Research on Application and Development of Key Technologies of Dynamic Wireless Charging System in New Intelligent Transportation System

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Abstract. With the development of electronic science and technology, Intelligent Transportation has entered a new stage. In recent years, IOT (Internet of Things) technology has brought many impacts on people's daily life and social development. IOV (Internet of Vehicle) technology is an important application of IOT technology in Intelligent Transportation System. The rapid development of IOV technology provides a guarantee for Intelligent Transportation. Therefore, accelerating the landing of IOV has a profound impact on the development of new Intelligent Transportation. Dynamic wireless charging technology has become one of the five cutting-edge technologies to accelerate the landing of IOV. Firstly, the article introduces the new Intelligent Transportation System and its key technology. Then the article analyzes the advantages of wireless charging and the composition of wireless energy transmission system. Finally, the article introduces the composition of the dynamic wireless charging system on electric vehicles, the application and development of dynamic wireless charging key technology in new Intelligent Transportation.

Keywords: Intelligent Transportation · Internet of Vehicle · Wireless charging · Wireless energy transmission · Electric vehicle

1 Introduction

In recent years, China's economy has risen rapidly, and people's material living standard has improved sharply, automobiles have become the most common vehicles. However, many problems has followed. Such as traffic safety, traffic congestion and transportation efficiency. All of them have tested the ability of city managers. In this context, the role of Intelligent Transportation Systems is particularly important. With the advancement of modern science and technology, new Intelligent Transportation System has seen some initial achievements. The Internet of Things technology has brought many impacts on people's daily life and social development. The Internet of Vehicles technology is an important application of Internet of Things technology in

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Intelligent Transportation systems. The gradual replacement of traditional energy sources by new energy sources is an important trend in the future. The advantages of electric vehicles are becoming more and more prominent. Therefore, electric vehicles have become an important direction for the development of the automobile industry. However, the inconvenience of charging hinders the development and popularization of electric vehicles seriously. Conventional charging devices have disadvantages, such as poor operability, low safety, and large floor space, which largely limit the large-scale promotion of electric vehicles. In contrast, wireless charging technology can solve the interface limitation problem and security problem faced by traditional conductive charging. Wireless charging technology gradually becomes the main charging way of electric vehicles. However, static wireless charging and wired charging both have the problems of frequent charging and short range. Continuous endurance is very important for public transportation vehicles such as electric buses. In this context, the dynamic wireless charging technology of electric vehicles emerges as the times require, it provides real-time energy supply for the running electric vehicles through non-contact way. Dynamic wireless charging technology has become one of the five cutting-edge technologies to accelerate the landing of IOV. The key technology of dynamic wireless charging has strong research value and broad application prospects in the new Intelligent Transportation.

2 New Generation of Intelligent Transportation and Key Technologies

Intelligent Transportation System, also called Intelligent Transportation System, integrates information technology, data communication technology, electronic control technology and computer technology into the transportation system. It strengthens the relationship among vehicles, roads and person, and it promotes safe and efficient integrated transport system. The Intelligent Transportation system meets the growing demand for public travel and material transportation by creating a transportation system that is fair, efficient, safe, convenient and environmental.

Intelligent Transportation is the hotspot and frontier of the world's transportation development. And Intelligent Transportation is the development direction of the future transportation system. With the continuous innovation of electronic information technology, Intelligent Transportation will enter a new stage. The new Intelligent Transportation effectively integrates IOT, big data, cloud computing, artificial intelligence, sensors, data communication, electronic control, operations research, and automatic control technology into transportation management system. It could strengthen the connection among vehicles, roads and users. Thus it forms an Integrated Transportation System that guarantees safety, upgrades efficiency, improves environment, and saves energy. It establishes all-round function, a real-time, accurate and efficient integrated transportation management system [1].

