

State of the Art Wireless Charging Technology for Electric Vehicles

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Abstract. Wireless charging technology for EV (electric vehicles) is a trend in the car of the future. Because it is a bit significant, such as driving with no emissions at all. When decelerating, the energy can be repeated in life. Noise and vibration are low. The core technology of electric vehicles lies in the "three electric" system, namely electric drive system, battery system and electric control system, these three systems constitute the key technology of electric vehicle. The advantage of wireless power transfer technology is that the weight and volume of the power system are significantly reduced, and the versatility and reliability are high. In this paper, wireless charging technology is divided into magnetic induction transmission and electric field coupling transmission. The research status and focus of this technology are summarized from the aspects of transmission coil, compensation network, power electronic converter and its control method. Finally, the compelling places and future directions of wireless charging technology are discussed.

Keywords: Electric Vehicles, Wireless Charging Technology, magnetic induction transmission, electric field coupling transmission.

1. Introduction

With the enhancement of human environmental awareness, the use of clean energy has become a consensus. Clean, non-polluting and renewable electricity will surely become the main energy for industrial and agricultural production and life in the future. Therefore, when choosing a car to travel, due to factors such as cost, efficiency, environmental protection, etc., new energy vehicles have become people's first choice. New energy vehicles can be defined as the automobile with new energy source or new power system. Without the use of customary fuel, new energy vehicles are divided into some categories: alcohol ether vehicles, pure electric vehicles, fuel cell vehicles etc. But among them, electric vehicles have their unique advantages. For example, a zero-emission electric motor in an electric vehicle replaces a fuel-powered engine, and the space and weight of the electric motor, fuel, and powertrain can be used to offset battery requirements. Compared with internal combustion engine vehicles, electric vehicles are simpler in structure, have fewer working and transmission parts, and require fewer maintenance requirements and maintenance orders. High energy conversion efficiency. At the same time, energy recovery can be performed during braking and downhill to improve energy efficiency. Favourable policies of the State Grid support electric vehicles for charging at night, which helps to stabilize the peak-to-valley difference in the grid. Electric Vehicles (EVs) becomes one of the major approaches of the reduction of the fossil fuel under the circumstance of global warming. As the extension of EVs in the marketplace, the demand of corresponding charge device increases remarkably. In its present form, the way of charging can be divided into three groups: 1) wired charging, 2) replacing the battery and 3) wireless power transfer (WPT). For wired charging, its operation will age the wire under long-term using, and its working efficiency is affected in snowy weather. Replacing battery can obtain higher efficiency, whereas the maintenance costs of batteries increase. Meanwhile, there are corresponding requirements for the model of EVs and batteries.

Comparatively, wireless charging avoids these shortcomings. WPT installs the transmitter underground which avoids the loss caused by the jack and makes the charging method more convenient and flexible. This charging pattern attracts wide attention.

Wireless power transfer has been implemented by Nicola Tesla a century ago [1]. At present, the major WPT technology of EVs can be categorized as three types: 1) electromagnetic radiation which is mainly transmitted by microwave or laser, based on the principle of microwave far-field transmission, 2) magnetic induction that is based on Faraday's law of electromagnetic induction, used mainly for short-range transfer, and 3) electric induction which uses high-frequency electric field to realize wireless transmission directly of electric energy through metal plates. For the characteristics of vehicle wireless charging, most of the research focus on the practical problems of vehicle charging, such as anti-offset capability of charging system, dynamic charging, and bio-security. This paper will analyze the core elements of this technology in two ways: magnetic field coupling and electric field coupling, and analyze the research direction and hot issues in three aspects: power electronic control, foreign object detection and biological safety. Finally, the future of this technology is prospected.

2. Magnetic induction/resonance

As shown in Fig. 1, this is a magnetic induction/resonance system of WPT for electric vehicles. Its transmission principle is mainly based on Faraday electromagnetic induction principle, which can be simplified into three main parts: car batteries, transformers, power grid. Between these main parts, the efficient transmission of energy is realized through rectifier circuit, compensation network and other structures. In WPT system, the focus is on how to improve the energy conversion efficiency, which refines two research interests: compensation topologies and coil design. Compensation topology is mainly used to reduce system reactive power, and it is also the discrepancy between magnetic induction system and magnetic resonance system. The transmission coil is a device for converting electric energy into field energy.

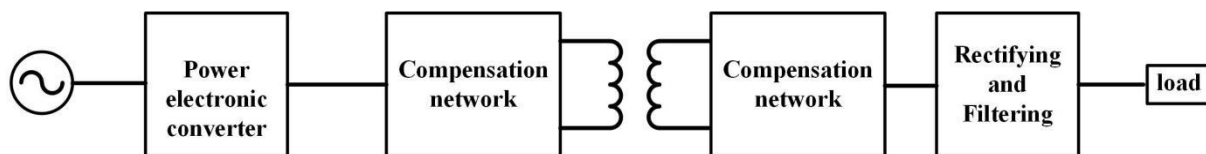


Figure 1. Magnetic induction system of WPT

2.1. Compensation topologies

In the simplified structure shown in Fig. 1, the wireless transmission coils are loosely coupled, thus a compensation topology (also known as a resonance network) needs to be added to ensure that the sending side and the receiving side can achieve efficient coupling. On the primary side, compensation network is implemented to achieve ZPA, which means the reduction of reactive power. On the receiving side, its application is aimed at ameliorate the transmission power. In addition, compensation topology decreases switch loss and achieve the soft switching of power transistors [2,3]. At present, the most basic compensation topologies include series compensation, parallel compensation and their complexity. In addition, there are some compensation topologies derived from the above modes, such as double-side LCL (hereinafter referred as LCL) and double-side LCC type (hereinafter referred as LCC).

