Applications of Dynamic Wireless Charging for Electric Vehicles

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Abstract. With the continuous enhancement of people's awareness of environmental protection and the plight of China's lack of oil, the development of electric vehicles has become a goal in China today. At present, one of the main obstacles restricting the development of electric vehicles is the lack of endurance capacity. At present, the mainstream solution is wired charging, but this method is inefficient. With the popularity of electric vehicles increasing, this method may be eliminated. Therefore, this paper will deeply study another way, that is, the more advanced wireless charging. By carefully reading the relevant literature published in recent years, this paper finds a large number of data to study the advantages, limitations and development difficulties of wireless charging. This paper found that wireless charging is not an emerging technology, but its application in electric vehicle charging still needs a large number of researchers to make innovation, and the anti-offset ability of wireless charging is insufficient, and the efficiency is unstable. However, compared with wired charging, wireless charging does not occupy ground space, and dynamic wireless charging can improve the long-distance driving ability of electric vehicles.

Keywords: Electric Vehicles, Wireless Charging, Dynamic.

1 Introduction

China's energy structure is dominated by oil, and 70 per cent of China's oil is dependent on imports, and cars consume 55 per cent of the total oil. At the same time, China does not master the core technology of fuel vehicles; but our batteries, motors and so on are in the world's leading position, the development of electric vehicles, is the most suitable way for China to seize the international automobile market. As we all know, oil as a non-renewable resource, the consumption of oil can not be regenerated within a short period of time. And oil as our country's important strategic resources, our country needs a large amount of oil reserves to face any unexpected situation. Therefore, it is urgent to develop and popularize electric vehicles.

One of the biggest obstacles limiting the development of electric vehicles is their low range. Many companies boast that the range of their electric vehicles is comparable to that of conventional cars, but in fact, due to the vastness of China and the complexity of its use, the range of electric vehicles is far from the actual

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requirements of the people in many cases. The reason for this is that the energy stored in a battery of the same size is far less than that of petrol. At present, there are three ways to solve the range problem of electric vehicles. One is to replace the batteries, which is currently done by replacing the dead batteries with charged ones at EV battery replacement stations, but this has obvious limitations. The replacement process is cumbersome, and consumers may be dissatisfied that the replacement battery is not as good as their original battery, and if the replacement battery is damaged before the next replacement, who should bear the loss, and its safety cannot be guaranteed. The National Grid's attempt in 2006 also ended in failure; policy, technology, and commercial factors are not favorable to the battery replacement method [1]. The second is wired charging, which is currently the mainstream charging method, where car owners charge their EVs at a fixed charging station like a car at a petrol station. However, this charging method is not as fast as refueling, which often requires the owner to wait 30 minutes to replenish the charge to 80%, and to maintain the battery life, the remaining 20% needs several hours to be fully charged. The slow efficiency of wired charging is not sufficient for use, given the potential for an increase in the number of electric vehicles in the future. Ageing charging plugs and wiring are also a safety hazard, and charging efficiency is greatly reduced in extreme weather. And, because the world has not yet introduced a unified standard, electric vehicles produced by different manufacturers may not be able to share the charging plug, greatly hindering the popularity of electric vehicles. Third, wireless charging, wireless charging can get rid of the limitations of the charging cable, charging in a stationary or even driving process, do not have to spend a lot of time on the road to charge, according to different use cases can also be done without taking up space on the ground, do not have to wait in a fixed position, do not need to queue up for waiting, do not need to worry about the safety of the operator directly in contact with the charging cable, with the security, efficiency and convenience.

It is because of the incomparable superiority of wireless charging technology that wireless charging technology has a huge potential for application in electric vehicles. In today's world, not only China is vigorously developing electric vehicles; Norway, Sweden, Germany, and other countries' electric vehicle penetration rate has been quite high, China must accelerate the development of electric vehicles, so as not to be subjected to other countries' elbow again in the future in terms of electric vehicles. Wireless charging technology can be used as a supporting technology for electric vehicles, the importance of which is self-evident. At present, wireless charging technology mainly has the following three methods - electric field coupling method, electromagnetic induction method and magnetic field coupling method.