The new Intelligent Transportation needs to be able to support integrated transportation; it needs the new generation of intelligent infrastructure, including traffic sensor networks, new generation communication systems, new energy distribution systems for extended roads, and many other technical facilities; it needs low-carbon and smart transportation tools; it needs services and management systems that require openness, sharing and coordination; it needs intelligent decision systems based on big data. Therefore, the overall framework of new Intelligent Transportation will take three systems (Intelligent Transportation Service System, Intelligent Transportation Management System and Intelligent Decision Support System), two support technology (Intelligent Transportation Infrastructure, Standards and Technology), and one environment standard (loose and ordered development environment) as the main content of development. Meanwhile new Intelligent Transportation covers the field of urban transportation, roads, railways, aviation, and water transportation. The overall framework of new Intelligent Transportation not only makes arrangements for the development and application of Intelligent Transportation systems, but also promotes the development of Intelligent Transportation advanced technologies and support of emerging strategic industries. Such as new national traffic control networks, cooperative vehicle infrastructure, intelligent vehicle, automatic train operation, integrated hub coordination, high-speed broadband wireless interconnection and high-speed wireless LAN (Local area network). At present, new technologies such as cloud computing, big data, and mobile internet are widely used in the fields of cooperative vehicle infrastructure systems, public travel convenience services, IOT, IOV, driverless, and electric vehicles. The electrification, intelligence and networking of vehicles have become the technological trend of the next Intelligent Transportation System [2, 3].

Besides the Internet and the Internet of Things, Internet of Vehicles becomes another important symbol of the future smart city. Internet of Vehicle is based on the intra-vehicle network, inter-vehicle network and vehicle mobile Internet. According to the agreed communication protocol and data interaction standard, it is a large system network for wireless communication and information exchange between vehicles and X (X: vehicles, roads, pedestrians and the Internet, etc.). It is an integrated network that can achieve intelligent traffic management, intelligent dynamic information service and vehicle intelligent control. It is a typical application of Internet of Things technology in the field of transportation. Internet of Vehicle can realize information sharing and collect information about vehicles, roads and environment through interconnection of vehicle and vehicle, vehicle and people, vehicle and road interconnection. Then it can process, calculate, share and publish collected multi-source data on the information network platform. In addition it can release effective guidance and supervision of vehicles according to different functional requirements, and provide application services of professional multimedia and mobile Internet. Internet of Vehicle technology provides a powerful guarantee for Intelligent Transportation. Accelerating the landing of Internet of Vehicle is significant for accelerating the development of Intelligent Transportation [4]. Five cutting-edge technologies for accelerating Internet of Vehicle include WIFI connection, smart bluetooth, NFC (Near Field Communication), wireless charging, and ethernet security. Driverless technology, wireless charging technology, and intelligent parking technology have been called "Iron riangle" of the future Intelligent Transportation. In a broader perspective, driverless technology is still one of the core components of Intelligent Transportation in the future. The real landing of unmanned driving still requires the support of two other core technologies to jointly construct a complete Intelligent Transportation Ecosystem. One is smart parking technology and the other is wireless charging technology.

3 Electric Car Dynamic Wireless Charging Technology

3.1 Advantages of Wireless Charging Technology

At present, there are two main charging methods for electric vehicles. One is wired charging, which is also called contact charging. Wired charging includes fast charging mode and slow charging mode. The other is wireless charging, which is also called non-contact charging. In the new Intelligent Transportation, wireless charging technology has obvious advantages over wired charging technology.

A comparison of the three charging techniques is shown in Table 1 below. From the Table 1, whether applied to smart devices or other fields, wireless charging technology has obvious advantages over wireless charging technology, which is the main direction of future development (See Table 1).

Table 1. A comparison of the three charging techniques.

Charging mode	Principle	Advantage	Disadvantage
Wired slow charge [5]	The wired slow charging mode generally uses a single-phase 220 V/16 A AC (Alternating Current) power supply. It uses a small AC current to charge a small power for a long time by the charger. Charging time is generally 6 h to 10 h	1. It could reduce cost of charging 2. It could improve charging efficiency 3. It could extend service the life of batteries	1. It is difficult to meet the user's demands of emergency charging and long-distance driving 2. Charging time is long
Wired fast charge [6–8]	The wired fast charging mode generally uses direct current mode with a large current of 150 A to 400 A. Charging time is about 20 min to 2 h	1. It can meet the user's demands of long-time and long-distance driving 2. Charging time is short	1. The high current charging has a negative impact on performance and life of batteries 2. It has a certain impact on the power grid
Wireless charging [9, 10]	The wireless charging is no need the cables to energy transfer. In the wireless charging mode, it need install a vehicle inductive charger on the car	1. It does not need the cables. It uses Conveniently and safely 2. It is conducive to the uniformity of multiple interface standards 3. It could adapt to a variety of harsh environments and weather	1. Equipment charges and maintenance charges are higher 2. Energy loss is relative high. The efficiency of wireless charging needs to be improved