The above modes are all based on uni-directional transmission. As an upgrade direction of this field, the bi-directional WPT system can realize the contraflow of energy between EVs and the grid. It has great advantages in idling standby, peak regulation, automatic power generation control, etc. [3].

2.1.1. Uni-directional transfer

At present, uni-directional transmission, as a common transmission mode, mainly involves six compensation networks, which are SS type, SP type, PS type, PP type, LCL type and LCC type.

Among them, the four most basic topologies are SS type, SP type, PS type and PP type. For the primary side, the parallel type needs current source to supply power, and the input impedance is too large and easy to be disturbed, which makes it has some problems in real operation. The S type can be connected with the voltage source inverter directly, and the low input impedance of series type has advantages in the connection of high-power devices. Use in secondary sided, the S type presents output attribute of constant voltage source, while the P type performs the output property of constant current source [4].

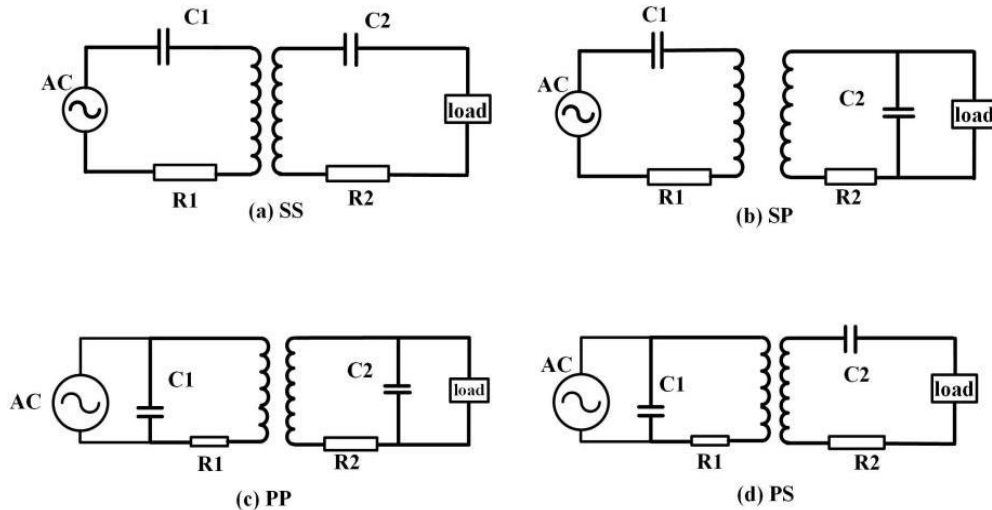


Figure 2. The circuit diagrams of four basic resonance compensation network topologies

On this basis, paper [5] uses MATLAB/Simulink software to simulate and analyze the mentioned topology. The original side with series compensation can achieve a larger transmission power, while the original edge with parallel compensation has a smaller transmission power. SS compensation can use a wide range of load resistance values, and SP compensation can ensure stable transmission efficiency [5-6].

Although the four mentioned basic topologies are easy to implement, their anti-offset ability is weak, which leads to the study of more complex compensation networks. LCL type and LCC type are compensation topology circuits derived from the four basic topologies, and their characteristics are analysed in detail in literature [7-9]. The LCL type circuit has the output characteristics of constant voltage and constant current under corresponding conditions. The LCC topology, similar to the LCL type, a DC isolation capacitor is on the coil branch by series connection to make the coil inductance and the DC isolation capacitor are equivalent to the coil inductance in the LCL topology when being connected in series. Thus, LCL topology can also achieve constant current output [8].

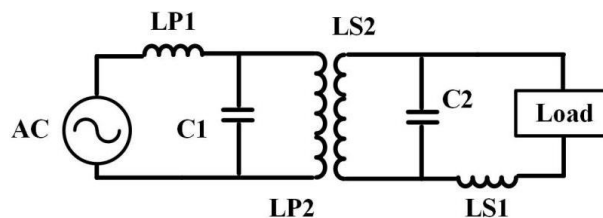


Figure 3. Schematic diagram of double LCL network

2.1.2. bi-directional transfe

The above modes are based on uni-directional transmission system, and there are corresponding studies on bi-directional transmission. In two-way transmission, three types of resonance topology are generally used: SS type, LCL type, and bilateral LCC type. To keep the symmetry of system, the compensation topologies of the mixture of S type and P type are not compatible. The reason PP type does not exist is that current source converter is needed for PP type, but voltage source converter is more common in practical application [10].

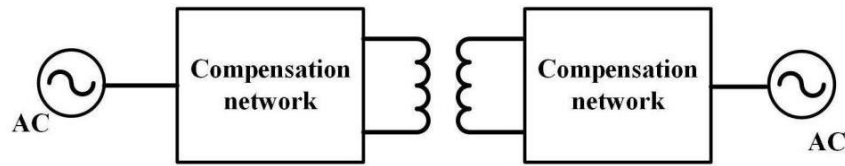


Figure 4. Simplified schematic diagram of bi-directional wireless power transfer system

2.2. Coil design

The transmission coil is a component of the wireless transmission system that transforms the electrical energy to the field energy. Therefore, it can be considered as a magnetically coupled element. Considering the skin effect and proximity effect at high frequencies, copper tubes or Litz wires are usually selected to wind [3,6]. The effective surface area is much larger than that of a single-core conductor because it is twisted or braided by multiple independently insulated conductors, which can effectively reduce the effects of skin effect and proximity effect [11]. To improve the coupling effect of the coil, ferrite is used as the material of it generally due to its high magnetic conductivity capacity.

