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Wireless Power Transfer

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Abstract

Wireless Power Transfer (WPT) is a new approach for the motion of electrical power without the use of the established wires or connections, involving the application of electromagnetic fields. The paper covers the main ideas, typology, and application of Wireless Power Transfer and difficulties in connection with it. There are two primary types of this technology: Far-field radiative and near-field non-radiative transfer – detailed analysis is given, including the use of microwave and laser power transfer for long range applications as well as in the paper explains the benefits of WPT such as convenience, added safety, and the opportunity to provide energy to devices in challenging locations. However, fundamental problems like lack of efficiency in power transfer, poor range, sensitivity of coil alignment and high cost of infrastructure are maintained. The paper discusses real world applications in consumer electronics, electric vehicles, medical systems and industrial automation. Under the development of technology, we would expect the increased use of WPT. May change power delivery in many applications.

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Introduction

Wireless Power Transfer (WPT) is a novel technology that allows transfer of electrical power from a power source to an electrical load without the physical need for connector or wires in between. This concept traced back to the experiments conducted by Nikola Tesla during the latter's decades has been greatly developed further by the modern science of electronic, materials, and communication devices. Presently, WPT is gaining a significant place in different domains such as consumer electronics, electric vehicles (EV), medical implants and industrial automation.

The under-pinning principle of WPT is that electromagnetic fields will be used to transfer energy across a gap. There are a number of techniques broken down with the most common being the inductive coupling, resonant inductive coupling, capacitive coupling, and electromagnetic radiation (e.g. microwaves or lasers). Inductive coupling based on the principle of magnetic fields that is created by coils is widely used in application such as wireless charging pads for smart phones etc. Systems using resonant inductive coupling can manage extended range and efficiency of energy transfer, thereby making them viable for larger-scale applications such as charging stations for electric vehicles.

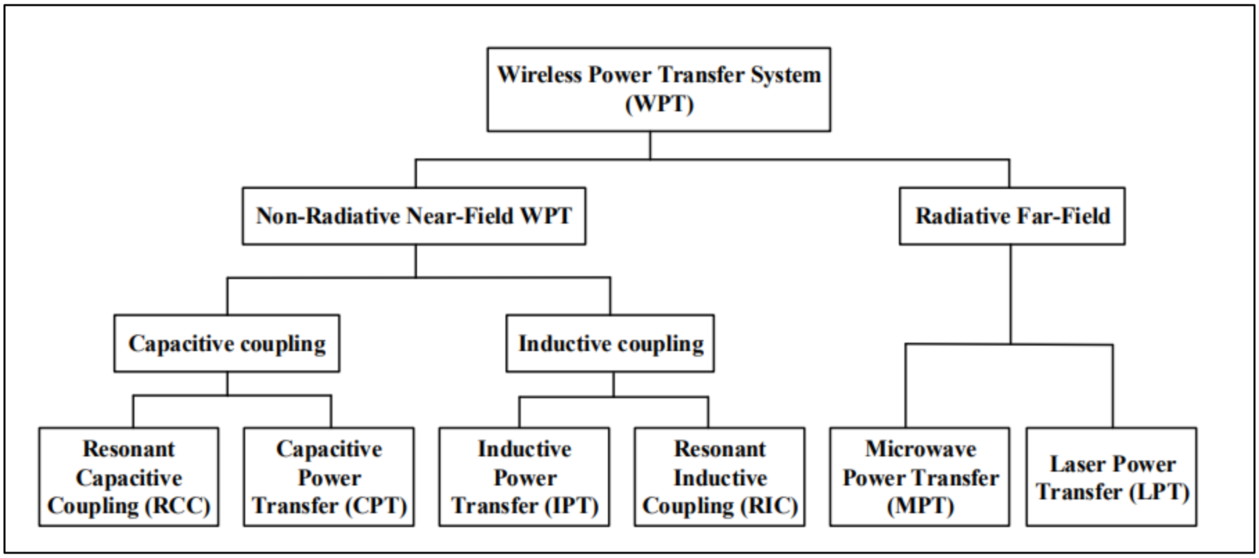
Convenience is one of the major benefits of WPT: WPT does away with the need to operate via the use of cables and connector, hence minimize wear and tear of the discussed technology while ensuring enhanced safety of the electrical systems by reducing contact with live wire. Furthermore, WPT can already empower new designs and usage in environments where wired connections are impractical/hazardous such as in underwater/space applications.