3.2 Dynamic Wireless Charging Technology

Wireless charging technology is derived from radio power transmission technology which is also called wireless energy transmission or radio energy transmission. Wireless energy transfer technology is a new energy transfer technology that can be used to take power from a fixed grid in a non-contact manner with electrical equipment. The wireless energy transfer system is mainly composed of an energy emitting part and an energy receiving part. The transmitting part comprises a grid power supply, a rectifying circuit, a high frequency inverter circuit and a transmitting coil. The receiving part includes a receiving coil, a high frequency rectifying circuit, a load and so on [11]. The Fig. 1 shows a structural topology diagram of wireless energy transfer system (See Fig. 1).

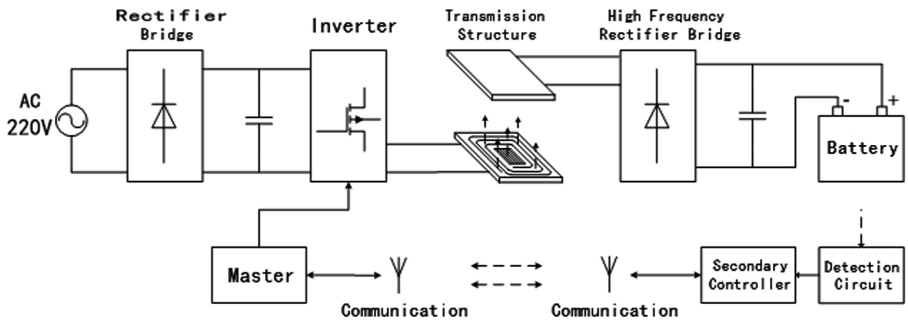

Fig. 1. Structure topology of wireless energy transmission system.

Wireless energy transmission system usually includes inductive energy transmission system and magnetically coupled resonant energy transmission system. The magnetically coupled resonant wireless energy transmission technology uses magnetic near-field coupled resonance mechanism with a wide operating frequency. At the same time, it has a large quality factor Q. Compared with the inductive type, the magnetic coupling type has a longer transmission distance, damage of magnetic coupling type is smaller, so magnetic coupling type is more suitable for dynamic wireless charging of electric vehicles [12]. In the electric vehicle wireless charging system, the most important is the design of the coil coupling structure, which affects the efficiency of the system, anti-offset capability and so on. In the design of the coupling mechanism, high permeability materials are often required to increase the coupling coefficient. Because of the cost, the current scheme mostly uses skeleton-type magnetic cores, including the thin U-shaped, I-type, monorail-type and double-track type of KAIST (Korea Advanced Institute of Science and Technology) of Korea, and the skeleton disc shape of the American Oak Ridge National Laboratory. The structural design of the magnetic core is closely related to the coupling parameter adaptability, magnetic shielding performance, and system cost. In terms of wireless energy transmission system communication problems, Oak Ridge National Laboratory of the United States advocates adopting Internet of vehicle protocol DSRC (Dedicated Short Range Communications) that meets the requirements of US Department of Transportation, and solves the problem of transmitter/receiver offset in wireless charging by communication closed loop.

The important application of wireless charging technology in the field of Intelligent Transportation is mainly to charge electric vehicles. The traditional charging mode limits the development of electric vehicles. Wireless charging technology overcomes the shortcomings of traditional charging technology. The charging device can be installed in a parking space underground or on a wall. No exposed interfaces also prevents the risk of electric shock. Moreover, there is no safety requirement for the plug-in interface, and there are no problems such as mechanical loss or contact loss, which makes the manufacture and maintenance of the charger simpler and cost significantly reduced. But even with wireless charging technology, electric vehicles still have problems such as low battery energy density, short cruising distance, high cost, heavy equipment, and frequent charging. In this context, wireless charging emerges as the times require. The battery is charged in a non-contact way during driving, and the electric energy is supplied in real time. The electric vehicle can be equipped with a fewer batteries, effectively improving the convenience of electric energy supply, and significantly increasing the durability of the electric vehicle [13].

