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Opportunities and Challenges for Wireless Power Transfer System

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Abstract. "In truth, WPT has at least 30 years of history with the term "IPT," using the same fundamental tenet that has already been established. The development of WPT technology has recently accelerated, with transmission distances at the kilowatt power level ranging from a few millimeters up to several hundred millimeters and a point loading efficiency of more than 90%, which applies to both static and dynamic charging environments. Due to this, WPT is particularly appealing for electric vehicles (EVs). However, the performance of wireless power transfer (WPT) systems in various WPT applications remains a significant design challenge. While the use of plug-in electric vehicles (PEVs) is growing, a technological advance is needed to address battery-related flaws. Even if battery technology is improving, the key growth barriers for EVs will continue to be price, dimensions, weight, delayed charge features, and low energy density. Additionally, many customers may not embrace PEVs as their preferred choice due to concerns about price. Dynamic wireless power transfer (DWPT)-enabled EVs have been offered as a solution to battery-related restrictions. The dynamic EV charging concept should be implemented using a WPT-capable infrastructure. As less energy storage is needed for operating the car wirelessly while driving, a battery pack can be lighter. WPT fixed charging refers to wirelessly charging the EV while it is parked, which is less complex in terms of design than dynamic WPT. In contrast to plug-in EVs, ordinary WPT does not extend the driving range of the vehicle. This chapter discusses cutting-edge WPT technology for future transportation and introduces performance indices for the WPT system."

Key words: Wireless power transfer, Dynamic EV Charging, Stationary EV Charging, Electric Vehicles

1. Introduction

The electrification of transportation has been ongoing for several years due to various reasons, including energy, environmental, and other considerations. Railway networks have had well-developed electric locomotives for many years, with trains moving along designated tracks and the conductor rail being easily powered using pantograph sliders. However, it is not as simple to obtain electricity in the same way for electric vehicles, which often require a powerful battery pack with a large capacity in order to operate at a decent range.Despite numerous government incentives, customers have not shown much interest in EVs up until this point, with government subsidies and tax breaks being crucial for growth in the EV market share. The issue with electric vehicles is solely the battery needed today, which is constrained by inadequate energy density, a short lifespan, and high cost of electric storage technology. Since an EV battery must concurrently satisfy all of the following criteria—high energy density, high power density, reasonable pricing, prolonged cycle life, acceptable safety, and reliability—it is challenging to build. Experts agree that lithium-ion batteries are the most cost-effective option for use in electric vehicles. However, the completed lithium-ion battery pack used in EVs only has an energy density of 90–100 Wh/Kg1, which is insignificant compared to gasoline's energy density of 12,000Wh/kg. A pure EV would require heavier, more expensive batteries to match the 300-mile range of a gasoline-powered car. At this time, a lithium-ion battery costs roughly $500 per kWh, and after accounting for the cost of the car's purchase, buying a battery-electric vehicle can cost consumers an extra $1000 a year in maintenance and energy costs. EVs are too expensive for many drivers, in addition to their lengthy charging times. Depending on how powerful the charger is connected, a single charge could take anywhere from 30 minutes to several hours, and if the battery runs out of electricity, EVs cannot be immediately ready. Owners frequently need to find a good moment to connect the battery and charge it, which can be problematic if they forget to plug it in later and lose battery power. Charging cords left on the ground can also create tripping hazards, while old, cracked cables that leak can pose additional risks, particularly in cold climates. Despite these challenges, people should have the courage to plug in regardless of the weather conditions, as failure to do so could result in an electric shock.

PEVs have been suggested as a potential future mode of transportation to address difficulties with the environment, energy, and other aspects. Despite obtaining several government subsidies and tax breaks, consumers still do not find EVs to be a compelling alternative. The energy storage technology is the main issue with electric vehicles. Current battery technology has some drawbacks, including size, weight, slow charging, and low energy density. An entire commercial lithium-ion battery pack, for instance, has a 100 Wh/kg energy density, which is substantially lower than that of a petrol engine. With present battery technology, a pure PEV cannot have the same range as a gasoline car. The broad use of PEVs is hampered by the existing PEV technology's significant limitations, including lengthy charging periods and mechanical issues with charging cords. Many of the risks and disadvantages related to cable-based charging can be removed with WPT technology. Dynamic WPT enabled EVs have the ability to charge while traveling down the road, extending their useful driving range while using less battery storage space. EVs with WPT capabilities are incredibly advantageous from both a