The coverage area, efficiency, and scalability of WPT systems are improving as technology progresses, which is opening the door to industry wide adoption. But issues such as energy loss, alignment sensitivity and regulatory aspects are areas that still need to be ironed out for maximum exploitation of the ordinary life environments by the use of wireless power transfer.

Classification of Wireless Power Transfer Systems

Wireless power transfer (WPT) systems or cordless power transfer or wireless power charging allow the transmission of electric power from source to load without the medium of physical connections i.e., the cables. The WPT essentially consists of two processes that follow one another: (i) transform the power to be transferred into a different type of energy; and (ii) send it to the target devices without the need for a static structure. Well-known procedures often include transforming the energy into an electromagnetic or magnetic field and then delivering it by electromagnetic radiation or magnetic induction, respectively.

The two main categories of WPT methods are near-field and far-field. When the transmitter and receiver are only a few millimeters or centimeters apart, near-field techniques are used. Examples of these include wireless charging or continuous WPT in implanted medical devices, charging handheld devices and, radio frequency identification (RFID). Conversely, far-field techniques may cover greater distances. They can be applied in situations when the transmitter and receiver are only a few kilometers apart. Sending electricity to ground equipment from a geostationary satellite is an example of a far-field technique.



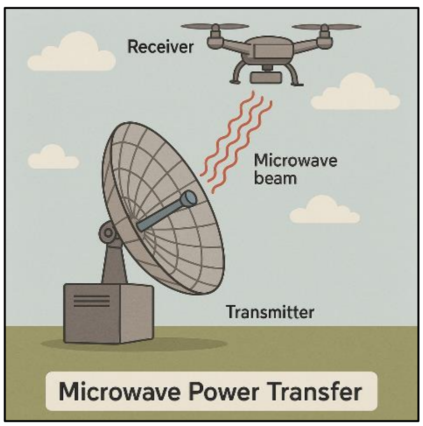
Radiative far-field systems are as shown in the figure above two types of: the ones that use microwaves, identified as microwave power transfer (MPT) and the ones that use lasers identified as laser power transfer (LPT). Similarly, non-radiative near-field wireless power transmission systems also divide into two categories: Inductive coupling and capacitive coupling, the inductive coupling also divided into two categories (inductive power transfer (IPT), which depends on magnetic fields for energy transfer and resonant inductive coupling). In addition, capacitive Coupling is also divided into two more categories which are (Capacitive power transfer (CPT), which exploits electric fields and, Resonant capacitive coupling).

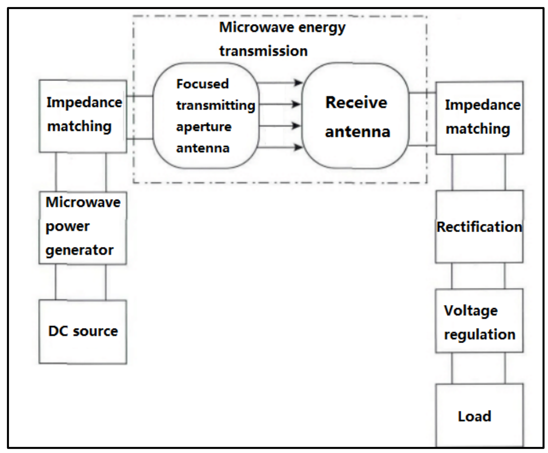
Radiative Far-Field Wireless Power Transfer

At the radiative far-field, wireless energy transfer relies on carrier electromagnetic waves in the shape of radio frequency signals to transfer energy. Later, the transmitter emits energy through the electric field residing in the electromagnetic wave. Local wireless power transfer does not require line of sight between a transmitter and a receiver as compared to far-field wireless power transfer. MPT microwave power transfer, and LPT laser power transfer.