Dynamic charging, that is, charging in the course of driving, can reduce the capacity of on-board batteries and vehicle quality. The dynamic wireless charging technology of electric vehicles mainly includes two types: magnetic coupling type and electromagnetic induction type.

The electric vehicle wireless power supply system consists of two parts: the transmitting part and the receiving part. The transmitting part is composed of a power conversion device, an electromagnetic coupling mechanism, and a power conversion device on the vehicle [14]. The specific system structure is shown in Fig. 2. AC power (AC-DC-AC change) is generated by powering from the grid, rectification, filtering, voltage regulation, and inverter. The energy is transmitted by the magnetic coupling mechanism, and the receiving part supplies the received alternating current (AC-DC) to the electric vehicle.

The wireless power supply system for electric vehicles should ensure that the electric vehicles transmit energy at a certain distance from the ground. The wireless power supply system consists of two subsystems: one system is road system, another system is road surface system. Road system is used for transmitting energy, which includes a rectifier, a high frequency inverter, a primary matching capacitor bank, and a functional rail. Road surface system is used for receiving energy, including receiving coils, secondary matching capacitors and rectifiers. Road system should have strong stability and a low enough price to withstand the harsh road environment. At the same time, the road surface system should have a smaller size and a lighter weight for installation on an electric vehicle.

In summary, the problems that need to be researched in the dynamic wireless charging technology of electric vehicles are as follows:

1. Electromagnetic compatibility: Electromagnetic compatibility problems are closely related to the quality of energy transmission, the electromagnetic interference to the system and the impact on the human body. Only by effectively solving the EMC problems, can the system operate safely, reliably and stably.

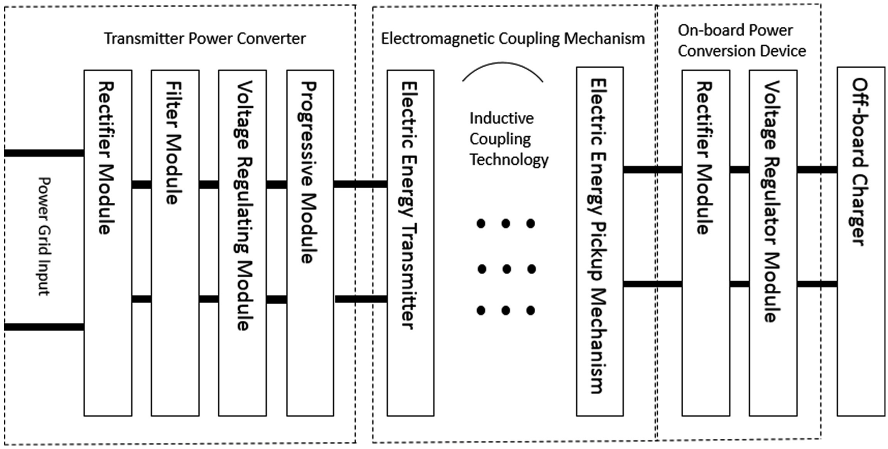

Fig. 2. Structure diagram of electric vehicle wireless power supply system.

2. Robust control of energy transfer: In the dynamic wireless power supply system of bipolar power supply guide rail, energy transfer is in a fast non-linear process, so the stability and response speed of the dynamic wireless power supply system are very important.
3. Coil design: The coil coupling structure is a key issue in the wireless charging system. The excellent coil structure has higher efficiency, lower electromagnetic radiation, and it can also reduce the cost of the power supply track.
4. Power supply efficiency: From the AC power supply to the DC output of the battery, the power supply efficiency determines the competitiveness of electric vehicles and traditional vehicles.
5. Electromagnetic shielding: The dynamic wireless power supply system has a long transmitting terminal and the road must be open, so the magnetic field limitation problem becomes more serious.
6. Power supply track segmentation and road construction: Power supply track segmentation can improve safety and stability, which is easy to maintain. Therefore, it is necessary to consider the track segmentation, control method, and reduce its impact on traffic during road construction.