The transmission coil only acts as the conductor of the electric energy in the magnetically coupled structure, so the focus is on how the magnetically coupled components can efficiently transform the field energy and the electric energy. At present, the structure relationship between field energy carrier and coil is the main research direction. Since the magnetically coupled transmitter elements are generally fixed, they are generally classified as static system and dynamic system from the receiver.

2.2.1. Static system

The static system can be also referred as fixed system. From the structural analysis, the transmitting end is divided into two types, namely circular and rectangular. The circular coil has no requirement for the direction of the vehicle entering, while the rectangular coil structure can better use the coupling area to cover the entire chassis area and prevent the magnetic field from being weakened by mutual cancellation and the magnetic flux from being reduced when the receiving coil is outside the magnetic field transmitting area.

Generally, the coils used for fixed charging are divided into single unilateral and bilateral winding. Among the bilateral winding, the most representative is the flux pipe structure proposed by Auckland University in New Zealand, and the H-type structure proposed by Saitama University in Japan. Literature [12] proposes an ideal bar topology structure based on the modeling and analysis of magnetic flux, so as to realize the constraint of magnetic flux. There is magnetic field leakage at the back of the bilateral winding. Although it can be shielded by external aluminum plate, the eddy current loss will reduce the system efficiency [3]. In addition, because the matrix is ferrite, such coupling elements are usually brittle and need to be filled with soft plastic or rubber materials, so they are less applied in practice [6]. In unilateral winding, plane spiral coil is used in most cases. The analysis shows that the DD shaped flat plate is used as the transmitting flat plate and installed on the ground. The DDQ or BP shaped flat plate is used as the receiving flat plate and installed on the vehicle chassis can achieve the most ideal charging effect [3].

2.2.2. Dynamic system

Dynamic charging means that the vehicle can be charged in motion, which enables the EVs to carry less battery packs, extend its range, and make the charging process more convenient. From the perspective of decoration, the transmission end is generally a fixed electrified track, which can also be composed of multi-section power supply tracks, namely centralized and segmented. However, due to the low transmission efficiency of centralized power supply track, which represents as the whole section of track must be cut off for maintenance during repair [13], more research is focused on segmented track and other new power supply tracks. There are some existing categories of dynamic wireless power transfer rail: Separate continuous single coil, rectangular long coil and double magnetic pole structure [14]. Due to the low magnetic field's exposure on the track, double magnetic

pole structure has high power density. Moreover, its structure is compact, which means that its construction difficulty is low. Solving the disturbance of the power source, literature [15-16] advanced a new three-phase AC excitation energy transmission rail that also improve the anti-offset capacity. However, this design still has the shortcoming of centralized track. At present, KAIST is in the leading position in the technology of magnetic coupling mechanism. For the segmented power supply rail, the paper [17] proposes a road type dynamic charging system based on the parallel mode of multiple primary windings, and the research shows that compared with the single primary winding, the power of the double primary winding is increased by 25% and the efficiency is increased by 27%.

3. Electric field coupling

Electric field coupling (Capacitive Power Transfer, CPT) is different from the IPT system. The CPT system uses a high-frequency electric field to transmit electrical energy, and the high-frequency electric field does not cause losses in the surrounding metal devices. Simultaneously, the CPT system can realize wireless power transmission only by relying on metal plates, which greatly saves costs, and at the same time overcomes the sensitivity of the IPT system to metal, making it more reliable and affordable. Compared with IPT technology, it can be widely used in metal-rich environments such as automobiles, factories and workshops in the future. Due to the many advantages of CPT, its research at home and abroad is being jointly carried out and gradually deepened. For example, in the aspect of electric vehicle charging, a four-pole plate CPT system structure for electric vehicle charging is proposed. When the distance between the coupling plates is 150mm, the transfer energy is 1.88kW, and the efficiency reaches 85.87%. However, since the CPT system works by supplying a very high high-frequency voltage to the emitter plate to excite the high-frequency electric field, the receiver plate located in the high-frequency electric field induces a displacement current to achieve energy transfer, which will cause the coupling structure to be extremely polar. Very high voltages are generated on the board that can compromise system safety. At the same time, when the CPT system uses the high-frequency electric field generated by the coupling plate for power supply, due to the parasitic capacitance between the metal car shell and the coupling plate, a high-frequency voltage will be generated in the high-frequency electric field. Injury to the human body and cause serious safety problems. Thus, the study on the induced voltage of body-shell, which is aimed at advancing a method to decrease the induced voltage has practical value. This study is the guarantee of the safe work of CPT system.