I. Microwave Power Transfer

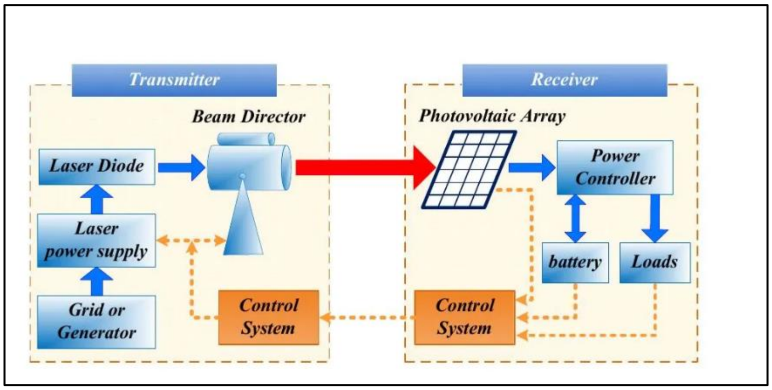
The system used in the Microwave Power Transfer MPT offers microwaves as the foundation for the transmission of electromagnetic radiation-powered energy in a wireless manner. One of its best-known applications is used in aviation primarily in accelerating unmanned aerial vehicles. The system employs its uncommon antenna and generates radio waves to radiate the energy throughout the surroundings. When it arrives at the receiving station, a matching cooker scoops and converts the electrical field energy into usable power to the load. Its main feature that marks this technology out is the capability to transmit at a high output and can be adjusted to suit various environments together with versatile signal-handling characteristics. Due to these aspects, the technology can be applied for remote electrical power transmission is across different factors of an environment. While presenting a variety of advantages, the system is limited by the low transmission performance that is typically below 10% and the high cost of large antennas that cause increased costs.





II. Laser Power Transfer

Since large antennas are essential for the transmission of the microwave energy, researchers are looking at using laser beams as an alternative for wireless transfer of power. Use of tightly collimated laser energy focused directly at the receiver guarantees maximum transmissions over long distances. The transmitter in this system converts electrical energy, most commonly drawn from a battery, to a single wavelength laser beam. An intricate optical arrangement is employed for the beam to guide it to the receiver. Both traditionally and for space applications, receivers are designed with photovoltaic panels, usually placed on satellites, to receive and convert laser radiation into electrical energy. This energy will either be used to charge the satellites batteries or to enable the running of motors on board. A critical component of these systems as in the case of MPT, there is the rectifier module that should operate with high efficiency. Yet, it is known that rectifier modules cause power losses, often causing efficiency to decrease by almost 10 percent. Advanced rectifiers overcome such issues by keeping and increasing the drive current, a process which has been discussed in detailed research. Although, there are several distinct benefits to laser-based power transfer, its clear disadvantages stand out when compared to those methods where microwave transmission are used. The major challenge is that precise laser beam direction required is the province of extremely sophisticated tracking and alignment mechanisms which are needed to guard against the laser radiation which poses threats to people and the local environment.

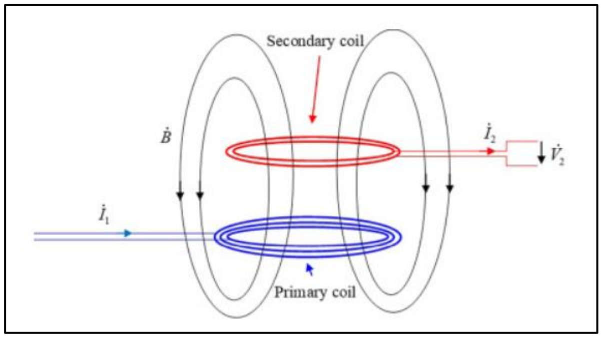


Laser-based power transfer suffers more from atmospheric interference (absorption and scattering from clouds, rain, snow, and fog) than the case with microwave transmission. However, this weakness has not tolled the bell for the increasing interest in laser energy transmission. The United Kingdom has a SPRINT program that helps Space Power Limited, a UK company, to design a LPT (Laser Power Transfer) prototype as joint venture with participants from Surrey University. This technology is engineered to supply the satellites in the nearness of Earth with power when they are not in contact with sunlight.