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consumer and sustainable energy perspective. For instance, WPT-enabled EVs can advance the idea of vehicle-to-grid while enhancing the distributed energy generation paradigm. Future motor/capacitor/WPT EV designs have been put forth, allowing for continuous charging and battery-free operation. WPT technology significantly enhances features including RF technology, near-field power transmission, power conversion and management, energy storage components, state-of-the-art materials and production methods, and EMC/EMI considerations. In terms of power transfer effectiveness, range, and power rating, WPT is still in its infancy. The intensive research investigations currently being undertaken will bring the idea of motor/capacitor/WPT EVs closer to reality for the entire world. The WPT system offers a wide range of potential applications as a promising energy transfer method. For electric vehicles (EVs), which may efficiently increase driving range without the need for additional batteries, wireless-charging technology is especially crucial. This article displays three potential application scenarios: online charging in an on-road system, intelligent energy management in a smart house, and charging and discharging in a parking lot. As previously established, electromagnetic induction, magnetic resonance, and microwave are the three primary processes through which WPT technologies can be implemented. Microwaves have been researched for decades as the primary method for transmitting power across large distances. Although energy can be wirelessly delivered over a few meters, the efficiency is somewhat low. Additionally, this technology calls for high operating frequencies, for the transmission of high power energy, frequencies like 900 MHz, 2.4 GHz, and 5.8 GHz are inadequate. The magnetic induction method, one of the near-field WPT technologies, may achieve power efficiency transfer of 70%–90%. But its primary application is for short-distance power transfer. The MRC approach, which has been recognized as the most promising in the future, is the favored option for relatively transmission of power. As a result, to achieve energy encoding, the MRC-based WPT system is suggested by this study.

2. Wireless Power Transfer

Wireless power transfer techniques employ a variety of technologies, including magnetic resonance coupling, lasers, photoelectricity, radio waves (RF), microwaves, and inductive coupling. These technologies can be broadly categorized based on the underlying mechanism, transmission range, and power rating. Wireless power transmission techniques can be categorized as near-field or far-field, depending on the distance at which power is transmitted. It is referred to as a far-field technique if the transmission distance exceeds the electromagnetic wave's wavelength. Remote energy transmission techniques include laser, photoelectric, radio frequency, and microwave, while near-field techniques include those based on magnetic resonance coupling and inductive coupling. Despite having a transmission range of many kilometers, efficiency and directionality must be traded off in far-field approaches. Far-field procedures usually have a frequency range that is substantially larger (in the GHz range) than near-field methods (kHz-MHz). Induction and near-field methods are used in combination to effectively convey high power at very close quarters (from a few centimeters up). As the distance increases, the performance of such devices falls off exponentially. MIT demonstrated an intermittent WPT system that is non-radioactive and based on magnetic resonance coupling in 2007, which has attracted attention from the research community due to its potential for practical applications that demand a long transmission range. Early innovators like Tesla, Hedin, and LeBlanc actively researched wireless power transmission in the early 20th century. Among these pioneers, Tesla had the greatest influence on short- and medium-range wireless power transmission (WPT), even influencing contemporary WPT applications. Tesla is regarded as a very forward-thinking innovator for his time. After his death on January 7, 1943, a remembrance article was published in the May edition of Proceedings of the Institution of Radio Engineers (I.R.E.), characterizing him as "a catalyst in the realm of technology, a brave innovator, and a visionary on a vast scale." In addition to his invention of induction machines and the wireless transmission of electricity and signals, Tesla's research contributed to numerous application domains. The wireless power transfer (WPT) system, one of the most revolutionary technologies, is attracting interest from a variety of devices, including portable electronic gadgets, implanted medical devices, integrated circuits, and solar-powered spacecraft. Additionally, numerous studies have shown that this technology is especially well-suited for electric cars (EVs), providing better vehicle-to-grid (V2G) energy mediation and battery charging for everyday driving. As a result, WPT technology not only modifies our old energy consumption patterns but also has a big impact on the general adoption of sustainable energy sources. The WPT system can be divided into two classes based on transmission range: near-field transmission and far-field transmission.