(1) Electromagnetic induction method is based on the principle that a conductor generates an induced electromotive force in a changing magnetic field to achieve charging.

(2) The electric field coupling approach essentially uses the electric field between a parallel plate capacitor and as a pathway for energy transfer.

(3) The magnetic field coupling method is to form a resonant loop by using the inductance of the receiving coil and the capacitance connected in parallel, and to form a receiving loop with the same resonant frequency at the receiving end as well, and to

realize high-efficiency wireless energy transmission by using the strong magnetic coupling formed by resonance [2]. This is the resonant wireless charging that is the focus of this paper.

2 Resonant Wireless Charging

2.1 Main Components

Fig. 1 shows that there are two parts of the system components. In the first part, the transmitting end consists of a coil connected in parallel with a capacitor in connection with a power source. In the second part, the receiving end consists of a coil in parallel with a capacitor in connection with a load. In specific applications, a feedback system may be loaded directly on the transmitting and receiving ends to regulate the output power, frequency, and so on.

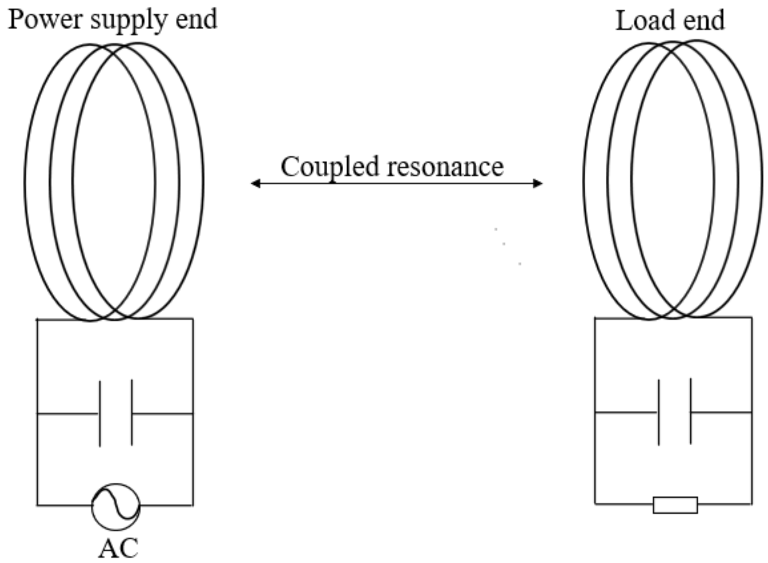

Fig. 1. Schematic diagram of magnetic coupling resonant wireless energy resonant coil [3].

2.2 Working Principle

Fig. 2 shows the composition of the charging system. Wherein the primary-side equipment includes a power grid, a primary-side rectifier circuit, a high-frequency inverter circuit, a primary-side compensation circuit, and a primary-side coil, and the secondary-side equipment includes a secondary-side coil, a secondary-side compensation circuit, a secondary-side rectifier circuit, and a power battery.

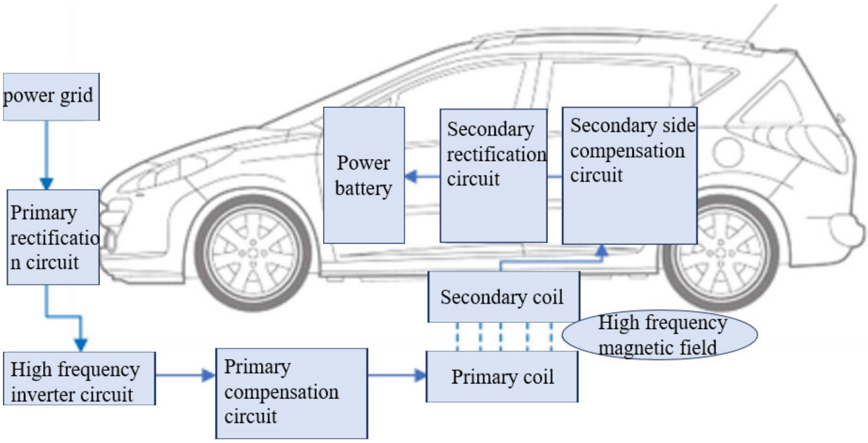

Fig. 2. Schematic diagram of the composition of the magnetic coupling resonant electric vehicle wireless charging system [4].