Non- Radiative Near-Field Power Transfer

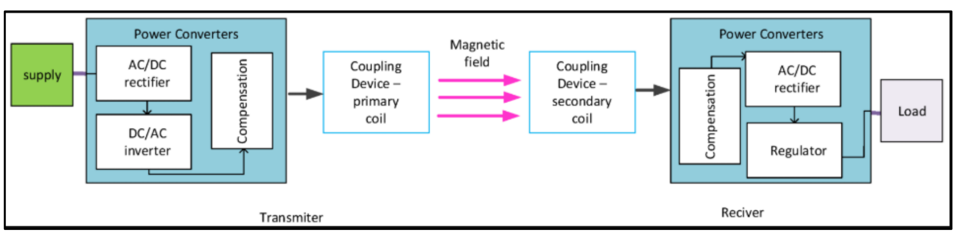
The standard system used in wireless power transfer draws on two important elements: a transmitter and a receiver. Energy may be transferred either in its magnetic or in its electric field. These include inductive power transfer (IPT) and capacitive power transfer (CPT). As plugins use for this technology the magnetic field, both components are adjusted as coils, the transmitter and the receiver. In the scenario involving transmission of electric field, two flat capacitive plates are employed, i.e., one with the role of the transmitter and the other one with that of the receiver. The extensive use of this wireless energy transfer for such industries as biomedicine, implantology, portable electronics, underwater robotics, and electric vehicles has meant that it has been not only intensively researched, but also extensively implemented. Near-field wireless power transfer has become the most advanced and widely used technology because of the rise in its implementation.

The accompanying diagram makes clear the process of energy transfer by inductive coupling, an essential method in close-field IPT systems.



I. Inductive Power Transfer

IPT technology is founded on the basic principles laid down by Ampère and Faraday, governing electromagnetism. Before the end of 1898, Nikola Tesla had shown the concept of wirelessly transferring power through this method. Previously, IPT systems were generally categorized into two key types: There are two types of wireless power transfer systems: inductively coupled wireless power transfer, i.e., IWPT or inductively coupled wireless power transfer (IWPT) and magnetically coupled resonance wireless power transfer, i.e., MCR WPT. Fig. below shows a typical system layout which is applicable to the IWPT and MCR WPT systematically.