3.1. Analysis of the basic principles of CPT

The basic principle of CPT The CPT system coupler is composed of 4 aluminium plates, of which the A and D aluminium plates are the power supply side, placed on the ground; the B and C aluminium plates are the electric vehicle side, placed on the electric vehicle chassis bottom. The primary-side rectifier and inverter module are equivalent to a high-frequency power supply, and the DC load is the electric source of EVs, which can be simplified as shown in Figure 5. Working principle: When the voltage on the plates A and D changes, the charge of the secondary side circuit will move directionally. If the plate A has a positive charge at this time, the plate D has a negative charge, which is determined by Coulomb. The law shows that plate B will be negatively charged, plate C will be positively charged, and the charge on the entire primary side and secondary side will remain constant. Therefore, when the polarity of the A board and the D board changes, the polarity of the B board and the C board will also change accordingly, then the B board and the C board are equivalent to a power supply working on the load, realizing the wireless transmission of energy [18].

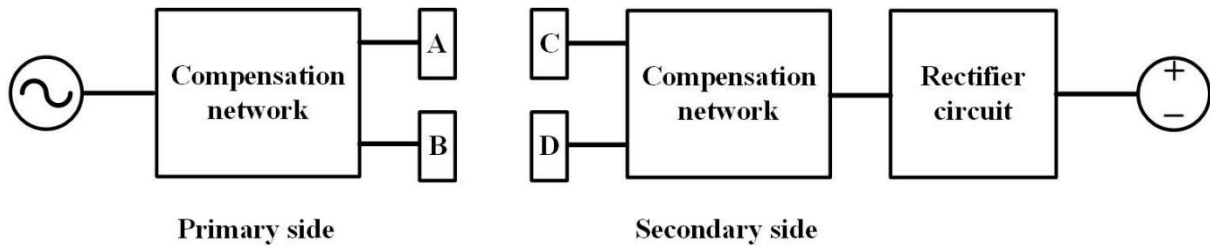


Figure 5. Principle of Capacitive Power Transfer

3.2. Electric field coupled wireless charging system for electric vehicles

A high-frequency inverter, a transmitting compensation circuit, a coupling circuit, a receiving compensation circuit, a high-frequency rectifier and a load, composes the CPT system for EVs. Among them, the coupling circuit is composed of four metal plates, and the receiving end on the electric vehicle and the transmitting end placed underground are composed of two plates, as shown in Figure 6. The high-frequency inverter in the picture converts the direct current into high-frequency alternating current and transmits it to the compensation circuit on the transmitter side. At this time, the receiving plates P3 and P4 placed at the bottom of the vehicle induce displacement current in the high-frequency alternating electric field, and the high-frequency rectifier converts the electrical energy into direct current after passing through the compensation circuit to provide a load at the receiving end for use [19].

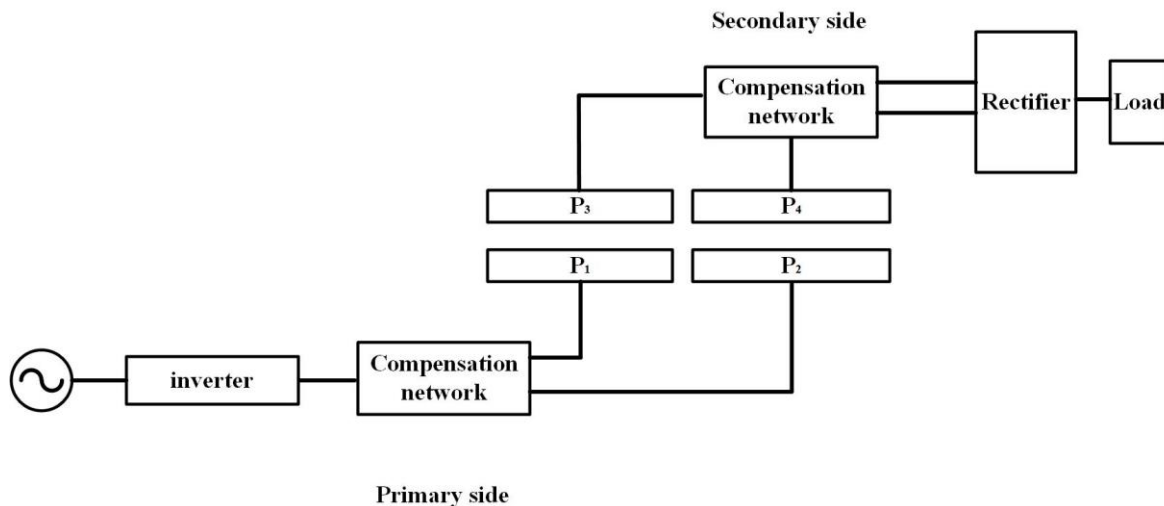


Figure 6. Topology of CPT system

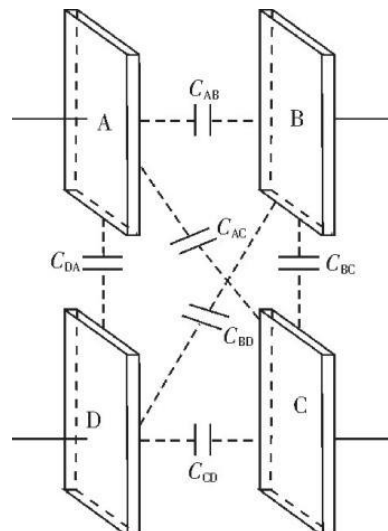


Figure 7. Distribution of parasitic capacitance between plates [18]

