Systematic literature review on wireless power transmission

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Abstract: In modern days, many power transfer technologies have been developed with and without cables. But plug-in cables have numerous drawbacks, such as exposed wires, bulky cables, and bad environmental impacts. Therefore, research on wireless power transmission (WPT) paid attention to researchers, academicians, and businesses in the automation industries. The wireless power transmission system (WPTS) is more popular to apply in various systems whichinclude televisions, household robots, laptops, and cellular phones due to its convenience and safety. In this article, the historical background of WPT technology, “radiative and non-radiative” wireless power transfer techniques are studied and also, evaluations of various “radiative and non-radiative” WPT techniques are tabulated.At last, the difficulties and future scopes of WPT innovation are introduced.

Keywords: Wireless power transmission System (WPTS), “radiative and non-radiative” power transfer, Inductive coupling, Capacitive coupling

1. Introduction

“The electrical power transmission from one place to another without any wires is referred to as Wireless Power Transfer (WPT)”. For several applications, the WPT methods are used, such as biomedical, automation industry, laptops, toys, cell phones, robots, battery-operated electric vehicles, and electronic devices[1]. Nowadays, researchers have created different strategies to transfer wireless power for long-distance significantly.

Depending on the energy transfer mechanism, WPT is categorized into “radiative and non-radiative” types[2]. For short and medium-range, the near-field powertransmission is operated at a distance smaller than the transmitted signal wave propagation [3]. The receiver distance of the short-range charging is smaller than the transmitting coil diameter. But, the receiver distance for mid-range varies from 1 to 10 times the transmitting coil diameter[4]. The inductive orcapacitive coupling power transfer scheme is of the “non-radiative” power transfer method.An operative distance of the “radiative or far-field” power transfer method is greater than that of the transmitting signal wavelength.

In this literature review, the history of “Wireless Power Transfer (WPT)” and the types of “radiative and non-radiative” power transfer methods are described. In the end, the major issues and future scopes of WPT were discussed.

2. Historical Background Wpt Systems

During a lecture, Han Oerested (1820), observedthe pointer movement of a compass when electricity flew through a conductor which indicatedan electric currentmagnetic effect. Andrie-Marie Ampere (1826)formulated the relationship between the magnetic field and electric current through his current law. In 1831, Michael Faraday established the “law of electromagnetic induction” which described that in a conductor there is an induction of electromagnetic force by changing magnetic field. A few years later, James Clerk Maxwell proposed that an electric field is produced in a wire as well as in an air gap even in the absence of an electric field and he created the formula for the relationship between changes in a magnetic field and induced electromagnetic force. Finally, in 1888, the existence of “electromagnetic radiation” is proved by Heinrich Hertz.

In 1891, Nicola Tesla developed the tesla coil for transmission of wireless power and he patented his Tesla coil [5]. In 1894, Teslahas lightened a lamp with a couple of coils by this wireless method [6]. In the same year, MauriceHutin [7] has issued a patent on 3 kHz frequency range Wireless power transmission.

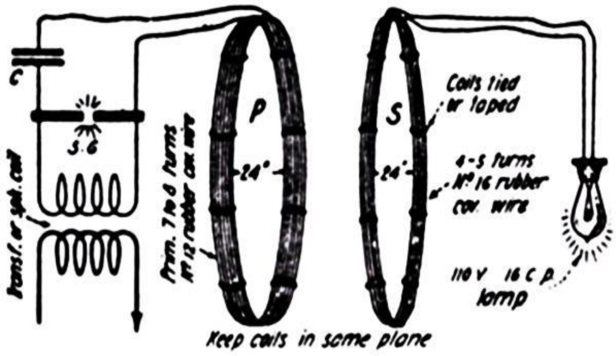

Fig 1. Tesla's experiment on light lamp with a couple of coilsfor wireless power transfer [6]

In 1895, Bose demonstrated electromagnetic waves to ring a bell remotely[8]. In 1896, Marconi transferred radio wave transmission effectively over 1.5 miles distance [9]. An airship motor with 75W was driven by wireless power through an air gap at a distance of around 100 feet in 1904 [10].

