Proceedings of the 4th International Conference on Mathematical Physics and Computational Simulation
DOI: 10.54254/2753-8818/2026.35234

The Current State and Optimization of Wireless Charging Technology for Electric Vehicles

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Abstract. Nowadays, wireless charging technology for electric vehicles has reached a high level both at home and abroad, whose foundational framework has already been established, while its application in daily life still cannot reach the expected ideal outcomes. At an attempt to better foster the commercialization and civilian application of this technology, this paper provides some optimization strategies on the base of electromagnetic induction principle to address the drawbacks in the field of transmission efficiency, transmission distance and thermal management and improve their charging efficiency. In terms of transmission efficiency, researchers proposed to remove the transmitting coil and the receiving coil relatively to achieve a larger overlap and then reduce transmission losses. As for transmission distance, the magnetic field frequency can be improved to enhance power transmission capacity and distance. Moreover, the method of strengthening heat dissipation and decreasing heat generation can significantly reduce thermal losses. In a nutshell, with the optimization in these three aspects, the researcher hopes to address some shortcomings of wireless charging and enhance the feasibility of wireless charging and facilitate people's daily life.

Keywords: electric vehicles, wireless charging, drawbacks, optimization

1. Introduction

These days, wireless charging technology for electric vehicles has become mature, with its charging efficiency reaching 90%. The dream of instant charging upon stopping and dynamic charging while driving gradually comes into reality [1]. As this technology becomes popular, the problem of insufficient power supply during driving can be solved, thus facilitating daily life. As a result, optimizing the process of wireless charging and improving charging efficiency has become an important research direction both domestically and internationally

As is known to us, there are three types of wireless charging systems covering the whole process of vehicle movement, which are static, dynamic, and quasi-dynamic respectively. And K.S. Margaret et al. found that the integration of static charging process requires enhancement after summarizing static inductive technology, evaluating its efficiency and analyzing successful applications [2]. To sum up, it points out that electric wireless charging technology has huge optimization space in the area of transmission efficiency, transmission distance and thermal losses. Therefore, conducting research towards this field holds significant importance for the establishment of static inductive

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charging systems for electric vehicles. Moreover, researchers dug deep in the optimization strategies such as compensation topology and anti-deflection. Compensation topology focuses on a circuit structure which is specifically designed to cancel coil inductive reactance and achieve impedance matching. Anti-deflection means the capability of one system to maintain stable output when its receiving coil experiences horizontal or vertical displacement. The efficiency of the charging system will significantly increase after optimizing these two fields.

This paper will discuss and analyze the optimized methods of wireless charging in electric vehicles from three aspects: transmission efficiency, transmission distance, and thermal loss. First, researcher can build a system to adjust the position of the transmitting and receiving coils to increase frontal areas to increase emission efficiency to extend transmission distance. Third, facing the situation that frequent thermal losses and equipment damage during wireless charging processes, it can be considered that taking some strategies to reduce heat generation and improve heat dissipation. This research is aimed at improving practical application of wireless charging and driving the development of this technology through a thorough analysis of its efficiency, distance and losses.

2. Fundamental principles

Non-contact is one of the most important characteristic of wireless charging, including the process of establishing electromagnetic fields and releasing electromagnetic waves between the charging and receiving devices to transfer energy and avoiding the complicated process of plugging lines. At present, wireless charging technologies mainly include electromagnetic induction charging, magnetic resonance charging, and electric field coupling charging, among which electromagnetic induction seems easier to understand its principle. Further still, the circuit above evolves into magnetically coupled resonant circuit after adding inductance and capacitance.

Here is a brief introduction of the principle of electromagnetic induction charging system. This system mainly depends on Faraday's law of electromagnetic induction, which alters the magnetic field to change the electric field and then induces the current. This theory bases on two coils to realize the process of charging, the releasing coil generating magnetic field by charging power and the receiving coil will accept the magnetic field above and then induce the corresponding currents. The efficiency of charging depends on the accuracy and distance between the releasing coil and the receiving coil.

3. Optimization study

3.1. Transmission efficiency

The transmission efficiency of electromagnetic induction wireless charging systems is highly dependent on the alignment accuracy of the corresponding coils. Research found that the mutual inductance coefficient will dramatically drop when the releasing coil and the receiving coil generates some displacement. This will cause coupling coefficient decreasing sharply and lose much magnetic flow. Such mismatch significantly reduces wireless charging efficiency for electric vehicles, turning the whole productiveness from the ideal 93% to below 85%. Meanwhile, different coil positions and design specifications will influence the alignment with the releasing coil.