At the same time, there are parasitic capacitances between the four plates of P1 P2 P3 P4, as shown in Figure 7. Thus, the system transmission power can be expressed as [19]:

$$P_{out} = \frac{(1-k_c^2)\omega_c C_M}{k_c^2} |V_1| * |V_2| \quad (1)$$

Simplifying the system model will help us to see the rules more clearly, so it is necessary to conduct a simple analysis of the equivalent capacitance model of the coupling mechanism. The coupled plate can be equivalently reduced to a three-port network model. The equivalent three-port coupling plate is shown in Figure 8, in which the emitter plate can be equivalent to a transmitting port 1, and its port voltage is V_{C1} . Similarly, the receiving plate can be equivalent to a receiving port 2, and its port voltage is V_{C2} . In order to study the voltage between the car shell and the ground, an equivalent port 3 is also equivalent to between P5 and P6, and its port voltage is V_{C3} . Among them, C_1 , C_2 , and C_3 respectively represent the equivalent parallel capacitance of the three ports. I_{C1} is the current equivalent to the effect of ports 2 and 3 on the transmitting port 1, and I_{C2} is the equivalent effect of the ports 1 and 3 on the receiving port 2. The current, I_{C3} is the current equivalent to the effect of port 1 and port 2 on port 3. I_1 is the current received before the emitter plate, and I_2 is the current transmitted to the compensation circuit on the receiving side after the receiving plate. I_3 is the current between the envisaged car shell and ground.

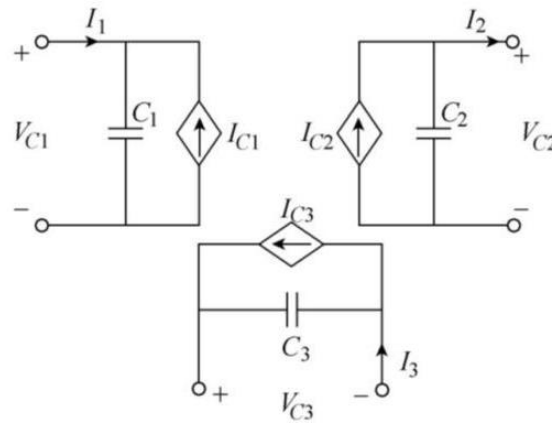


Figure 8. Schematic diagram of equivalent three ports of coupling plate

3.3. CPT system parameter optimization

According to the above analysis, in order to optimize the voltage on the simulated car shell and reduce it to the requirement of no harm to the human body, the design idea of the parameters of the optimization method is shown below

- (1) Select the plate spacing of the CPT system according to the project, and determine the corresponding parameters
- (2) Select the corresponding parameter V_{in} V_{out} P_{out}
- (3) Select the system frequency f
- (4) Determine whether f meets the requirements according to the formula

$$f \geq - \frac{P_{out} (C_2 C_{M13} + C_{M12} C_{M23}) (C_1 C_{M23} + C_{M12} C_{M13})}{69.72\pi (C_1 C_{M12} + C_{M13} C_{M23}) D} \quad (2)$$

$$C_p = \frac{\sqrt{-\frac{P_{out} D (C_1 M_{23} + C_{M12} C_{M13})}{\omega (C_2 C_{M13} + C_{M12} C_{M23}) (C_3 C_{M12} + C_{M13} C_{M23})}}}{V_{in}} \quad (3)$$

$$C_p = \frac{\sqrt{-\frac{P_{out} D (C_2 M_{13} + C_{M12} C_{M23})}{\omega (C_1 C_{M13} + C_{M12} C_{M13}) (C_3 C_{M12} + C_{M13} C_{M23})}}}{V_{out}} \quad (4)$$

(5) If the requirements are met, the C_p C_s capacitance value is calculated according to the formula: if it is not met, f is reselected according to the above formula

(6) Calculate the L_1 L_2 L_p L_s value according to the CLLC characteristics to complete the parameter design.

3.4. CPT main technical defects

Since the CPT technology uses electric field coupling, the intermediate medium is air, so the coupling capacitance is very small, usually only tens of pF, so energy transmission needs to be carried out in a high frequency state. The experimental difficulties of this system mainly focus on the design of high-frequency inverter and system compensation network. In the experiment, first of all, to reduce the power tube loss and increasing the frequency of the input current on the primary side, the high-frequency inverter is supposed to work in a high-frequency soft switching state; at the same time, a suitable compensation network is used to increase the inter-board voltage between the aluminum plates. , Under the action of high-voltage and high-frequency alternating current, the transmitting board forms an interactive electric field with the receiving board to form a displacement current, thereby realizing high-power transmission. In the follow-up research, the inverter frequency will be further increased, and a more suitable compensation network will be selected to enable the system to achieve kilowatt-level energy transmission [20].

4. Power electronic converters

In order to make the charging current close to the Mars curve, EVs use variable voltage intermittent charging mode [21]. In this case, to realize the energy stability control, the system mainly depends on the power electronic converter. As shown in figure 9:

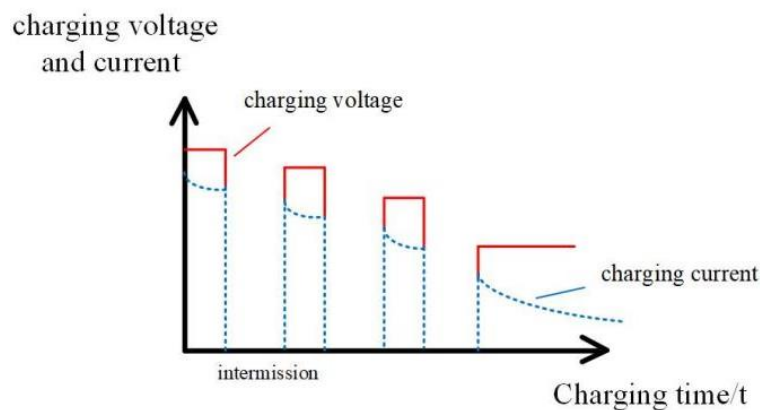


Figure 9. Voltage and current curve diagram of variable voltage intermittent charging [19]