The power supply at the transmission end is turned on with sinusoidal current, and a changing magnetic field is generated at the coil end due to the changing current, and the coil at the receiving end is charged to the capacitor at the receiving end after generating an induced electromotive force under the action of the changing magnetic field. When the frequency of the input sinusoidal current is equal to the resonant frequency of the coil and the direction of the current changes at the same moment, the direction of the magnetic field changes, and the receiving coil generates an induced electromotive force, which in turn generates an electric field that pushes the charge to move through the capacitor, resulting in the discharge of the capacitor of the receiving coil. The periodic change in the direction of the sinusoidal current at the transmitting end leads to the generation of an induced electromotive force, and then the induced electromotive force drives the current to flow in the receiving coil, and when the current flows in the coil at the receiving end, it causes a change in the magnetic field, and this change generates a reversed induced electromotive force, which pushes more current to be generated in the coil, and by virtue of this kind of positive feedback, the current is continuously amplified in the receiving coil, until the receiving coil's electromagnetic energy reaches its maximum value. If there is a load on the coil, the transmitting end will continuously transmit energy to the receiving end, thus enabling wireless energy transfer [3].

2.3 Examples of Applications

Wireless charging is not something new that has only emerged in recent years, scientists have been working on this technology as far back as the late nineteen nineties. American scientist Nikola Tesla He used the earth as a conductor and used the earth's electromagnetic waves to transmit electricity, and he built a huge coil to try to transmit electricity around the world [5].On 6 July 2007, Marin Soljacic's scientific team at the Massachusetts Institute of Technology (MIT) in the United States presented in Science that they had achieved wireless charging by magnetically coupling a resonance at the 9.9MHz same-frequency resonance, will be about 2m away from the power of 60W light bulb light, and the whole system efficiency reached about 40%; in the distance of 1m, the efficiency is even as high as 90% [6].

Around 2010, a research group from the University of Zaragoza, Spain, published a concept of wireless fast charging of buses in bus stations to reduce the need for high-capacity batteries in electric buses and obtained results with a transmission distance of 15 cm, an output power of 2 KW, and an efficiency of up to 92% [7,8].

In 2013, Nanjing University of Aeronautics and Astronautics (NUAA) cooperated with ZTE to establish the first wireless charging line for buses in China [9].

2.4 Advantages and Disadvantages

Table. 1 shows the differences among three types of charging. Electromagnetic induction wireless charging is the use of loose-coupled transformers to achieve power transmission, this method is highly efficient, high power, but these advantages can only be exploited if the transmission distance meets a few centimeters, so this method is commonly used in electric toothbrushes, mobile phones, implantable medical electronic devices [4].

Magnetic coupling resonance type wireless charging has higher efficiency than other wireless charging methods, the transmission distance is farther, able to reach several metres so that the energy transmission in the middle distance, and on the front suspension of the alignment of the accuracy requirements of low, strong resistance to offset ability. The magnetic field coupling method is used, so it is harmless to human body. However, the quality factor and frequency characteristics of the coil are very demanding [10].

The high level of safety enables magnetically coupled resonant wireless charging to be used in the medical field, where it is safe for charging implanted artificial organs, for example.

Microwave radiant wireless energy transmission of energy transmitter end of the microwave emission at the receiving end is converted into electrical energy. Its biggest advantage is that the transmission distance is long, up to thousands of meters, but its shortcomings are also obvious: microwave easy to communications interference, slow propagation speed, narrow band, poor directionality, low efficiency, low power.

