The Optimization of Wireless Charging for Electric Vehicles

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Abstract. Nowadays, there are two types of charging methods for electric vehicles: wired charging and wireless charging. Compared with wireless charging, wired charging has the problems of fixed charging locations, exposed charging cables, and the risk of electric leakage when used on a rainy day. Wireless charging has received widespread attention in the market through its convenience and safety, but the improvement and optimization of its efficiency has always been a crucial topic in industry research. This article discusses the problem of the low wireless charging efficiency of electric vehicles. Firstly, it provides an optimization scheme from charging detection, then proposes a range from the transmission distance, and finally analyzes and optimizes the wireless charging scheme of electric vehicles in terms of transmission materials. This study finds that improvements from the above three perspectives can greatly improve the efficiency of wireless charging, provide a sustainable solution for the convenience of electric vehicle charging, greatly improve the charging efficiency of wireless charging, and improve the possibility of large-scale application of wireless charging of electric vehicles becoming a reality.

Keywords: Electric vehicles; Wireless charging; Increased efficiency.

1. Introduction

At present, there is a shortage of oil and coal resources in the world, and the combustion of oil and coal resources is seriously polluting the environment. Taking our country's oil consumption as an example, the oil import volume in 2009 was about 204 million tons, and the import dependence reached 52%, far exceeding the international warning line standard of 35% [1]. In order to avoid the above problems, power resources have been widely used, and as of the end of December 2024, the cumulative installed power generation capacity in the country was about 3.35 billion kilowatts. With the widespread application of power resources, the development of electric vehicles is becoming more and more rapid. The power, method, and convenience of charging have become the main issues that need to be optimized [2]. Now, our country's electric vehicle wired charging methods are mainly divided into household power charging stations and public charging stations. Although this charging method ensures high charging power, it is more troublesome and also reduces the utilization rate of parking spaces.

Wireless charging, also known as wireless energy transfer, is a way of converting electrical energy into other forms of energy through a transmitter, and then converting other forms of energy into electrical energy after a certain transmission distance. Considering the convenience of wireless charging, it has now been widely studied how it can be applied to electric vehicle charging solutions [2]. However, the loss of wireless charging mode is still a major problem, and how to analyze and optimize wireless charging for electric vehicles from the aspects of charging detection, transmission distance and transmission efficiency is an urgent topic to be studied. This paper starts from the basic principle of electric vehicle wireless charging, and optimizes and analyzes the charging detection, transmission distance and transmission materials of electric vehicle wireless charging according to the current scientific and technological level, so as to visually improve the efficiency of electric vehicle wireless charging.

2. Basic Principle Of Wireless Charging For Electric Vehicles

2.1. Wireless Charging Theory

Wireless charging is a charging method designed according to Ampere's law and Faraday's electromagnetic induction principle, which is mainly divided into two parts in the wireless charging system of electric vehicles: one is in the charging area (transmitting port) , and the other is inside the electric vehicle (receiving port) [3]. When the transmitter feels the receiver, energy transfer begins. In this process, the circuit in the charging area will generate a corresponding magnetic field through the change of current, it means the electrical energy will be converted into electromagnetic field energy, and the electromagnetic field energy will be converted into electrical energy when it reaches the battery inside the electric vehicle, when this process forms a loop, wireless transmission of electrical energy can be realized.

2.2. Wireless Charging Circuit Structure

As shown in Figure 1, the wireless charging circuit diagram of an electric vehicle is mainly consist of an alternating current(AC) power supply, a transformer, and a battery circuit in an electric vehicle. Because the electric vehicle charging circuit requires direct current(DC) power, in the process of converting electromagnetic field energy into electrical energy, the rectifying circuit is inserted into the circuit to convert AC power into DC power. When the sinusoidal image of the AC power is in the positive half-axis, D1 and D4 in the rectifying circuit will conduct. When it is in the negative half axis, D2 and D3 will conduct, which ensures that the direction of the current is always in one direction during the charging process of electric vehicles. Figure 2 shows the voltage of the two channels waveform. Channel A is the voltage waveform measured by the power supply, and channel B is the voltage waveform on the electrical side.