But the background of the above discussion is not limited to automobile wireless charging. Therefore, considering the difference between wireless charging and wired charging, it is mainly reflected in power electronic control as follows: The former has a large air gap between the

transmitting end and the receiving end; The transmission coil works at high frequency circumstance; There is electrical isolation and information isolation between primary and secondary coils. At present, one-sided control and two-sided control are both the general method. The power electronic converter implementation method can generally be divided into DC-DC and AC-AC [22]. Accordingly, in addition to unidirectional transmission charging, there are also control methods for bidirectional transmission.

4.1. Uni-directional transfer

For most charging scenarios, EVs can only obtain power frequency AC. Therefore, for the high-frequency characteristics of vehicle wireless charging, the converter is required to convert 50 \ 60Hz AC into tens of kHz high-frequency AC. The general unidirectional transmission system is based on the control of DC-DC converter, as shown in Figure 10:

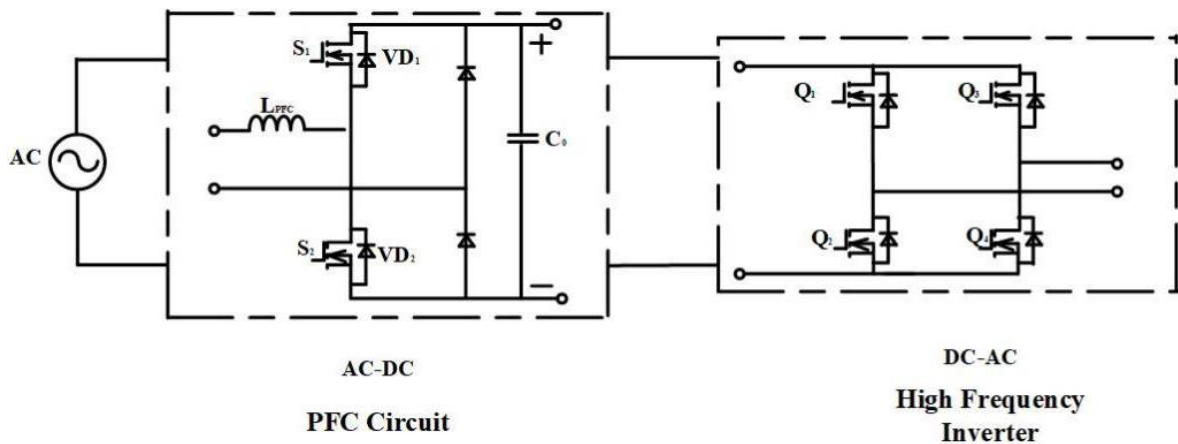


Figure 10. Block diagram of the AC-DC-AC converter for EVs

The working process is as follows: the low-frequency AC enters the high-frequency inverter after rectification and voltage regulation, and then is converted into high-frequency AC and enters the receiving side through the transmission coil. In addition, for the DC-DC converter, literature [21] proposed a kind of H_{∞} nonlinear controller and its parameter optimization. The research shows that the dynamic reflect speed of the system is rapid, the maximum steady-state voltage offset rate is 6.2% in the charging phase, and the dynamic response time can be controlled within 0.3 ms, which basically conforms to the Mars curve. DC-DC converter has become a research hot-spot because of its stable control and strong operability. However, since the control method adds one level of electric energy conversion, the efficiency decreases. Therefore, document [23] proposes an AC-AC converter to reduce switching devices and power loss, but at the zero-crossing point of the input power supply, the resonance current will be greatly reduced.

4.2. bi-directional transfer

Replacing the receiving end of the traditional one-way radio energy transmission system with an uncontrolled rectifier bridge to an H bridge, the typical structure of the bi-directional transmission system is obtained [24], as shown in Figure 11. Meanwhile, for the friendliness of the system to the power grid, a primary AC-DC converter is usually added between the sending side and the power grid to achieve power factor control (PFC) and energy feedback.

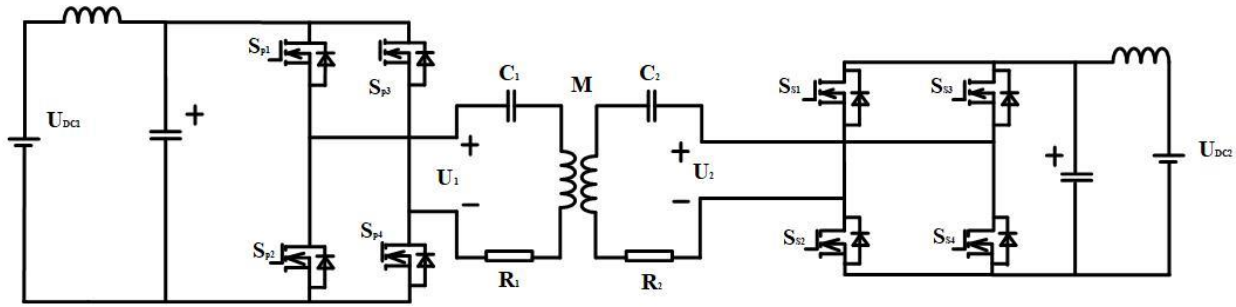


Figure 11. Topology of the BWPT system [22]

Because the bi-directional transmission system is more complex, its variable control, topology circuit and mathematical model are different from the uni-directional transmission system. Literature [10] has analysed three compensation topologies of the bidirectional transmission system. Compared with uni-directional transmission system, bi-directional transmission system is more sensitive to system parameters and control variables, the corresponding control is more complex, and needs better robustness and adaptability.