Table 1. Comparison of wireless charging mode indicators

	Transmission power	Transmission efficiency	Transmission distance	Working frequency	Characteristic
Electric field coupling type	Several tens of watts	Medium high	A few centimeters	10khz-150khz	Light weight, little impact on the environment, low working

					frequency, high output power, good safety, poor anti offset ability
Microwave type	Decades of watts to tens of kilowatts	Medium low	A few meters to several thousand meters	Multiple use of S and C bands	Long transmission distance, high working frequency, poor transmission efficiency, low power density, high transmission loss and low energy utilization
Magnetically coupled resonant type	A few watts to tens of kilowatts	High	A few centimeters to a few meters	1mhz-100mhz	High transmission power, medium transmission distance, strong anti offset ability, high safety factor and high requirements for resonance

2.5 Analysis of Basic Resonance Compensation Topology

Resonance compensation improves the load impedance characteristics of the coupling device. Fig. 3 shows four kinds of networks.

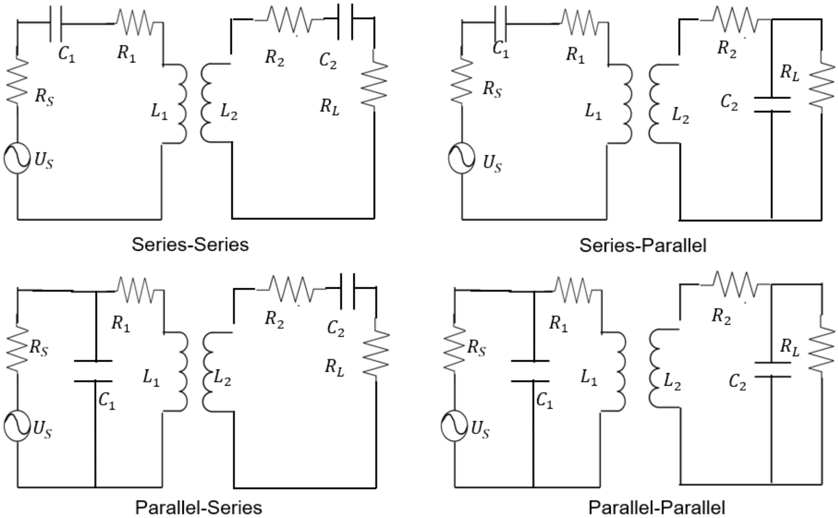

Fig. 3. Four basic resonant compensation networks [11].

In magnetically coupled resonant type system the compensation network is classified as series-series, series-parallel, parallel-parallel and parallel-series type. R_L is the charging load, ω is the operating angular frequency, and U_S is the high frequency alternating current, and R_S is the internal resistance of the power supply, C_1 and C_2 are the equivalent inductance of the transmitting and receiving coils, respectively. L_1, L_2 are the internal resistances of the transmitting and receiving coils, respectively, and M is the mutual inductance between the transmitting and receiving coils. The system operates at resonance when the Table. 2 are satisfied.

Table 2. Relationship between coil cointegration capacitance and inductance

Compensation structure	Compensation capacitance C_1	Compensation capacitance C_2
Series-Series	$\frac{1}{\omega_0{}^2 L_1}$	$\frac{1}{\omega_0{}^2 L_2}$
Series-Parallel	$\frac{L_2}{\omega_0{}^2 (L_1 L_2 - M^2)}$	$\frac{1}{\omega_0{}^2 L_2}$
Parallel-Parallel	$\frac{L_1 L_2{}^2 - M^2 L_2}{\omega_0{}^2 (L_1 L_2 - M^2)^2 + M^4 R_L{}^2 / L_2{}^2}$	$\frac{1}{\omega_0{}^2 L_2}$
Parallel-Series	$\frac{L_1 R_L{}^2}{\omega_0{}^2 L_1{}^2 R_L{}^2 + \omega_0{}^4 M^4}$	$\frac{1}{\omega_0{}^2 L_2}$

3 Dynamic Wireless Charging

As shown in the Fig. 4, according to different usage situations, it can be divided into dynamic wireless charging and static wireless charging. The principle of dynamic wireless charging is the same as that of resonant wireless charging. According to the different structure of the energy transmitting coil, the dynamic wireless charging system can be divided into the long track transmitting coil structure EV dynamic wireless charging system and the short segment transmitting coil structure EV dynamic wireless charging system; according to the different number of charging cars, it can be divided into the independent and cluster EV dynamic wireless charging system [12].