4 Application and Development of Key Technologies for Dynamic Wireless Charging of Electric Vehicles

From the application and development history of wireless charging technology, the research on wireless charging theory is relatively deep and mature, and there are many practical applications and a few commercial products. At present, the leading countries in the field of dynamic wireless charging on electric vehicles are United States, New Zealand, Germany, Korea, Japan and other countries [15–17].

The University of Auckland in New Zealand worked with the German company Wampfler AG to develop the world's first wireless charging bus in 1997. The underground pavement of bus stop is equipped with 80 A and the radiat with working frequency of 13 kHz. The bus is equipped with ten receiving terminals, which charging power is 30 kW and charging current reaches 250 A. The bus has been operated in the Rotorua Geothermal Park in New Zealand, it effectively overcomes the harsh natural environment of the region. At the same time, Wampfler AG has also developed a 100 kW dynamic wireless power train prototype. The train track is 400 m long. Because of the dynamic power supply, the battery pack is no longer installed on the train. The University of Auckland has also conducted a series of research on the design of coupling mechanisms. In 2010, a double-sided coil consisting of a rectangular core plate and a vertically coiled cable was proposed. Later, a single-sided polarized coil composed of a horizontally wound cable on a magnetic core plate and a double-D-Quadrature (DDQ) pick-up coil structure was proposed [18].

The Oak Ridge National Laboratory of the United States has researched the transmission characteristics and dielectric loss during dynamic wireless charging of electric vehicles. The ground transmitting end is a series connection of two transmitting coils. The research shows that the transmission power and efficiency are greatly affected by the position of electric vehicle. It is necessary to adjust the frequency through the closed loop of 2.4 Ghz communication in order to adapt to the position change [19]. Zeliko Pantic's group of North Carolina State University in the United States has researched the dynamic wireless charging technology of electric vehicles powered by battery and super capacitors, and they discussed the application prospects of this technology in the field of urban transportation. Their research is also based on inductively coupled power transfer technology [20]. In 2013, Professor Chris Mi's team in University of Michigan has achieved radio power transmission at 2 kW to 6 kW with efficiency of over 94%, and the working frequency of the system is less than 200 kHz, which is very suitable for wireless charging of electric vehicles [21]. Stanford University has developed a mobile charging system for electric vehicles, which can charge while driving. The wireless charging efficiency could reach 97% [22].

Germany's VAHLE has developed CPS (Contactless Power Systems) since the end of the 20th century, and then VAHLE has published non-contact power access solutions and related products for ground transportation lines, electric monorail driving systems and transport vehicles. The power capacity of VAHLE's conventional power acquisition device is 500 W to 3 kW, but it is for high-power equipment. Their newly developed special power acquisition device has a single power capacity of 100 kW. It has been successfully operated in Bombardier's train test line.

The KAIST has conducted a lot of research on dynamic wireless charging technology for electric vehicles in recent years, and this kind of electric vehicles based on electric wireless power technology is called OLEV (Online Electric Vehicles). Their research focuses on the design of electromagnetic coupling mechanism and electromagnetic field shielding. Since the first generation was released in February 2009, the generations of OLEV related parameters that Korea has introduced are shown in Fig. 3.

Related parameters of OLEV in Korea						
	1G	2G	3G	3'G	3'G	4G
Vehicle	Car	Bus	SUV	Bus	Train	Bus
Date	Feb.27,2009	July. 14,2009	Aug.14,2009	Jan.31,2010	Mar.9,2010	2010-(under development)
System Spec.	air-gap=1cm efficiency=80%	air-gap=17cm efficiency=72%	air-gap=17cm efficiency=71%	air-gap=20cm efficiency=83%	air-gap=12cm efficiency=74%	air-gap=20cm efficiency=80%
EMF	10mG	51mG	50mG	50mG	50mG	<10mG
Power Rail Width	20cm	140cm	80cm	80cm	80cm	10cm
Pick-up Power	3KW/pick-up	6KW/pick-up	15KW/pick-up	15KW/pick-up	15KW/pick-up	25KW/pick-up
Pick-up Weight	20kg	80 kg	110 kg	110 kg	110 kg	80 kg
Size	55*18*4cm	160*60*11cm	170*80*8cm	170*80*8cm	170*80*8cm	80*100*8cm
All the efficiencies are measured by AC grid voltage to on-board battery terminals.						