5. Foreign object detection and bio-security

Because of the special working circumstance of wireless charging system for EVs, the foreign object, especially metal object, is a potential risk. Experiments show that a coin placed in the car wireless charging system will be heated quickly due to the eddy current effect, and its temperature after 2 minutes is enough to ignite most flammable objects in life [25]. In addition, because the EVs wireless charging system works at high frequencies, the electrical energy and field energy are continuously alternately transformed, and the high frequency oscillating electromagnetic field is triggered in its periphery [6]. Thus, the level of electromagnetic radiation has an impact on biological safety is very important for the popularization and application of this technology.

5.1. Foreign object detection

A foreign object is defined as any object that is located on the primary or secondary equipment, and it is neither part of an electric vehicle nor part of its wireless charging position [26]. Living object, and metal object are the major categories of foreign object in WPT system [27]. For metal object that enter the system will relieve massive heat, which can be detected by temperature sensor or thermistor. In addition, the pressure sensor can also find the metal foreign matter through deformation. The above method can be generally referred to as the sensor detection method. Its advantages are that there is no limitation by the power level, operating frequency and operating state of the WPT system, and is no effect by the offset between the energy primary and secondary coils [28]. However, since the accuracy of the sensor needs to be improved and other non-metallic foreign matters may trigger the sensor, other detection methods have emerged. According to the current research, an inductance detection coil added in the WPT system of electric vehicles can detect metal matters by the change of coil impedance or the change of open circuit voltage [29]. As shown in Figure 12, the metal object in the coil will affect the equivalent input impedance of the coil.

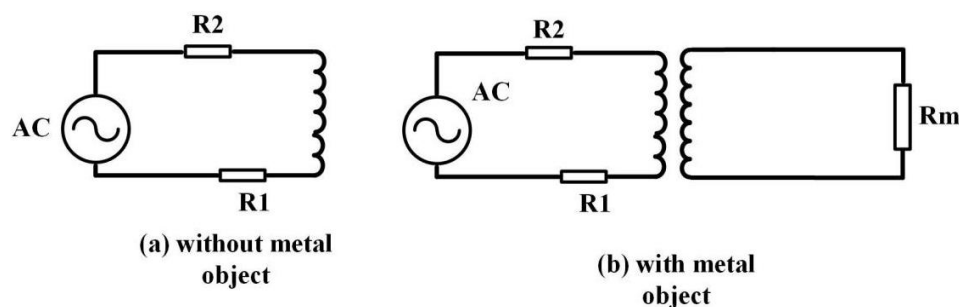


Figure 12. Spiral inductor coils equivalent circuit with metal object(b) or without metal object(a)

Based on this principle, literature [29] proposed a balanced coil method foreign object detection system and its corresponding algorithm. This medium has a good effect on the detection of small foreign matters, such as paper clips or coins. At the same time, so as to solve the cross disturbance between the power fluctuation and the introduction of foreign matters, the detection decision quantity is taken as a new observation, and its dispersion coefficient is calculated. When the dispersion coefficient is large, it indicates that it is affected by metal foreign matters; on the contrary, there is only the influence of power fluctuation. For LOD, the organism can be used as a dielectric. When the organism enters the detection coil, it is equivalent to that the stray capacitance of the coil to the ground is increased [30]. Literature [30] has carried out modeling calculation for the situation when the organism enters the detection coil, and it shows that the organism will reduce the coil impedance. In addition, in addition to coil detection, literature [27] also summarizes other studies on detection methods of biological foreign bodies. The radar sensor is mainly used to detect the distance and speed information to determine whether there is a living body entering the charging area.

5.2. Bio-security

The principle of FR electromagnetic exposure can be limited by specific absorption rate (SAR) whereby the physiological reflect of human body determines its range. SAR can be express as the electromagnetic power absorbed by biological tissue per unit mass. SAR is defined as [31]:

$$SAR = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left(\frac{dW}{\rho dV} \right) \quad (5)$$

Since it is difficult to directly measure the power parameters, the SAR value of an organism can be calculated using the following equivalent formula [32]:

$$SAR = \frac{\sigma}{\rho} |E|^2 \quad (6)$$

For the different positions of the human body in the vehicle, the SAR value also changes correspondingly. At the same time, corresponding to different organs of the human body, the relevant parameters also have different settings. Literature [31] analyzed the SAR values and other relevant physical quantities of different positions and organs of the human body at 85kHz. According to the data comparison [31], the electromagnetic environment has more obvious effects on the lungs, heart and kidney, but all meet the minimum safety indicators. In addition, with the improvement of medical level, cardiac pacemaker has become a routine treatment. Therefore, medical implant devices inside the human body should also be analyzed accordingly [32]. Moreover, the bio-security analysis should also be performed for electric ambulances that may be promoted in the future to ensure safety in use [33].

