable for the development trend of modern smart devices. Since energy is transferred through direct magnetic coupling, the process does not require any intermediary medium or complex conversion mechanism, thus it has relatively high energy conversion efficiency, responds quickly, and provides stable transmission.

However, its disadvantages are also evident: First, this technology has a high requirement for precise alignment of the coils. Once the coils are misaligned or the distance deviates too much, the charging efficiency will drop significantly or even fail completely. Second, its effective charging distance is relatively short, usually limited to a few centimeters, which restricts its application in the field of long-distance wireless power transmission.

At present, electromagnetic induction is widely used in various wireless charging devices, such as smartphones, smartwatches, electric toothbrushes, and other small portable devices. In addition, with the development of technology, it is also gradually being applied to the wireless charging systems of electric vehicles, especially showing great potential in automatic charging devices for short-distance parking spaces. In the future, with further optimization of material technology and power management systems, electromagnetic induction is expected to play a greater role in industrial robots, medical implant devices, and public transportation charging systems. Figure 1 shows a simplified structural diagram of electromagnetic induction.

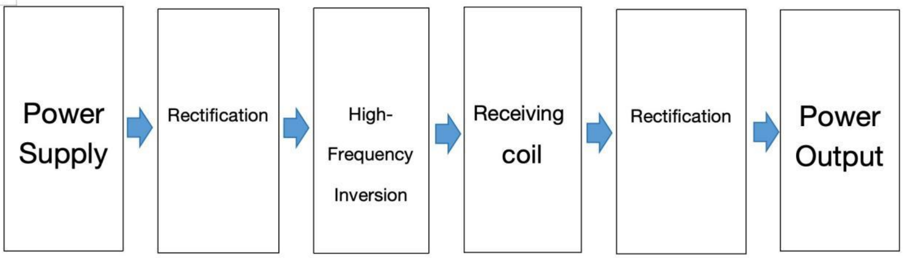

Fig. 1. A simplified structural diagram of electromagnetic induction.

3 Magnetic Resonance

3.1 Principle of magnetic resonance

Magnetic resonance wireless charging technology is a method of energy transmission based on the principle of electromagnetic resonance. This technology involves setting resonant coils at both the transmitting and receiving ends. When the resonance frequencies of these two coils are the same, strong resonant coupling occurs. This resonance enables energy to be efficiently transmitted between the two ends through a magnetic field, with long-distance transmission efficiency being significantly higher than that of traditional electromagnetic induction methods. Especially when there is a considerable distance between the two coils, the resonance effect can significantly enhance the coupling strength, allowing energy transfer to maintain high efficiency.

3.2 Advantages and disadvantages

This paper finds that compared to traditional electromagnetic induction methods, magnetic resonance technology has clear advantages in many ways. First, it can achieve a longer energy transmission distance. Even if there is some gap between the sending and receiving coils, it can still maintain relatively high energy efficiency. Second, the magnetic resonance system is more tolerant of coil misalignment, meaning it allows some positional deviation between the two coils without largely affecting the transmission efficiency. Because of this, the technology works better in dynamic or space-limited situations.

However, magnetic resonance technology still faces some challenges in real applications. Since the design of the resonant coils is quite complex, the production cost is higher, which is not conducive to large-scale use. Also, when working at high power, the system generates a lot of heat, so extra cooling devices are needed. This makes the whole system larger and the structure more complicated.

More importantly, this technology is still in the experimental research stage. Issues related to its reliability and safety still need further verification, and its long-term operational stability and potential impact on the human body require continuous monitoring and evaluation.

3.3 Application fields

Although magnetic resonance wireless charging technology is still in the experimental and optimization stage, it has broad potential application prospects. This paper finds through literature review that it is applied to the wireless charging of electric vehicles, where it is used in transmitting devices installed under parking spaces. It is also used in aerospace fields such as microwave-powered aircraft and satellite solar power stations, which are examples of long-distance power transmission applications. Among these, satellite solar power stations have become important aerospace projects actively developed by countries such as the United States and Japan, as they are considered effective strategies for addressing the human energy crisis [6–7]. Figure 2 shows the magnetic resonance circuit diagram.

