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Wireless Power Transfer: Applications and Future Directions

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ABSTRACT

Across many sectors, including consumer electronics, medical devices, and the automotive industry, Wireless Power Transfer (WPT) has emerged as a revolutionary technology. This work investigates the basic principles of Wireless Power Transfer (WPT), classifying it into near-field and far-field techniques, and analyses its use in supplying power to devices without physical connections. The analysis presents an evaluation of the use of WPT in consumer electronics, the medical industry, and electric cars, emphasising the technology's potential to transform these areas. Furthermore, the study discusses the obstacles related to efficiency, safety, and regulatory compliance that impede the extensive use of WPT. Lastly, the future prospects of Wireless Power Transfer (WPT) are examined, with an emphasis on developing technologies that may enhance its economic feasibility and incorporation into common applications.

Keywords: Wireless Power Transfer, Near-field Methods, Far-field Methods, Consumer Electronics, Medical Devices.

INTRODUCTION

In the past decade, electronic devices have been revolutionized by low power VLSI systems. There are four wireless power transfer (WPT) applications: radiofrequency energy harvesting, fixed WPT to infrastructure components, wireless charging system, and implantable medical devices. RF energy harvesting collects/sinters energy from satellite/passive RF, TV, and AM/FM radio communication. Fixed wireless power transfer uses external orthotic/in-sole systems. Implantable medical devices use high and low power electronic devices for wireless charging and battery charging [1]. Wireless energy transfer, essential for various applications such as sensor networks, medical implants, and electric vehicles, is becoming increasingly popular. The industry predicts that charging via plug and socket will soon be outdated, with wireless power transfer gaining attention for its commercial potential [2].

FUNDAMENTALS OF WIRELESS POWER TRANSFER

Wireless power transfer, also known as wireless power transmission, utilizes specially designed systems to transmit electrical energy without any physical connection at a designated distance. There are several fundamentally different ways to tackle wireless power transfer systems, which can be mainly divided into near-field and far-field methods, depending on the distance between the receiver (Rx) and the transmitter (Tx). Far-field methods involve the use of microwave radiation and light to transmit energy, while near-field methods can be carried out by either electromagnetic induction or electromagnetic waves. Among the mentioned configurations, electromagnetic induction is a well-practiced wireless power transfer method that has attracted considerable attention for various applications from power grids to portable devices. For example, medical devices can take advantage of this ability for in vivo implant charging, and the concept is applied to charge electric vehicles [3]. Electromagnetic induction is the simplest wireless power transfer system, and it is directly related to Faraday's law of electromagnetic induction. In this simple method, the basic concept of power transmission can be represented as B * A * cos(theta), where A is the transfer surface area, B is the magnetic field strength, c is the distance between the Tx and the Rx, and theta is the angle between the magnetic field and the receiver normal. The system can deliver power, which is the time derivative portion of the transferred magnet kinetic energy, and the formula can be simply expressed as d/dt (dB * A * cos(theta)), assuming that B and A are time independent. After reviewing the fundamental principles and the three main methods of wireless power transfer, it is worth discussing some studies on wireless charging technologies focused on developing alternative applications and improving device performances [4].