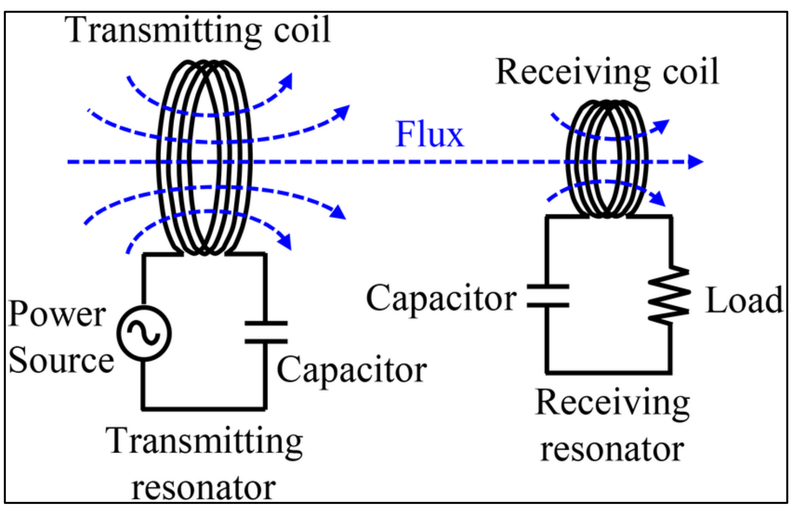


Several key components are installed on the transmitter side of the system shown in Figure above. First, rectifier converts the fluctuating current drawn from an outside power grid into a constant direct voltage that is tailored for usage. Later a DC/ AC inverter transforms it to alternating voltage for transfer. The final section of the transmitter setup is the transmitting coil. On the receiving side there is the circuit with the receiving coil which has AC/DC rectifier which is built to convert the received alternating voltage into DC voltage and also voltage regulator for guaranteeing the stable output. The closer the separation between transmitter and receiver the more the coupling coefficient decreases. Consequently, higher voltage losses caused by leakage inductance and lower efficiency of power transmission appear. To overcome this challenge, additional compensation components are incorporated into the circuit to produce a resonant system. As a primary basis, capacitors are installed using various setups on the entities of both the receiver and transmitter side. Such elements can be added in order to reduce the electrical impedance of the system, particularly when the leakage inductance is greater than mutual inductance.

1. Inductive Coupled Wireless Power Transfer

Inductively Coupled Wireless Power Transfer (IWPT) technology works by using a magnetic field generated between neighbouring transmitting and receiving coils to transfer energy. This technology operates in a manner very similar to an air core transformer. The system typically operates at kilo Hertz frequencies and is suitable for ranges up to 40 mm, but supports several kilowatts of power levels. With increasing distance between the transmitter and the receiver from 20 mm to 100 mm, coupling coefficient is reduced from 0.6 to 0.1, and the efficiency of transmission decreases from about 80% to 40%. Both coupling coefficient and efficiency calls attention to such matters as coil winding and the physical design and size of the coils.

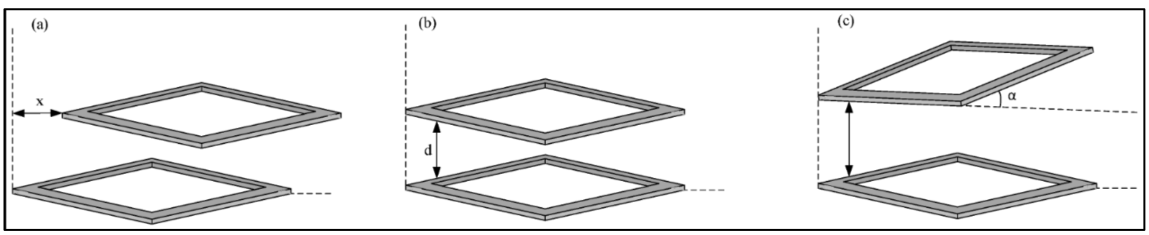
The main benefit of IWPT without doubt in its uncomplicated structure and the high efficiency of it against its competitors. Use of a low operating frequency makes energy transfer safe. However, there are number of limitations to this approach including restricted effective range, low electromagnetic coupling, and inadequate mutual inductance. In addition, running the system generates significant heat accumulation, mainly caused by winding losses. Changes in the spacing between the coils dramatically reduce their efficiency. Perfect matching of the relative position and distance between the coils of the transmitter and receiver is necessary for optimal performance to be maintained.



2. Magnetically Coupled Resonance Wireless Power Transfer

Underlying mechanism that links both IWPT and MCR WPT technologies is air-core transformer. However, for MCR WPT achieved resonance frequency for both transmitting and receiving coils is necessary. In most cases, such technology as MCR WPT can be effective in the range of several kilohertz to multiple tens of megahertz. It is possible to safeguard containing the energy at a few meters distances without compromising it with environmental conditions like weather events. The transfer of energy in the MCR WPT is not dependent on the necessity to achieve proper alignment between the source and the receiver. Power transfer can occur until the receiver is still within the effective limit of the transmitter.