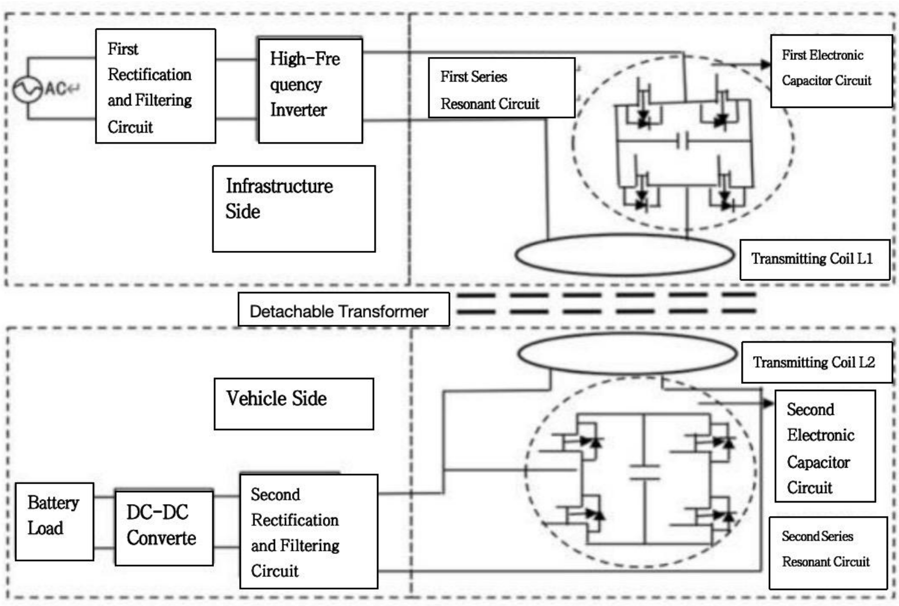

Fig. 2. The magnetic resonance circuit diagram.

4 Development and Design of Wireless Charging for Electric Vehicles

4.1 Circuit and electromagnetic optimization design

In electric vehicle wireless charging technology, the importance of system efficiency is beyond question. System efficiency can be increased, energy loss reduced, and stable output ensured through improvements in resonant circuit design. Wang Qiang studied the optimization of soft-switching technology and the addition of an inverter. He built a 3kW experimental prototype to demonstrate that installing soft-switching can improve system efficiency. In addition, a review finds that Wei Shuguang studied zero-voltage conversion. He designed a 28V/100A auxiliary circuit to improve circuit efficiency [8–9].

4.2 Study of temperature effects on resonant circuits

In many fields of electronics and communications, the performance of resonant circuits shows high sensitivity to temperature variations. Fluctuations in temperature cause changes in the parameters of key components in the circuit, thus affecting the stability of the resonant frequency. Wang Qiang studied how temperature changes in the range of 0K to 0.6K affect the resonant frequency [10]. He found that as the temperature goes up, the resonant frequency drifts and gets smaller. This happens because the temperature coefficients of the inductor and capacitor cause their values to change with temperature, which then affects the resonant frequency.

4.3 Study of soft-switching technology in resonant circuits

Soft-switching technology includes Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) [11]. Zhang Qinhua worked on reducing energy loss by making sure the voltage or current across the switching device goes down to zero before it starts conducting. To improve the efficiency further, this paper puts ZVS and ZCS together, using a composite resonant circuit to raise the efficiency and power of wireless charging for electric vehicles.

Zero Voltage Switching (ZVS). Ruan Xinbo, in related research, introduced the idea of Zero Voltage Switching (ZVS), where the switch turns on when the voltage is close to zero, which helps to lower the energy loss during switching [12]. To make this happen, first, a resonant inductor (L) and resonant capacitor (C) are added to the circuit to build an LC resonant circuit, which makes the voltage resonance possible. Then, just before the switch turns on, the voltage drops to nearly zero because of the resonance effect, so when the device turns on, it avoids the energy loss that would happen if it turned on under high voltage. Finally, when turning off, the resonant circuit also helps bring the voltage down to zero earlier, which improves the efficiency and reduces electromagnetic interference (EMI).Chen Zhiying, in his work, designed a ZVS composite PWM full-bridge three-power converter to achieve ZVS. This converter can reduce the input filter and improve the dynamic performance of the converter [13].

Zero Current Switching (ZCS). In the Zero Current Switching mode, the switching device completes the turn-off operation when the current approaches zero, thereby significantly reducing turn-off losses and electromagnetic interference (EMI) [14]. In this mode, first, a resonant inductor (L) and resonant capacitor (C) are introduced to make the current waveform in the circuit exhibit a sinusoidal variation, forming a natural resonant process. Next, the resonance causes the switching device to turn off when the current approaches zero, significantly reducing energy loss during the turn-off phase. Finally, since the current decreases to zero at a relatively slow rate during the turn-off process, it avoids the voltage spike phenomenon caused by a large current change rate (di/dt) in hard switching operations, thereby further improving the electrical performance and reliability of the system. Xu Feng proposed a novel FB-ZVZCS-PWM converter topology, which effectively realizes zero current switching for high-power lagging legs [15].