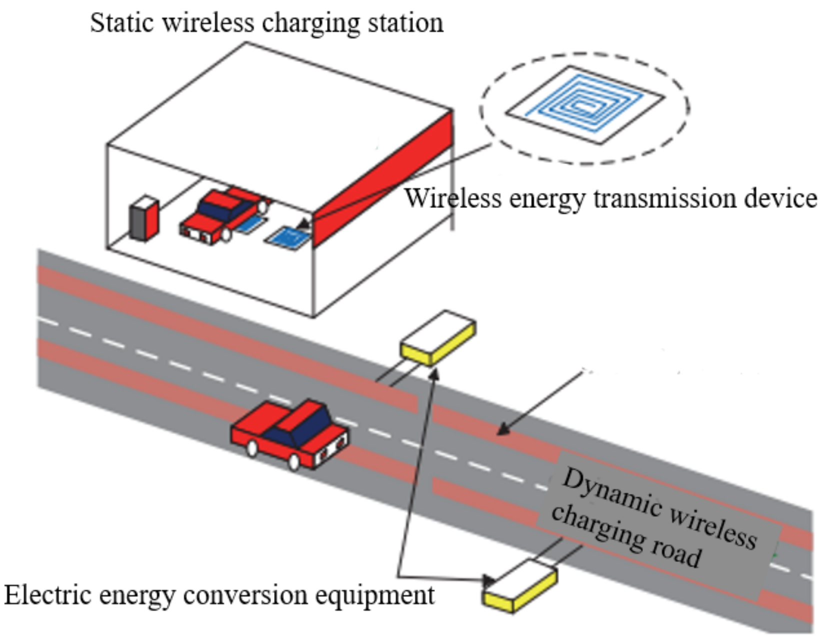

Fig. 4. Classification of wireless charging technology for electric vehicles in different operation scenarios [12].

3.1 Main Components

Fig. 5 shows that long track transmitting coil structure clustered electric vehicle dynamic wireless charging system in which only one coil or a single transmitting coil length can be fused that multiple electric vehicles are dynamically charged at the same time. The ground system has power converters, resonance compensation circuits, etc. in addition to the transmitting coils; the vehicle chassis is loaded with receiving coils [11].

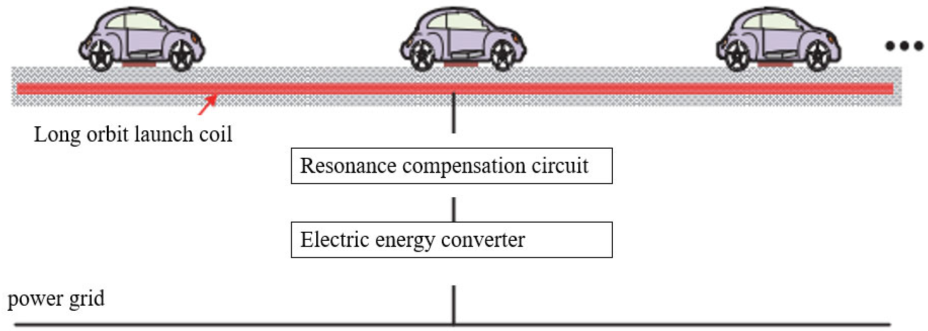

Fig. 5. Schematic diagram of dynamic wireless charging system for clustered electric vehicle with long track transmitting coil structure.

As the Fig. 6 shows, installing a large number of short segments transmitting coils on the road also requires a large number of power converters and resonance compensation circuits, as well as controllers or converters to control whether the transmitting coils work or not. The difference between short segments and long tracks is that short segments only need the spell coils underneath the EV to work to give the EV work [12].