APPLICATIONS OF WIRELESS POWER TRANSFER

Wireless power transfer technology has experienced fast growth. In general, wireless power transfer can be used in various applications, including consumer electronics, such as mobile phones, laptops, eBooks, wearables, streamers, AR, VR; electric vehicles to extend their range of operation, aviation industry to provide power to vision systems, drones and robots; industrial IoT and automation to extend battery life of devices; medical devices to provide internal power supply from external source and small satellites through large solar arrays. In the future, various interfaces may depend on wireless power transfer and the applications will be diversified, including, but not limited to, expandable screens, keyboards, pointing devices and headsets. This provides a better solution for smartwatches, activity tracker bands, AR/VR headsets, and smart eyewear beyond the limitations of consumer electronics devices [5]. Continuous energy transfer: Wireless power transfer is commonly used for continuous power supply and charging applications in devices, such as health monitoring devices. It extends device life and allows for long-term maintenance. For example, sales of pacemakers increased from 1 million to 3 million from 2009 to 2017. Similarly, sales of insulin pumps and defibrillators have also grown. More than 20 million different Active Implantable Medical Devices (AIMDs) have been shipped by various companies, with the expectation that active AIMDs from single vendors will exceed 100 million devices. This growth will be further fueled by the development of next-generation implanted devices from companies like AXON, Cerebral Therapeutics, and Nexeon Medsystems. For instance, Nexeon plans to market its implant/in vivo neuromodulator, providing continuous chronic FNS for more than five years for pain relief. Established companies like Medtronic and Purdue Pharma are also embracing this concept, with the marketing of their energetically powered drug delivery pump that will last over 16 years for the treatment of severe pain. Plenoptic is a major supplier of batteries that are delivered through real-time wireless recharging. This system will be approved for mission-critical operations, including clinical heart attacks. Overall, wireless power transfer complements traditional battery usage by providing real-time battery information to users before transitioning to wireless transmission [6].

CONSUMER ELECTRONICS

Wireless power transfer (WPT) technology is mainly being developed and experimented in consumer electronics. It is believed that in the near future, WPT-embedded smartphones, wearables, and household gadgets would coexist for mobile applications. Efforts to adopt WPT in mobile technology could result in increased market penetration. For example, a study has proposed a sustainable home wireless charging system that doubles up as furniture. Smartphones placed on these home office furniture items, such as desks and tables, can be wirelessly charged using COTS WPT technology. Nevertheless, embedding quasi-static WPT in smart furniture poses some challenges. The fully installed wireless charging device must not exceed the human exposure limits set by the International Commission on Non-Ionising Radiation Protection (ICNIRP). The WPT-embedded smartphones are designed to operate as an IoT device for information exchange. Not only have attempts been made to implement WPT within smartphones and smart furniture, but some low-power WPT receivers have also been designed to operate as a communication device. One advantage of WPT-embedded mobile technology is longer electronic device lifetimes due to less frequent battery replacements, reducing e-waste. Some consumer electronics require small, detachable and highly efficient WPT receivers for portability, while others are intended for indoor charging and can radiate more power. IKEA table lamps enhance user experience and battery life, but do not offer direct wireless charging through the table. On the other hand, wireless keyboard WPT receivers embedded in IKEA tables enable wireless charging for smartphones. Market penetration of WPT technology and convenience for household use are crucial for commercial success. Different classes of consumer electronics have varying WPT requirements based on their specific applications, such as power and distance. Understanding these requirements is essential for viable and commercial WPT designs.

MEDICAL DEVICES

Powering of medical devices is an area of high interest for wireless power transfer. The benefits of using wireless power transfer for medical device powering include increased patient comfort and reduced time for patient recovery, i.e., a shorter hospital stay. Many research groups around the world are currently investigating or have already made commercial systems available whereby implanted electronics within the body can be powered wirelessly. Implantable biomedical systems can range from gastric neuro-stimulators which are used to counter obesity, blood pressure sensors, cochlear implants to restore hearing, retinal and visual cortex implants to restore sight, and brain cortico spinal implants to restore physical movement to the paralyzed and chronic pain alleviation for headache. These systems need to be low cost to implant, but have a long system lifetime for patient quality of life and inclusiveness to installation locations. Safety is critical. The transmission power is directed to the internal location where the receiver is implanted. Data security and the protection from having the device powered-up for "implant locate and access" by potential unauthorized personnel is also being addressed. A general review of wireless power applications for medical devices is given in, showing some of the applications for which wireless powering is being developed. Many of the applications shown in the aforementioned are high-power, with typically 20 W of power to 2,000 W being delivered to the device wirelessly. The motivation for this is to firstly achieve maximum power transfer to internal devices and secondly to lower both the transmission frequency and the associated field strength or field penetration within the body. More recent development in the field are of the transcutaneous wireless charging and communications links (using a base station transcutaneously) suited to operating within a hospital or other medical facility working with fine grained control over the charging link, with transmission power as low as 40mW. In some recent work implants up to a gauge of 14 have been investigated within animals for trials on wireless charging which exceeds experimental results of Class D implantable device antennas to date [7].