Magnetic resonance coupling (MRC) processes, such as inductive, capacitive, and capacitive-coupled electromagnetic fields, are used in near-field energy transfer. For instance, inductive power transfer (IPT) systems can benefit from applying a transient load detection model that can accurately recognize load circumstances. The adoption of a dynamic IPT system was then recommended to automatically boost the field strength for better energy transfer efficiency and emissivity. In 2011, an IPT system with a limited rail width was proposed to charge EVs on the go. The energy supply of this system would span the entire width of the road surface. A bidirectional inductive power interface for plug-in EVs and V2G services has been created to allow the simultaneous and controlled charging or draining of multiple EVs. In 2014, IPT systems utilizing the mutual coupling effect of planar inductors were developed. IPT also released an overview article that went into great detail about the system's advancements and difficulties. Additionally, a capacitive-coupled contactless power transfer (CCPT) system that passes through metallic materials and successfully prevents eddy current in IPT systems was designed and put into practice. CCPT created a technical summary of the system's mechanism in 2013. Long-distance power transmission is related to sensor networks in military and aerospace applications. Microwaves can be used in general to wirelessly transport electricity. For the microwave wireless power transfer (WPT) technology, a revolutionary rectenna architecture was unveiled in 2012 that guarantees good power conversion efficiency across a huge range of input power levels. Power can also be transmitted over such a great distance using lasers. The idea of a laser-based WPT approach was developed by Simmered and Purcell. As already indicated, numerous researchers have made significant advancements in the operation, circuit layout, and transmission efficiency of various WPT systems. However, the adoption of the WPT technique is constrained by the nearly complete lack of research into safety issues. A multi-receptor WPT system, such as an EV charging system, promotes high converted energy conservation, for instance. Designing and implementing a novel energy encryption approach is the goal of this effort to enable secure energy transfer for various WPT systems.

3. Dynamic EV Charging

Theoretically, the problem of EV batteries can be solved with an endless driving range via dynamic WPT-enabled infrastructure that can continually charge EVs while they are moving. However, the use of such a system depends on infrastructure growth, which is constrained by its expense. Additionally, the system's power level, the vehicle's speed, and the amount of time the vehicle spends in the WPT-enabled zone all affect how much energy the WPT receives. Based primarily on the transmitter array architecture, there are two types of dynamic EV charging: split transmitter coil array and single transmitter track. The first type has a transmitter track that is significantly longer than the receiving path and is wired to a power source. In section coil array-based designs, several coils are linked to high-frequency power sources. Transmitter track-based systems are easier to control because the track is played from a single source. As the car travels along the track, the coupling coefficient is nearly constant. Several meters make up the transmitter track. However, there are a number of problems with this kind of design. To prevent dangerous exposure, the electromagnetic field that is emitted into the uncoupled area must first be subdued. Second, a compensating capacitor needs to be dispersed across the path to account for the significant inductance. Construction now faces an additional obstacle as a result. Third, only a small amount of the transmitter is covered by the receiver, making the coupling coefficient very low. Ferromagnetic materials are typically utilized to direct magnetic flux and improve efficiency. Track-based systems have a significantly narrower relative range than unity. On the other hand, a split coil array minimizes coupling issues while eliminating field exposure and needing dispersed compensation. This does, however, present some additional design difficulties. It is vital to keep an eye on the receiver's location as the load goes through the array and change to the proper power source as needed. Additionally, the distance between the transmitter coils needs to be set correctly. As the transmitter and receiver are separated, efficiency declines because the power transfer is disrupted when the coils are too far apart. The coils cannot be kept too near to one another for two reasons. First, the negative mutual inductance between nearby transmitter coils produces considerable negative current stress. Second, adding more transmitters to a given link length results in higher design costs. Another design issue is the connection of source converters to several coils. One or more transmitter coils can be linked to a transformer simultaneously, or a transformer can be connected to each coil separately. For controlling the power flow in both situations, the system complexity is substantial. The best design can be obtained by analyzing split coil-based designs. Three nearby transmitters are operated simultaneously in an analogous circuit.