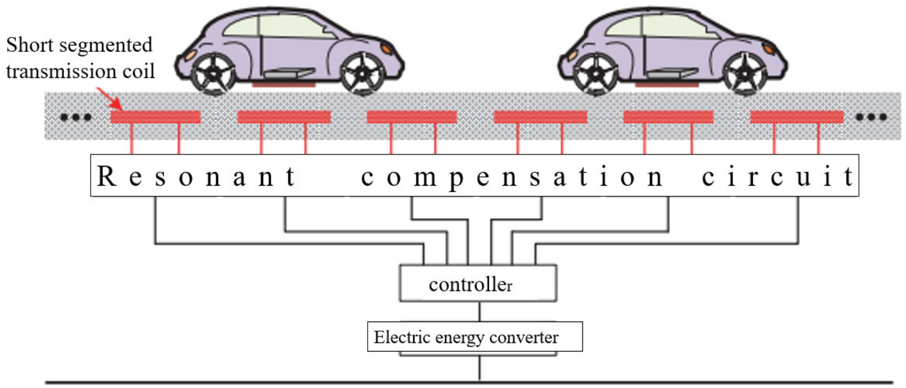

Fig. 6. Schematic diagram of dynamic wireless charging system for clustered electric vehicle with short segment transmitting coil structure.

3.2 Advantages and Disadvantages

Static wireless charging solves part of the charging problem, but it does not solve the problem that the battery storage energy does not meet people's needs for long-distance driving, which is compensated by the dynamic wireless charging method. It allows electric vehicles to be charged while driving. This way of charging and using electricity at the same time can reduce the frequency of stopping to recharge during long-distance driving and improve the ability of electric vehicles to drive long distances [7].

Dynamic wireless charging method can also solve the problem of low battery energy density, with dynamic wireless charging technology, can reduce the cost of making batteries, reduce the use of metal and reduce the pollution of the environment. And effectively avoid the bottleneck of the technology to improve battery energy density.

3.3 Difficulties Currently Facing the Technology

Complex application scenarios, the high frequency and high voltage operating mode of the system will generate a large amount of heat, and the warming will cause the performance of the components with defined parameters to change, making the defined system unstable.

Differences in the location of EVs lead to differences in charging efficiency, and how to keep the charging efficiency of moving EVs at as high a level as possible is a challenge for practitioners.

High-frequency and high-voltage operating modes may cause electronic interference to the surrounding electronic devices, in order to be able to put this technology into practical use, researchers need to study the effective electromagnetic shielding technology [7].

3.4 Deflection-Resistant Characteristics of Magnetically Coupled Coil Lifting Systems

When electric vehicles use wireless charging technology to charge batteries, whether charging in a stationary state or charging in the driving process, the output coil and the receiving end coil will inevitably appear offset phenomenon, the output coil and the receiving end coil will greatly reduce the charging efficiency when the offset occurs, so the study of how to improve the coupling mechanism of the anti-offset characteristics of the wireless charging technology to speed up the application of the road must be taken.

4 Conclusion

Through research of around 3000 words, this article finds that wireless energy transmission has enormous potential in the application of electric vehicles, with convenience, safety, efficiency, and more that wired charging does not have. Enterprises and countries around the world have combined wireless charging with public transportation. However, at present, this technology is still not mature enough, and there is a lack of improvement in anti-offset ability. The error in relative position can lead to a decrease in transmission efficiency, resulting in increased loss of resources and time. Magnetic coupling resonant wireless charging is more suitable for electric vehicles compared to microwave wireless charging and electric field coupling. Magnetic coupling resonant wireless charging requires lower position accuracy, transmission distance that meets the application scenarios of electric vehicles, and higher transmission efficiency. However, this method requires higher coil quality, which is a huge challenge for manufacturers. In response to the phenomenon of leakage inductance leading to low coupling coefficient and low power, resonant compensation mechanisms can to some extent solve these problems. In order to always keep the system working in resonant state, resonant compensation mechanisms should be applied in the system. In terms of solving the long-distance transportation capacity of electric vehicles, dynamic wireless charging is superior to static wireless charging, which can reduce the time for electric vehicles to recharge during long-distance transportation. This is of great help in increasing the popularity of electric vehicles. With dynamic wireless charging technology, the technological bottleneck of improving battery energy density can be avoided.

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