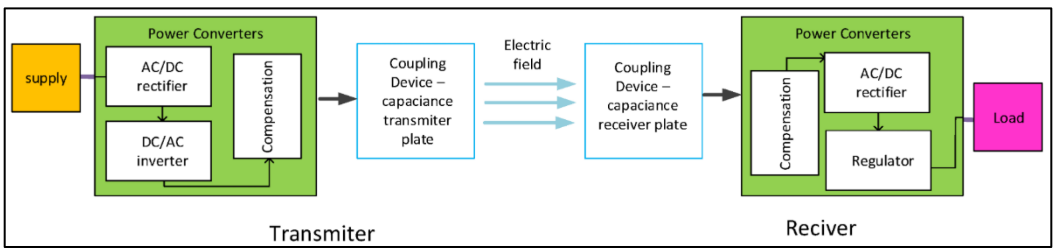
The relationship between the configuration of the transmitting and receiving coils and the coupling coefficient are important as the coupling coefficient is critical for the efficient power transfer. Various orientations of the transmitting and receiving coils are shown in figure 3. In the cited study, the authors used rectangular-coil configurations. An inner window of the dimensions of 498 mm × 10.4 mm × 20.2 mm was found in each coil. The coils consisted of 12 turns, and 212 μH of self-induced inductance was measured for one single coil. the effect of coil spacing (d), inclination angle (α), and horizontal distance in terms of placing the receiver from the transmitter on the overall k valuehas been examined. The results of these investigations are presented in the following figure.



Changing the position: horizontally (a), vertically (b), and at the angle (c) of the transmitting and receiving coils with a rectangular cross-section.

II. Capacitive Power Transfer

Capacitive Power Transfer (CPT) technology operates on the principle using capacitive coupling between the transmitter and the receiver, and here both become electrodes of the form of metal plates for the capacitor. An alternating current from the source charges the transmitter causing it to produce an alternating electric field and sent to the load on receiver plates. Cost-wise, CPT usually performs better than IPT, but practical application passes under a limitation, which requires the transmitter and receiver to be in close proximity. Furthermore, though it is not as safe as other methods, CPT has been applied in medically unattractive situations like medical implants. The versatility of the system and its compact shape allows it to be used in reconfigurable systems and robotics. Use the figure below to help visualize a CPT system.



As shown in the figure above, both the transmitter and the receiver in this arrangement also carry similar functional blocks like those in the Inductive Power Transfer system, but each plays identical roles outlined earlier. What makes this setup different from the previous one is that flat capacitor has two plates, which take care of the interface between output of the transmitter and input to the receiver.

Advantages and Disadvantages of Wireless Power Transfer Systems

Earlier, we discussed how the wireless power transfer systems are classified defining their major properties, fundamental differences and the contexts of greatest applicability. The following part of this paper is dedicated to discussing the pros and cons of the provided technologies. From the table below, several parameters of IPT technology were made to stand out while another table presents a comprehensive comparison of all WPT systems.

Parameter	MCR WTP	IWPT	CTP
Operating frequency	Very high	High	Medium
Hysteresis losses	None	Appear	Appear
Eddy current losses	High	Medium	Low
Coupling coefficient	<0.25	>0.5	~1
Efficiency	Medium	High	Medium
Distance	Medium	Medium	Low

Comparison of parameters of various IPT technologies

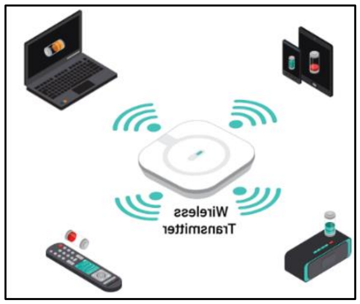
	CTP	ITP	MPT	LPT
Advantages	High power transfer (up to several kW)	Possible to obtain a higher efficiency (90%)	Long effective transmission distance of up to several km	Long effective transmission distance of up to several km
	Transfers power without generating an eddy current	High power transfer (for several kW)	Suitable for mobile phones	Suitable for mobile phones
	Reduces costs by using metal plates as the transmitter and receiver	Good galvanic isolation	Has the potential to transfer several kW	Has the potential to transfer several kW
	Very good for small applications but can also be used in large applications such as electric vehicles	Can be applied from small (phone) to large devices (electric vehicles)		
Disadvantages	Limited efficiency in the range of 70–80%	Limited transmission distance from cm to m	Low efficiency, less than 10%	Low efficiency, less than 20%
	Short transmission distance (max. 100 mm)	The significant eddy current losses limit the application area	Complex implementation	The line of sight to the receiver
	Some challenges as a result of conflict between the transfer distance, power, and capacitance value			