5 Conclusion

With the rapid development of the electric vehicle industry, wireless charging technology is gradually becoming an important direction for future charging methods. This paper conducted an in-depth analysis of the currently mainstream wireless charging methods—electromagnetic induction and magnetic resonance technologies—summarizing their technical principles, advantages and disadvantages, and current applications. It further explored optimization methods in resonant circuit design, the impact of temperature changes, and soft-switching technologies, effectively improving energy transmission efficiency and reducing system energy consumption.

However, the current stage of wireless charging technology for electric vehicles still faces some limitations. First, electromagnetic induction is limited by short transmission distance, requires precise coil alignment, and suffers from certain energy losses; second, although magnetic resonance can increase transmission distance and tolerance, it has a more complex system structure, higher cost, and significant heat dissipation issues under high-power transmission. In addition, resonant circuits are sensitive to temperature changes, easily causing frequency drift and affecting system stability; the implementation of soft-switching technologies also requires complex control logic and higher-cost power electronic components.

In the future, with continuous advancements in material technology, electromagnetic compatibility design, system integration, and intelligent control algorithms, wireless charging for electric vehicles will develop toward higher efficiency, longer transmission distance, lower cost, and greater stability. Overcoming current technical bottlenecks and realizing truly universal, intelligent, and efficient wireless charging will become a key driving force in promoting green transportation and smart mobility.

References

1. Joun, G. B., Cho, B. H.: An energy transmission system for an artificial heart using leakage inductance compensation of transcutaneous transformer, IEEE Trans. Power Electron., 13(6), 1013–1022(1998).
2. Papastergiou, K. D., Macpherson, D. E.: An airborne radar power supply with contactless transfer of energy—Part I: Rotating transformer, IEEE Trans. Ind. Electron., 54(5), 2874–2884(2007).
3. Liu, X., Hui, S. Y.: Simulation study and experimental verification of a universal contactless battery charging platform with localized charging features, IEEE Trans. Power Electron., 22(6), 2202–2210(2007).
4. Chen, Q., Wong, S. C., Chi, K. T., Ruan, X.: Analysis, design, and control of a transcutaneous power regulator for artificial hearts, IEEE Trans. Biomed. Circuits Syst., 3(1), 23–31(2009).
5. Cao, L., Chen, G., Ren, X., Ruan, X.: Research Progress of High-Efficiency Wireless Charging Technology for Electric Vehicles, Trans. China Electrotech. Soc., 27(8), 1–13(2012).

6. Wang, Z., Wang, T., Qiu, B.: Wireless power transmission and solar power satellite, Space Electron. Technol., 3(2), 6–12(2006).
7. Lin, W., Zhang, Y., Wang, G.: Power transmission by microwave—a propulsion for modernization construction, Sci. Technol. Rev., 12(3), 31–34(1994).
8. Zhang, L., Wang, H.: Advanced control strategies for induction motors, Electr. Mach. Control, 20(3), 63(2016).
9. Wei, S., Ma, X., Yan, Z.: Research on an Improved ZVT Dual-tube Dual-Forward Converter Circuit, Power Electron., 39(4), (2005).
10. Wang, Q., Guo, K., Zheng, J., Zhou, M.: Research on Transmission and Temperature Characteristics of half-wavelength Superconducting coplanar Waveguide resonators, J. Low Temp. Phys., 5, 361–367(2019).
11. Zhang, Q.: Background and Theory of Ceramic Capacitors, Radio Telev. Inf., (12), 87–89(2014).
12. Ruan, X., Yan, Y.: Soft-switching Technology of DC Switching Power Supply, Sci. Press, 2000, vol. 1.
13. Chen, Z., Ruan, X.: Zero-voltage Switching pwm Composite Full-Bridge Three-level Converter, Proc. CSEE, 24(5), 6(2004).
14. Fan, S., Gao, B., Yang, J., Sun, L., Duan, J.: Active clamped ZVS soft switching technology with low voltage and current stress, Proc. CSEE, 41(13), 4616–4627(2021).
15. Xu, F., Xu, D., Liu, Y.: A New Type of Full-bridge zero-voltage zero-current Switching pwm Converter, Proc. CSEE, 24(1), 147–152(2004).