In 2007, the research group of"Massachusetts Institute of Technology (MIT)", presented a magnetresonant WPT system, to lighten 60W bulb at a distance of 2m with 60 cm-diameter and an efficiency of 40% using a couple of coils and they called it "Witricity" [11]. Intel replicated the MIT group's experiment to transfer the wireless power to lighten the bulb with 75% efficiency at a short distance in 2008 [12]. In 2014, Rim, and his team from "Nuclear and Quantum Engineering" at "KAIST" University, transmitted inductive power with a frequency of 20 kHz signals with variable efficiencies of 29%, 16%, 8% to a distance of 3,4, and 5m respectively [13]. In reference [14], the research between 2001 and 2013 on wireless power transfer is summarized. Also, the USA, South Korea, China, and Japan the major four countries that are actively working on the WPT field [14].

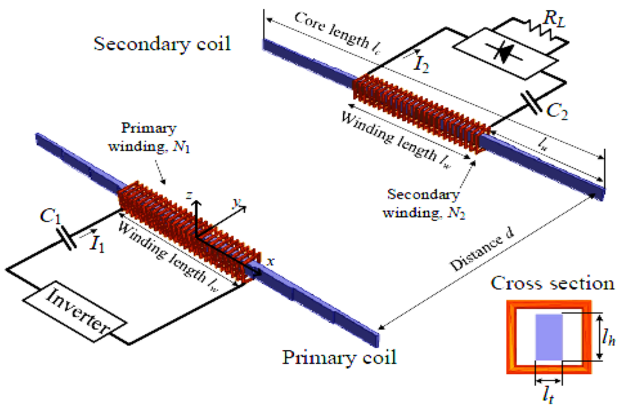

Fig. 2. General configuration of a proposed system [13]

3. Radiative Power Transfer

"Radiative propagation or far-field power transfer" technique depends on the effect of the electric field due to electromagnetic (EM) waves. The conditions of the EM wave propagation are,

- The space between the transferred signal and the received signal is larger than the transmitted wavelength.
- The dimension of the transmitter section should be greater than ten times the transmitted wavelength.

There are two kinds of radiative power transmission techniques. They are "directive and non-directive". Laser and microwaves with 300MHz - 300GHzfrequencies are utilized to transmit radiative power. In microwave power transmission, "Rectenna" is a device, which convertsthe microwave signals into DC power. The study [15] has suggested a microwave power transmission with a frequency of 2.45GHz to be utilized to solar power satellites with the dimension of transmitting cable ought to be 1Km, where the rectenna at the receiver side is 10 Km, which is unfeasible. Increasing frequency can limit the element of the reception apparatus, yet there will be a drawback of the air assimilation of the microwave.

Currently, the directivemethod of radiative wireless power transfer was used to charge the electrified vehicles remotely [16]. According to [17], the author has suggested that the system uses the transmitter power on roadside focused to rectify 80% of 10KW power to energize electric vehicles. During the wireless power transmission systemdesign, electromagnetic compatibility should be considered. Depending upon the design and infrastructure, commercializing these systems iscostly. High-frequency microwave wireless power (60 GHz) is used to powered mobile devices in cell phone networks. However, the feasibility needs additional calculation of the experiment[18-19].

To transfer power to compact devices, Omni-directional RF power transfer technology may be used for a non-directive application. The radio signals are transmitted in the same direction; to power ultra-high Radio Frequency Identification tags,the radio signals can be used for a 10m operating range[20-21]. Multi-directional RF power transfer technology is used for low-frequency limits. Using a non-directive radio frequency power transfer techniquewith a 20-200μW/cm2power density range can be utilized incontactless powered sensor networks. The realization of the data rate 500 kbps, the authors developed the 1.79mW transmitter power and 0.683mW receiver powerof a very low-power sensor network, by using the far-field method [22] and similar work has been done with batteries for power the sensor networks [23-24]. Radio Frequency (RF) energy harvesting technology converts RF waves into DC at a power level of mW to μW which is used for low-power applications such as power sensors, electronic devices, and calculators [25-26]. There are different forms of ambient waves. TV broadcast, Amplitude modulated radio broadcast,Wi-Fi routers, and electromagnetic waves of a satellite are used to harvest the energy from different microwave ranges [27-34].

4. Non-Radiative Power Transfer

“Non-radiative or Near-field”WPT technique is used to get high efficiency. The limitation of this method is that it can transfer the signal to a small distance, where the transmitted energywavelengthis greater than the receiver distance.

(a) Short Range:

For short-range wireless power transmission, the capacitive and inductive couplings techniques are used. In short-range power transmission, the receiverdistance is smaller than the coil diameter.