Advantages and disadvantages of the WPT technology

Applications of Wireless Power Transfer

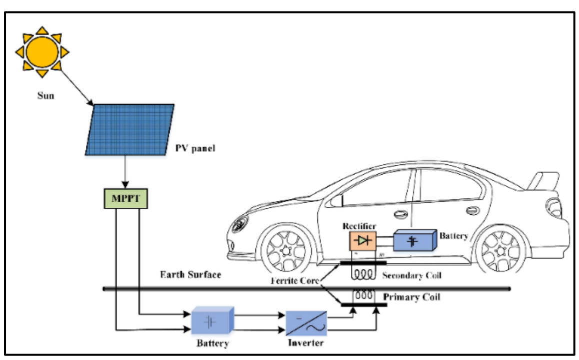
1. Consumer Electronics

Wireless Power Transfer has been widely utilized in the area of consumer electronics. In the past few years, it has become popular that smartphones, smartwatches, and wireless earbuds all have widely adopted inductive or resonant coupling for wireless charging. Carrying out a physical connector removal, this technology reduces wear and enhances universal convenience for users. More and more homes and offices are switching to wireless charges pads, in-built furniture chargers, and long-range charging hubs.



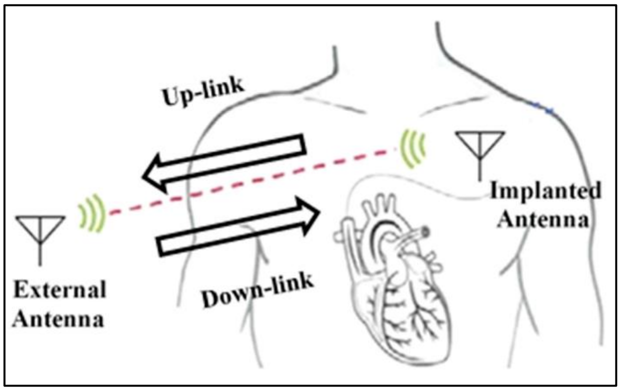
2. Electric Vehicles (EVs)

Wireless Power Transfer is gaining fast traction in the electric vehicle market. Developers are in the works to have systems in which EVs will be wirelessly charged as they are parked upon charging pads. The elimination of cables makes this system more secure for the public and reduces the likelihood of mechanical breakdowns. New developments are foregrounding the concept of dynamic wireless charging – where transmitters embedded in roads make vehicles capable of being charged in motion, with the intent of revolutionizing transport and alleviating range fears.