In order to effectively reduce energy losses originating from misalignment between the two coils, Vatsala et al. proposed a method that the system can autonomously move the releasing coil to reduce misalignment between releasing and receiving coils and thus improving charging efficiency. This technology creatively utilizes Hall effect sensors to adjust the position of the receiving coil. The research greatly improve transmission efficiency through the perfect alignment of the two coils [3]. This proposal has proved the significant state of the coils' relative position during the wireless charging process, but the process of adjusting the position of the receiving coil means that more space is required within the car, making its space utilization efficiency decrease. From another point of view, Haijian Sun et al. proposed making use of radio frequency identification positioning to position where the releasing and receiving coils are [4]. This method utilizes an algorithm of maximum likelihood estimation to correctly get the coils' variable location while its drawback is expensive as it consumes so much computer power.

Therefore, why not consider the relatively cost-effective infrared technology for coil alignment (as shown in Figure 1). This technology mainly take use of the infrared sensors installed on the charging equipment. The sensor will release some infrared signals which will then be reflected or scattered to the sensor before. Then the position of the electric vehicles can be monitored and then the receiving coil can be positioned for accurately aligning and enhancing charging efficiency [5]. Meanwhile, the researcher proposes a feedback system to ensure the alignment. The process is when the charging efficiency is relatively low, the system will provide feedback to the infrared sensors which will then re-track the previous process and analysis the corresponding reason to ensure that the releasing and receiving coils always keep reasonable alignment. Here is a simplified operational diagram as follows.

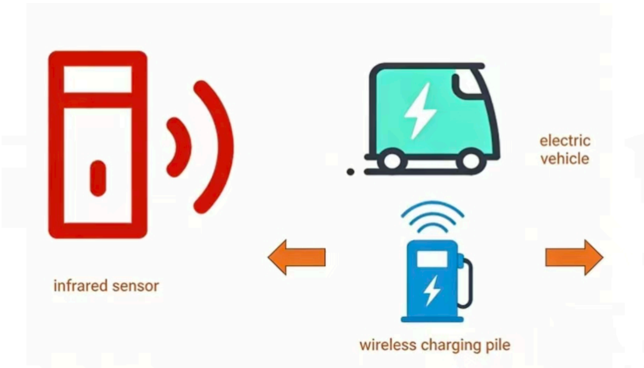

Figure 1. Schematic diagram of wireless charging transmission optimization [5]

3.2. Transmission distance

There is a close relationship between wireless charging efficiency and transmission distance. Since this technology mainly uses electromagnetic waves to transform energy, but the air will prevent the spread of the wave, which will cause the decrease of the energy. Therefore, transmission distance cannot be so long. At the same time, research found that the transmission efficiency will decrease as the distance reduces for magnetic coupling-based power transfer systems, so the transmission distance should not be too short. With the intention to solve the above problem, Ronghuan Xie et al. Found that the application of a relay coil can significantly contribute to the transfer of the two coils. Then it can be used to achieve power conversion between two electric cars, which is truly innovative that it makes energy transmission between vehicles into real life [6]. This research informed that if a relay coil is added between the releasing and receiving coils, the transmission distance of wireless charging could be further extended. As a result, research can first consider maintain the two corresponding coils at a reasonable distance so that it can achieve an optimal efficiency without adding the relay coil [7].

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Substantial researches have found that high-frequency electromagnetic waves damp less during air. Thus, to a certain extent, appropriately increasing the frequency will reduce the transmission loss. Therefore, researcher considers adopting electromagnetic waves with high frequency to solve the distance weakness [8]. At the same time, the frequency should not be against national regulations and human daily life should not be interfered by electromagnetic waves.

Figure 2 as below presents a diagram for optimizing wireless charging distance in electric cars. The horizontal axis represents transmission distance (0–350 mm) and the vertical axis indicates transmission efficiency (55%–100%). The diagram describes thee nonlinear relationship between transmission efficiency and distance. At 50 mm the efficiency reaches 70%, and then it sharply drops to 60% at 80mm. Then it remains stable around 60% from 80mm to 350mm. As for transmission efficiency, it reaches its peak of 88% at 150mm. In this graph, it is found that transmission efficiency can be enhanced with reasonable distance added.