6. Future research

Table 1. Comparison between different WPT technologies

WPT Technology	Advantages of Application	Disadvantages of application
Magnetically coupled resonant WPT	(1) Provides high power transmission at KW level (2) Mature technology has entered the commercialization stage (3) High transmission capacity	(1) High power applications require more equipment (2) Higher manufacturing costs (3) The coupling mechanism occupies a large space, and the coil has obvious heat (4) This method does not penetrate metal propagation
Electric field coupled WPT	(1) Lower cost for energy transfer using metal plates (2) No control of electromagnetic interference EMI (3) This method can penetrate metal propagation (4) Coupling mechanism occupies less space and generates less heat	(1) Energy transfer efficiency depends greatly on the gap size (2) Wireless energy transmission is destructive to the transmission channel (3) Electric field leaks cause more damage to humans and have greater danger

The comparison between various WPT technologies is summarized in Table 1. Due to the low charging efficiency, the charging distance of various WPT charging methods is the nearest charging, and the cruising distance is one of the obstacles for the development of new energy vehicles. Dynamic wireless charging allows electric vehicles to carry a smaller capacity battery, which can continue to provide energy for the car. Not affected by bad weather, whether the maintenance costs are too high, relatively large investment, static wireless charging is more flexible. Therefore, the static wireless charging is more advantageous [34].

Research status of static electric vehicle wireless charging technology at home and abroad. It can be seen that the technology has been fully researched in each charging mode, whether there are still a number of problems that need to be solved. They are mainly in the following aspects:

Structural optimization problem of the system. The traditional electric vehicle wireless charging structure is mostly AC-DC-AC converter, etc. In order to reduce the cost and volume of the charging system to improve the efficiency. Therefore, by optimizing the system structure, improving the control strategy, optimizing the control algorithm, reconstructing the compensation network, and by improving the relationship between the main coil and the compensation coil by using a new structure, such as the new bilateral LCC compensation topology [35], which will help to contribute to overall system performance. The optimal distance between two coils, as well as the winding and arrangement of the coils, can be found to improve transmission efficiency.

Wireless charging standard setting. There are four national standards. But the more mature commercialization of wireless charging system technology and the longer-term use and promotion require Unification of standards and continuous improvement of compatibility between standards, to achieve unification of standards in order to achieve unification of the market, and gradually improve the development of wireless charging system standards is a necessary task for commercial development.

The establishment of the system dynamic model and topology improvement. Such as high-performance coupling mechanism design problems, energy transfer robust control problems, etc. Most contactless charging systems are based on steady-state models and do not include analysis of transients and non-linear system characteristics; the mathematical model of the WPT system has been improved to create an accurate dynamic system model that allows analysis of the relationship between system output voltage and system parameters. The study of low impedance matching topology, coil

structure coordination and control methods is a promising area of research, as it improves the stability of the system. [36].

System safety protection problem. Such as when a foreign body appears between the coils of the wireless charging system, which will cause the temperature of the end plate to rise. It can easily cause fire hazards, which can be detected through the development of thermal imaging technology, microwave radar technology, thermocouple technology, image recognition technology, etc. However, the current detection range, detection accuracy, cost and the cost of maintenance are unstable and require continuous development before they can be put into future commercialization.

Environmental protection utilization of automotive electric energy. The intelligent management of electric energy is realized through the in-depth application of computer and automation technologies in the smart grid [37], and the secondary utilization of renewable energy and power sources is explored through the in-depth development of scheduling, automation, and flexible transmission technologies. Such as maintaining the efficient utilization of electric energy through reverse electric energy input to the user's home during the peak period of power consumption in the grid.

Accurate positioning of the charging system the position of the transmitter coil and the receiver coil plays a key role in the transmission power and charging efficiency of the wireless charging system, and is very sensitive. If the position deviation of the coils will substantially affect the transmission power and charging efficiency. Exploring new charging performance detection sensors can solve the problems of coil misalignment and foreign impurities that affect charging efficiency, such as through TMR sensor matrix [38], which can be applied to stationary and dynamic WPT, which has a broad application prospect.

7. Conclusion

This paper reviews the current state of development of electric field coupled and magnetic field coupled wireless charging technology for electric vehicles, and also suggests directions for its current shortcomings, and organizes and analyzes future development methods and optimization approaches. The first part is a technical review of magnetic induction wireless charging technology in two aspects: (1) compensation topology and (2) coil design design. The technological advances have improved the system performance, but to improve the energy conversion efficiency should also be studied such as higher-order networks and high network circuits to optimize the structure of two-way wireless transmission systems. The second part is a technical review of electric field coupled wireless charging technology in two aspects: (1) the advantages and disadvantages of capacitive WPT charging technology; (2) the control methods of power electronic converters and an analysis of how to improve the overall transmission efficiency. The third part is a technical review of wireless charging technologies in terms of safety: (1) foreign object detection; (2) biosafety. At this stage there is still a need to find breakthroughs regarding both composite shielding and radiation reduction methods. The fourth section provides a summary of the limitations and future directions of wireless charging technology. Both technologies are currently commercialized, but more research by scholars is needed before they can be fully operational, develop a systematic approach to parameter design, and reduce costs. The wireless charging technology for electric vehicles is being studied in depth, and it is expected that the technology will be widely used in the near future and will facilitate the commercialization of electric vehicles and achieve the dual carbon goal.

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