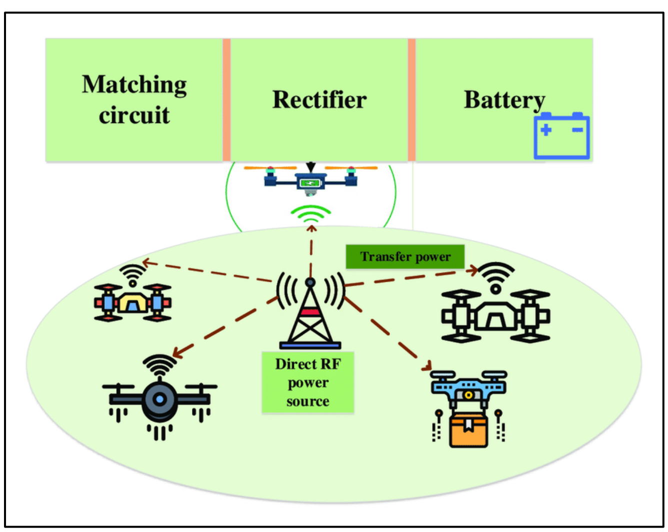
3. Medical Devices

WPT is irreplaceable in healthcare, that allows pacemakers, cochlear implants and neurostimulators to work efficiently. These devices require a reliable and constant source of power, and the use of wireless transfer of energy eliminates the need for ongoing invasive surgery to change the batteries. The feasibility in terms of safety and tissue-permeability of the WPT based on magnetic resonance renders it a perfect technology for human tissue based reliable power delivery.



4. Industrial and IoT Applications

Wireless power transfer (WPT) is applicable to industrial automation in powering rotating machine or moving robots without the risk of wire damage or exposure to dangerous environment. In the IoT world, WPT makes it possible for sensors and smart devices to do their thing in inaccessible or sealed places, increasing system reliability and reducing the need for upkeep.



Challenges and Limitations of Wireless Power Transfer

Wireless Power Transfer enjoys many benefits, although it poses serious challenges and limitations. One major issue that emerges through energy loss in transmission especially when the distance is long or device alignment is weak. Since some of the WPT systems have a limited range, it is normally applicable to those situations where distances involved are small. Costs associated with constructing the infrastructure needed for WPT are often high. These challenges need to be overcome in order to enhance the practicality and the adoption of WPT.

1. Efficiency and Energy Loss

Wireless power transfer is plagued with the issue of efficiency. Conventional power transferring techniques are known to suffer little energy loss, but WPT – especially when the distances are long – frequently suffers significant loss of power due to such factors as terrestrial reflections, inconsistencies in the coils, and electromagnetic interference. Using inductive coupling as an illustration, one draws an example of an entity that is of the highest efficiency only when the transmitter and the receiver are properly located and within close proximity. Because of losses of energy caused by transmission or scattering at far-field methods such as microwave or laser-based WPT, they are not ideal for everyday use.

2. Limited Range

Effective transmission distances are a trade-off for some solutions to wireless power. The use of inductive and resonant coupling as far-field technologies is restricted to the operation at distances which span more than a few centimeters to a few meters. Despite far-field systems' ability to provide power on the kilometer scale, challenges associated with their safety, disturbance to the environment, and inefficient energy transfer make them impractical. The enveloping constraint on the range of transmissions restricts the implementation of WPT on a large scale, such as residential or urban power demands.

3. Cost and Infrastructure Requirements

WPT technology implementation will generally require a specific set of infrastructure assets to be deployed such as charging pads, embedded transmitters, or line of sight-based setups. The needs for infrastructure along with the constant expenses that come with these systems go above and beyond what is offered by traditional wiring. The cost and complexity of infrastructure and technology, render dynamic EV charging and space-based power transmission applications unsuitable for large scale deployment for now.

Conclusion

Wireless Power Transfer, WPT, is the key to wireless energy that does not require direct electrical connection. Benefits include speedier user experience, enhanced safety, reduced wear & tear on devices and the ability to wirelessly supply devices located hard to access or within sealed areas. The scope of WPT is accelerating rapidly and with consumer electronics, electric cars, medical implants, and industrial auto, there are great performances.

Despite the great promise that WPT has, it is currently facing formidable challenges. Specific problems include limited transmission capacity, inefficient performance as a result of a distance, necessity of precise alignment and safety issues related to the rapidly-spreading dangers of electromagnetic radiation. Moreover, installation costs and the risk of interference of systems in some environments prevent technology large-scale implementation.

Ongoing research and development of technology are in place to break through these bottlenecks with a view of improving efficiency, increasing range and improving safety. WPT is due to become the essential ingredient for future energy landscape thanks to the emerging wireless power innovations, which will facilitate greener, smarter, and more versatile energy transport for companies and consumers.

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