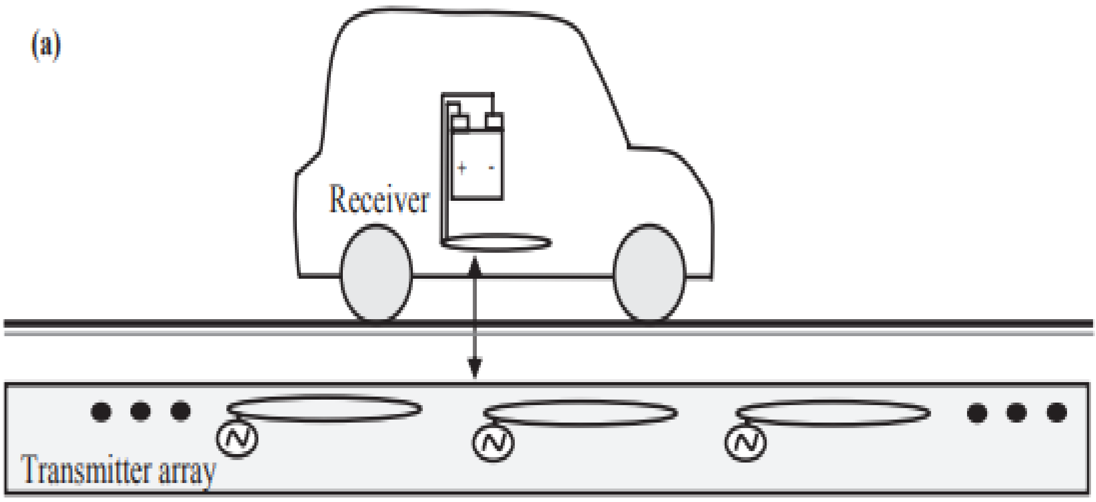

FIGURE 1. Dynamic EV charging with segmented coil array.

4. Stationary EV Charging

PEVs will have their standard WPT replacing the charging wire. Once the car reaches the charging station, the WPT system is activated. The low-frequency utility electricity is transformed into high-frequency AC power using a high-frequency power converter. Power is then transferred from the transmitting resonator to the receiving resonator through a resonant electromagnetic field. To charge the battery pack, the power intake of the secondary resonator is adjusted. There are two main types of power converters used in WPT: indirect and direct. In the indirect conversion process, the utility power is first converted to DC and then to high-frequency AC electricity. The indirect power conversion of AC-DC AC involves two

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conversion phases. On the other hand, the direct conversion method immediately converts electricity from a low-frequency voltage to a high-frequency voltage in one phase. Urban locations such as parking lots and bus stops can use the charging system. Both static and dynamic EV charging have been studied and documented in the literature. Laboratory tests of EV static and dynamic WPT have been conducted, but more research is needed to improve performance, standardization, cost efficiency, and safety considerations before they can be widely used for commercial purposes. As far as possible, the charging process should be automated. Compared to dynamic WPT, stationary WPT for EV charging offers a broader market acceptance and lower implementation costs. Resonators are usually made of ferromagnetic materials and shaped like pads for stationary EV charging. Ferrite resonator coils can be classified as double-sided or single-sided, depending on how the magnetic field is distributed. Double-sided resonator types span the magnetic flux over the resonator's two sides, requiring additional safety measures to prevent eddy currents from developing in the EV chassis. The optimal solution is not a double-sided resonator coil due to significant shielding losses. In single-sided resonator coils, the flux is directed towards the receiver by a layer of ferrite beneath the coil. Designs with circular unipolar pads and rectangular double D (DD) shaped coils achieve improved coupling in both radial and axial separation.