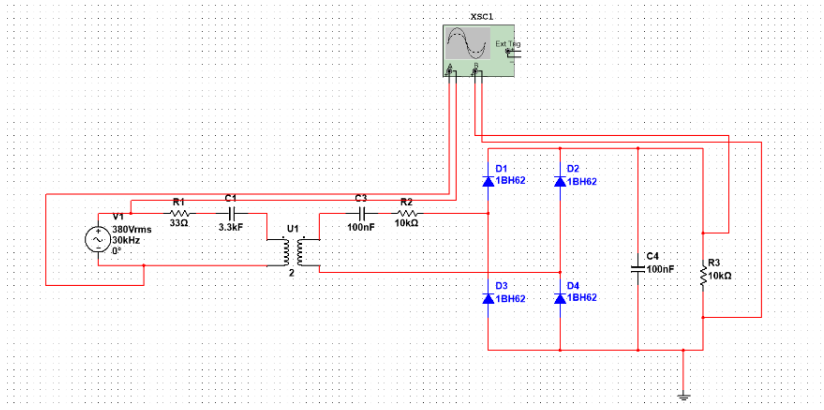

Fig. 1 Wireless Charging Circuit Diagram of an Electric Vehicle

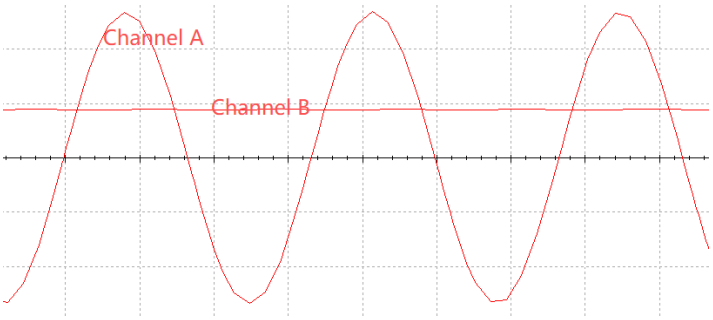

Fig. 2 Voltage Waveform Diagram of Electric Vehicle Wireless Charging Circuit

2.3. Features of Wireless Charging

Wireless charging is different from wired charging, which does not require users to charge with too many cumbersome wires. It not only simplifies charging steps, but also improves the utilization rate of parking spaces, because users can also park an electric vehicle in a position without fixed

wired charging stations, and avoid the disadvantages of charging cables that are prone to electric leakage when exposed to thunderstorm weather.

At present, the battery used in electric vehicles is large in size and high in weight, which increases the loss during driving of the car, but if wireless charging is used, the size of the battery can be reduced by carrying a power bank. This action reduces the load on electric vehicles, solving the concerns about power consumption during the driving of the electric vehicle, and also reduces the manufacturing cost of the electric vehicle.

3. Optimize Structure

Wireless charging of electric vehicles needs to meet four requirements: power level, charging distance, charging efficiency, and insulation [4]. Its transmission efficiency is mainly limited by three aspects. The first is charge detection; the second is the transmission distance; The third is the transmission material. The material of the coil will directly affect the current transmission efficiency [5].

3.1. Charge Detection Optimization

When the electric vehicle is not parked in the wireless charging parking space, if the power supply is still sending electrical energy, it may be connected to the ground and cause a short circuit, which is a very serious circuit malfunction, so how to ensure that the electric vehicle is parked in the charging area, and how to maintain constant current and constant voltage during the charging process is also a problem to consider.

The first consideration method is the position detection of the receiving end, which mainly determines the specific position of the car according to the position relationship between the coil in the ground and the coil of the car [6]. Sun Tian et al. conducted receiving ports position detection based on the principle of LPE position detection, and studied that the positioning accuracy reached 96% in the range of ±600~±800mm [6]. This positioning method greatly improves the positioning accuracy during wireless charging and ensures that there will be no problem of transmission path deviation during the positioning process. The second method tends to account for changes in current during the charging process [7]. In order to meet this requirement and detect the change of current during the charging process, Li Jiangnan et al. proposed a 3.3kW magnetically coupled resonant EV-WPT system [7]. This system uses a BUCK circuit for constant current detection, which quickly restores the current at the load to its original value if the current at the load changes. The 3.3kW magnetically coupled resonant EV-WPT system ensures that the current at the receiving port remains stable, which not only ensures the transmission efficiency can reach 85%, but also ensures the safety of the electric vehicle battery.

3.2. Transmission Distance Optimization

Due to the damping and attenuation effects of the air medium, the process of wireless charging must generate heat. According to the law of conservation of energy and the law of thermodynamics, when the electromagnetic field energy is transmitted farther, the higher the energy lost by the electromagnetic field, and then the less power is converted. Therefore, it is concluded that for the process of magnetic resonance coupling radio energy transmission, the smaller the longitudinal transmission distance, the higher the transmission efficiency. Machura and Li propose that static charging usually uses 40cm as the upper limit of the longitudinal transmission air gap distance of wireless charging, and in their experimental study, they find that Oak Ridge National Laboratory (ORNL) makes transmission efficiency greater than 95% when the transmission air gap is less than 16cm [8]. This limitation of longitudinal transmission distance and research has greatly improved the efficiency of wireless charging.