AUTOMOTIVE INDUSTRY

The wireless power transfer could be attractive to be integrated where "touchless" power connections are most useful, including: the principle of electric vehicles (EVs); EV parking stations; intelligent transportation systems; "auto-storage" networks, particularly when vehicles need to be parked for extended periods of time, these networks could be useful for distributed electricity storage and even during short parking periods this energy storage could be used for variable loads. Despite the plethora of applications where charging an electric vehicle with wireless power transfer can be useful, the main area where it has seen interest in the automotive industry with some level of market penetration is for the wirelessly charged electric car [8]. The current strategy of charging electric vehicles outside of the road networks/fast charge stations will likely need level-3 wireless charging for consumer acceptance. Wireless power transfer can significantly aid the adoption of electric transportation. Environmental issues like water and dirt affect these systems. Adjusting car suspensions when regenerative braking effect is increased is necessary. Vehicles with regenerative braking systems based on induction motor technology require special control systems. Vehicle air suspension control systems and wheel motors are complex and costly. Adjusting vehicle height can decrease wind resistance and increase fuel economy. A prototype has proven the feasibility of this development. Ambulance and emergency command control vehicles are being considered. Efficiency is offset by high vehicle weight, battery inefficiencies, and fuel logistics. Housing estates can reduce pressure on the grid by sharing electricity and alternative drive technologies are important [9].

CHALLENGES AND LIMITATIONS

Wirelessly transferring power can enhance sensor, medical device, and electronic capabilities. However, challenges including efficiency, design limitations, regulations, safety, medium losses, and SAR hinder widespread implementation. Overcoming these obstacles would unlock numerous promising applications for WPT [10]. The efficiency of the WPT system substation depends on the efficiency of different subcomponents like inverters, power transformers, filter resonators, and rectennas. MIT researchers have suggested conveying energy wirelessly via magnetic fields and spreading the associated peak magnetic field energy limits to 1 percent of the storage energy. Certain factors must be taken into account for the use of WPT systems, such as maximum electric field, exposure reduction factor, specific absorption rate value, and displacement from an adult. Further research is still needed to specify the safety limit and integrate it into the standard protocol assessed by the International Committee. Regulatory bodies such as the European Telecommunications Standards Institute in Europe and the Federal Communications Commission in the United States have defined Specific Absorption Rate (SAR) limits to ensure wireless energy transfer and cell phone communications are safe [11].

FUTURE DIRECTIONS AND EMERGING TECHNOLOGIES

This section explores future directions in wireless power transfer, including the use of resonant cylindrical tubes as waveguides. Research in fundamental wireless power transfer may shape the future of wireless energy systems. Two-coil system research will continue to develop more efficient energy transfer methods [9]. There is further research needed for wireless power transfer to become a commercially viable area of study. Inductive charging for Intelligent Transportation Systems (ITS) may be the most active research area in the next five years. As Electric Vehicles (EV) become more abundant, manual charging will become unsustainable, leading automotive manufacturers to explore wireless charging methods [12. 13].

CONCLUSION

Wireless Power Transfer represents a significant advancement in how energy is delivered to devices across various sectors. While its applications in consumer electronics, medical devices, and electric vehicles showcase the potential of this technology, challenges such as efficiency, safety, and regulatory issues must be addressed for WPT to achieve widespread adoption. Future research and development will likely focus on overcoming these obstacles, paving the way for innovative applications and more efficient WPT systems. As the technology continues to evolve, it holds the promise of reducing reliance on traditional charging methods, leading to more sustainable and user-friendly energy solutions

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