Fig. 3. Related parameters of OLEV in Korea.

The first generation of OLEV uses an E-type core with an efficiency of 80% at an air gap of 1 cm. The efficiency decreases with the increase of the air gap, and the efficiency drops sharply with the offset of the receiving terminal. However, it has successfully confirmed the possibility of wireless power supply for electric vehicles. The second generation of OLEV uses a thin U-shaped core that increases the transmission distance from 1 cm to 17 cm and increases the offset tolerance. The third generation of OLEV uses a skeleton core arrangement that enhances compression resistance and reduces cost. The fourth generation of OLEV uses an innovative I-structure power supply track. The receiving coil has a power of 25 kW and a side shifting capability of 24 cm. At the same time, the I-type power supply track is only 10 cm wide, which greatly reduces the cost. In 2012, KAIST has researched two structures of monorail and dual-track. The dual-track divides the magnetic circuit into two parts, making it less susceptible to magnetic saturation. To achieve the same effect, the monorail must have double thickness. But the monorail type can obtain a larger amount of side shift. At present, Korea OLEV mainly adopts dual-track structure. In 2015, the Korean Academy of Higher Science and Technology established a 12 km long dynamic power supply demonstration project for electric buses driving on the road in Yuwei City of South Korea. In the field of wireless power supply technology for railway trains, the KRRI (Korea Railway Research Institute) has researched the whole wireless power supply system for railway trains, and made an experimental device with power of 1 MW and track length of 128M. The coupling mechanism adopts a long straight guide rail at the launching end and enhances the coupling performance by two small U-shaped magnetic cores. Because the track is longer and the inductance is larger, in order to reduce the voltage stress of capacitance, the capacitance is dispersed in the radiation coil [23].

Japan's Toyohashi University of Science and Technology and Ulsan University of Science and Technology in Korea has researched the electric field-coupled electric vehicle dynamic wireless power supply technology, which is coupled to the transmitter end buried in the ground through the receiving end of the wheel. Compared with the magnetic energy coupling of magnetic field coupling, the electric field coupled magnetic field radiation is small, the structure is simpler, the impedance matching is easier, and the dielectric constant of the tire is higher than air, which can improve the transmission efficiency and distance [24]. In 2011, the University of Tokyo in Japan worked with Nagano has developed a contactless power transmission system based on the principle of electromagnetic resonance. Compared with electromagnetic induction transmission system, it has a longer transmission distance and a slightly lower transmission power and efficiency [25].

Research on wireless charging theory in China is relatively late, but universities and institutes in China have researched on technology and application of wireless power transmission.

In October 2011, the "Key Technologies and Application Prospects of Radio Power Transmission" Academic Salon funded by the Chinese Association of Science and Technology was held in Tianjin University of Technology, which was the first academic conference in the field of radio power transmission in China. Subsequently, many academic conferences in the field of radio power transmission were held in China (See Table 2), showing the good development trend and prospects of radio power transmission technology in China [18, 26].

Table 2. A comparison of the three charging techniques.

Conference date	Conference place	Conference topic
In 2011	Tianjin	Key Technologies and Application Prospects of Radio Power Transmission
In 2012	Chongqing	Seminar on Radio Power Transmission Technology
In 2013	Guiyang	Symposium on Key Technologies and Applications of Radio Power Transmission
In 2014	Nanjing	International Symposium on Radio Power Transmission Technology and Applications
In 2015	Wuhan	Academic Conference on Radio Power Transmission Technology and Applications
In 2017	Chongqing	International Symposium on Radio Power Transmission

5 Conclusion

This paper introduces the application and development of dynamic wireless charging technology in the context of a new generation of Intelligent Transportation. With the popularity of electric vehicles, dynamic wireless charging technology has paid more and more attention in the world. The research on dynamic wireless charging technology of electric vehicles is still in the stage of continuous development and improvement, but in the near future, electric vehicles on highways will automatically receive power supply from the road surface below. The new Intelligent Transportation is coming.

Dynamic wireless charging technology can not only provide key supporting technologies for Intelligent Transportation, but also promote the development of Intelligent Transportation.

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