Most of the current science is focused on the optimization of longitudinal distances, while ignoring the optimization of horizontal distances. In the process of lateral distance research, it can be found

that lateral distance also plays a pivotal role in wireless charging. Yang Shuai, Wang Xiuping, et al. do research through MATLAB simulation, the simulation experiment of the lateral deviation interval of the coil shows that when the lateral length deviation is less than 13.04cm, the transmission efficiency is greater than 80%[9]. This study limits the lateral length deviation in the wireless charging process, fills the research gap, plays a key role in improving transmission efficiency, and is an important measure to improve wireless charging of electric vehicles.

3.3. Transfer Material Optimization

The coil is the main material used in the circuit transmission process, and its wire material, structure, including the material and shape of the magnetic core, will affect the power of wireless charging.

For the material of the wire, Zheng Guangjun proposes that the Leeds wire can be used to solve the skin-like effect, because its surface area is large, and the current density distributed on the surface of the coil wire is less than that distributed in the center of the wire[10],and Ahmad A, Alam M S, Chabaan R propose cementitious composite medium, this material can increase the efficiency of wireless charging transmission to 86%[11].

The winding structure proposed by Zheng Guangjun is a multi-layer coil Z-type series structure, which reduces the equivalent capacitance through the staggered connection of the upper and lower layers, making the resonance more stable, and when the stable resonance point is reached, the transmission efficiency can be effectively improved[10].Another structure is proposed by Xu Xianfeng et al. , which is called D4 coil magnetic coupling structure, this structure can make the magnetic field distribution is more concentrated in the middle of the magnetic coupling distribution, so that the magnetic field distribution between the coils is more uniform and the transmission current transmission is more stable[12]. During wireless charging, these two corn structures have a higher transmission efficiency than the original single-layer coil structure.

The material and shape of the magnetic core have also been widely studied and used in wireless charging of electric vehicles. Palani et al. propose that the ferrite core inserted between the coils concentrates the magnetic field in the central area of the coil, which improves the coupling coefficient, reduces the transmission loss, and improves the transmission efficiency[13]. For the shape of the magnetic core, Chakibanda V and Komanapalli V L N propose four shapes they are rectangular, S-shaped, D-shaped and I-shaped ferrite strips. The four types of cores are analyzed according to the simulation software, and the optimization effect of shielded type I ferrite cores is the best in terms of coupling coefficient[14], although the volume of this shape is relatively large, it increases efficiency by 6.446%, making it the best choice.

4. Challenges and Developments

Due to the certain distance between the electric vehicle and the ground, the gap between the transmitting port and the receiving port is large, and the coupling coefficient is only 0.01-0.2. At the same time, a large air gap can also increase the risk of radiation leakage during charging, leading to health problems[15].Moreover, the heat generation during the charging process is also a problem that should not be underestimated; if the temperature is too high, reaching the melting point of the battery is easy to cause spontaneous combustion. Finally, the electromagnetic field generated during wireless charging may interfere with the electronic components in the vehicle, which can cause malfunctions after a long period of interference, such as the radar, which may pose a threat during driving.

In the future, in terms of optimizing the wireless charging distance, the distance between the two ports can be reduced by increasing the height of the transmitting port or lowering the electric vehicle. For heat generation during charging, the temperature can be reduced by reducing the indoor temperature or installing circulating cooling pipes around the battery to reduce potential safety hazards in the future. Considering the electromagnetic field in the process of wireless charging, metal

shielding can be installed near the transmitting port and receiving port to prevent the electromagnetic field generated by wireless charging from spreading outward.

5. Conclusion

Compared with wired charging, wireless charging is more convenient and more in line with the development trend. This essay mainly represents the principle and circuit structure of wireless charging for electric vehicles, and different aspects that can prove the efficiency, including optimization of charge detection, limit charging distance, and transfer material optimization. First of all, optimization of charge detection can be optimized from the parking and charging process of the vehicle, these two ways are not only improve the utilization rate of electrical energy, but also ensure the safety of electric vehicle charging process; Second, wireless charging is necessary to consider effect of longitudinal distance on the efficiency of power transmission and maximum the lateral distance; Finally, the transmission material can consider start from the material of the wire, the structure of the coil and the core, it should not only restrict to traditional materials, but also various new materials should be applied to wireless charging of electric vehicles, and more approaches need to be considered to improve the efficiency of power transmission at the same time.

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