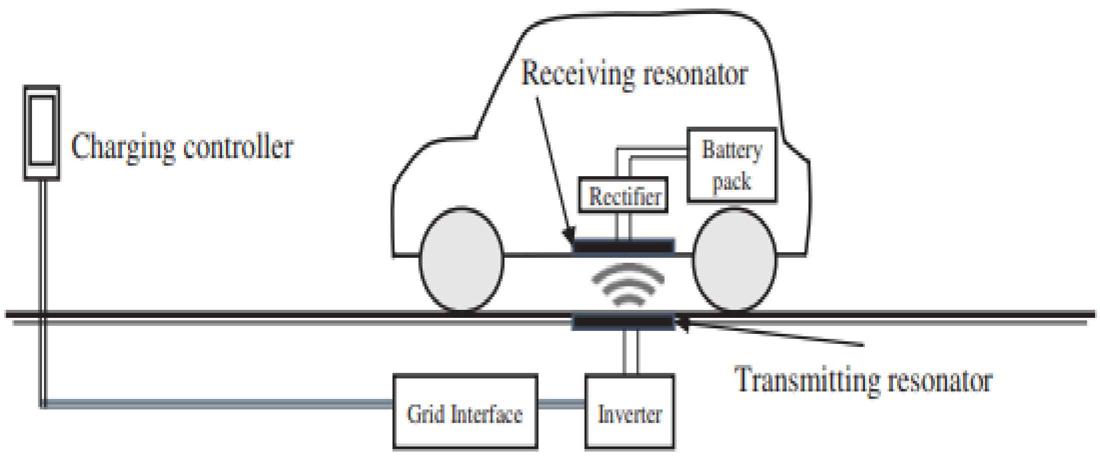

FIGURE 2. Stationary WPT for EV

5. Application Electric Vehicles

As environmental regulations increase to limit car emissions and air pollution, the electrification of automobiles is gaining momentum. For electric vehicles, batteries serve as primary energy storage devices. However, EV batteries come with drawbacks such as high cost, large size, and limited operating duration. Electric cars (EVs) are a major contributor to the development of more environmentally friendly transportation. To make the supply of electricity from the grid to EVs efficient and convenient, wireless power transfer (WPT) technology is most frequently used for contactless charging. Magnetic resonance coupling is used for automotive applications because it enables high power transfer with efficiency comparable to plug-in charging. However, the magnetic field produced by the currents flowing in the WPT system's coils when using this technology is a major concern as humans are exposed to electromagnetic fields. Therefore, protecting against electromagnetic fields should be a priority. In reality, metamaterials can extend the range and efficiency of transmission due to their special characteristics. It's important to note that basic research on metamaterials for wireless power transfer (WPT) applications is currently underway. While the use of metamaterials in WPT has mostly focused on lights and laptops, in contrast to electric cars and implanted biomedical devices, they offer a variety of potential applications in high-power portable mobile devices, implantable biomedical devices, and electric vehicles. When the transmitter and receiver have the same or a similar resonant frequency, resonant coupling enables WPT detection, offering a fresh perspective on some of the most promising uses of WPT based on metamaterials. Despite numerous studies concentrating on enhancing WPT performance and increasing the distance based on metamaterials (147-151), there are still some obstacles to be overcome. Metamaterials are typically made with metallic components and result in significant energy loss, which restricts their development and applications. Therefore, low loss metamaterials are urgently needed to enhance WPT performance. In the future, research may focus on structural architectures and metamaterial production methods to make a breakthrough. A significant scaling up of transmission power (up to a few kW) in the low-frequency range (10 kHz to 20 MHz) stimulates real-world applications for energy storage and electric cars. Low power applications are also the main emphasis of WPT technology. Therefore, subsequent work should focus on obtaining metamaterials with high energy in the low-frequency area. However, dynamically tunable metamaterials might also be a worthwhile area to research. WPT has been applied to expand the working range of electric car batteries. During brief stops at stations with receiving and transmitting coils, batteries can be charged using a transmitting coil buried in the road and a coil placed on a bus or train. A method of harvesting energy that uses the motion of a bicycle to create kinetic energy was described. According to their test results,

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more than 6.6 MW of electricity can be produced when riding normally. They discovered that the energy harvesting gadget could produce electricity while cycling uphill without adding to the cyclist's mechanical effort.

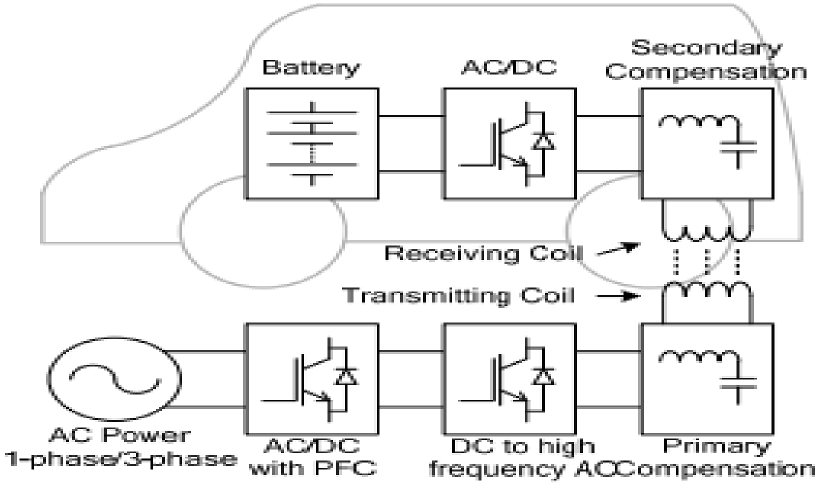

FIGURE 3. Typical wireless EV charging system

6. Conclusion

This chapter covers wireless power transfer (WPT) technology for electric vehicle (EV) battery charging, including performance metrics such as effectiveness, converted power, ranges, and misalignment tolerance. The scientific community's contributions are highlighted through a thorough examination of the WPT system, including modeling techniques and their benefits. Design issues and WPT approaches for EV charging are also described. The next stage of transport electrification has been identified as dynamic WPT for EV, and recommendations for WPT coil designs are offered through a case study. This article provides an analysis of wireless charging for electric automobiles, recognizing that environmental and energy-related problems necessitate vehicle electrification. There are several benefits to comparing wireless charging versus wired charging. When roadways are electrified with wireless charging capability, the basis for EVs to enter the mass market, regardless of battery technology, will be laid. Technological advancements have made wireless EV charging possible, but further research is needed in topology, control, inverter design, and human safety to fully realize its potential.

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