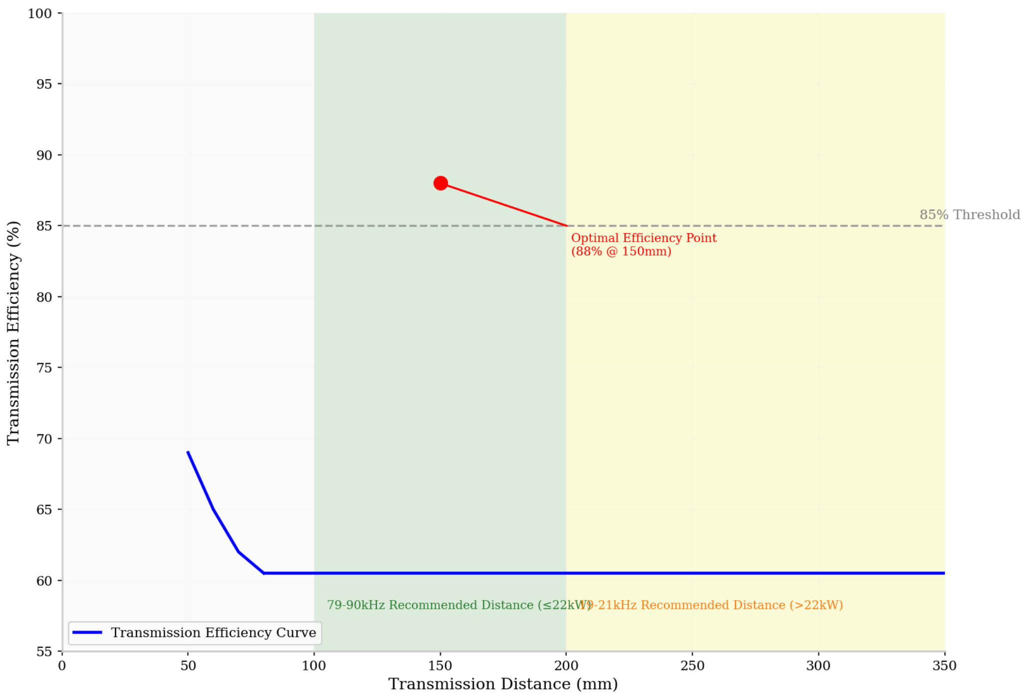

Figure 2. Schematic diagram of distance optimization for wireless charging in electric vehicles [8]

3.3. Thermal loss

During the process of electromagnetic induction, one kind of loss—eddy will be induced around nearby metallic conductors because of the change of magnetic field. These eddy currents change electrical energy into heat, causing loss. At the same time, the skin effect indicates that currents with high frequency tend to concentrate on the conductor's surface. This will result in an internal vacuum, effective conductive area shortage and then lead to high resistance and copper losses which will generate more heat.

Patrick A.J. Lawton proposed that modifying the magnetic structure of ferrite materials could effectively lower temperature by approximately 100 degrees, which will significantly reduce the thermal loss and avoid structural thermal failure. From researchers point of view, this study focuses on the internal structure of materials at its source and then innovatively optimize the inner structure [9]. Furthermore, a compensation network is a good choice to reduce thermal loss. After

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continuously adjusting the values of inductance and capacitance, it can reduce the generation of reactive components and minimize inefficient conversion. Hong Haisan and his colleagues also introduce to enhance coupling strength of magnetic fields, which will then further improve the efficiency of wireless charging. What's more, it is advised to install cooling fans near the receiving coil to lower temperature and implement temperature monitoring systems and high temperature alarm devices from the point of heat dissipation [10]. This will effectively prevent component damage and any emergency.

4. Challenges and development

Although wireless charging technology can be optimized in the above three aspects, these methods still have certain limitations. For example, when using infrared distance measurement method, it is unavoidable to be interfered by the surroundings because all living things emit infrared radiation. Further still, during the process of increasing transmission distance by increasing the frequency of electromagnetic waves, human health is harmed to some extent. Therefore, it is not hard to find that wireless charging still faces numerous challenges up to now.

However, new energy vehicles has already demonstrated advantages over fuel vehicles in saving energy. Developing new energy cars gradually becomes a trend from now on, thus people should make effort to come over the challenges above. Maybe future research could focus on how to mitigate the impact of external infrared ray on distance measurement. What's more, compare different radio frequency identification methods to achieve reasonable coil alignment accuracy. Furthermore, study the effects of wireless charging frequencies on human health and so on.

5. Conclusion

This paper discusses the drawbacks and optimization methods of electromagnetic induction wireless charging technology for electric cars from three aspects: transmission efficiency, transmission distance, and thermal loss. And research shows that with the addition of infrared photoelectric positioning technology and real-time feedback mechanisms, the alignment between the releasing and receiving coil has become more accurate, thus increasing the transmission efficiency. As for the transmission distance, in order to address the challenges, it can reasonably enhance operating frequency to reduce the loss in the air. Additionally, compensation network could be established to reduce the thermal loss caused by eddy current losses and skin effect. And cold treatment and temperature monitoring can be added to effectively ensure the system work safely.

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