(i) Inductive Coupling:

Inductive coupling is familiar with its simple working principle; the energy will be transferred to the secondary coil from the primary coil by varying the magnetic flux which will induce the secondary voltage at the receiver. Therefore the wireless power transfers to load by an inductively coupled coil. For a distance of around 10cm, the power can be transferred with a frequency range of 20-40KHz. Depending upon the relationship between flux flow direction and the charging surface (Horizontal and Vertical approach), the inductive couplings are classified into two types. [35].

Commercially, wirelessly charged products such as an electric shaver, toys, electronic toothbrushes have existed significantly in the market. Such power products are adopted with fixed positioning receiver load [36]. Generally, an inductive coupling charging technique generates the eddy current in the conductor which leads to electric shock, flickering, and arcing hazards. To solve this problem, a thin EM shield is provided under the charging pad and around the receiver coil. The authors [37-39], demonstrated this technology by applying air forced cooling method to avoid the contact of the external metallic electronic devices. By designing a high-frequency WPT system using “Class-E” transmitting efficiency with the frequency of 134 kHz, 295W power,and 75.7% efficiency is developed. A scheme based on inductive charging for medical applications can be transferred 20W power to a distance of 1cm with 80% efficiency has been proposed by the authors. Also, the main changes between high-power and low-power inductive coupling have been distinguished [40]. An MIT research group developed a wireless charging technique called “MagMIMO” to charge the wireless devices with a distance of around 30cm away [41].

(ii) Capacitive Coupling:

The power is transferred over an electric field across two electrodes in capacitive coupling. The quantity of powertransferred is proportional to the frequency range. By increasing the frequency, the transferred energy can be increased with and vice versa. The merit of this technology is that power can be transferred through metal which can be used for low-power applications but cannot be used for biomedical applications. When high voltage is passing through the electrodes, it affects the human beings and materials connected to it.

Thecapacitive coupling is classified into two categories. They are (i) Unipolar design or longitudinal design and (ii) Transverse or Bipolar design. In bipolar circuits, the receiving plates are constantly adjusted to the charging plates.

(b) Medium Range:

In the mid-range, power is transferred with a distance between 0.5m - 5m. The systems have been proposed with the operating frequency range of 10 kHz-200MHz with two coils, three coils, and four coils. Thismethod can be utilized by homes and offices to energize and transfer power [2]. The two types of proposed techniques to transfer the power are magneticallycoupled and inductively coupled resonance power transfer systems. The frequency of the resonant circuitis more reliable due to its reduced leakage and hence long-distance power transfer is possible. Using electromagnetic field analysis, the relationship between air gap length, frequency, and power efficiencywas studied for the magnetic coupling circuit [42].

5. Future Challenges And Scopes

The main challenge in the non-radiative power transfer method is the transmission distance. This can be improved by integrating core links to increase the reliability in medical applications. Low power efficiency is the main limitation in mid and long-range power transfer technology. Also to achieve maximum efficiency in a mid-range requires impedance matching [2]. By maximizing the inductive coilquality factor, design with proper load drive, impedance matching between transmitter and load for different distances. The development of an adaptive rectifier for a resonant magnetically coupled circuit is also desired [43]. Reduction of transmitter and receiver model, reduction of interference with external object surrounded by the device are the other issues in a mid-range power transfer system to be addressed [44]. During the design stage, the following factors should be considered for both short and mid-range power transmission. First, it should not have any data corruption data in credit cards or smart cards. Also, the emitted magnetic flux should not have fire hazards, and nearby objects should not be heated up. Second, it should be capable to find the position of transferredenergy [45].

The main objectives of “radiative or far-field” power transfer systems are directivity and efficiency improvement. Even thougha microwave with a high gain rectenna nearly kilometer distance with an efficiency of around 90% has been utilized by several systems.These systems are still affected by the requirement for an end to end connection[46-47]. To cover more area and a directive antenna to improve the efficiency, there is a need for an omnidirectional antenna.To find the location of the load andtransfer the radiated beam, the transmitter is required.

6. Conclusion

Wireless power transfer technology gains more attention among researchers due to its safety and cordless power supply for many industrial and electronic applications. It is a promising technology in the past decade. This systematic literature review, the historical development of power transmission technology, types of microwave “radiative and non-radiative”WPT techniques, and its evaluation table were presented. Finally, some of the difficulties and future workshave been discussed.

Table 1.EVALUATION OF VARIOUS “RADIATIVE AND NON-RADIATIVE” WPT TECHNIQUES

S. NO.	DESCRIPTION	TYPES OF MICROWAVE WPT TECHNIQUES					
		RADIATIVE (FAR-FIELD)		**NON-RADIATIVE (NEAR-FIELD)**			
1	**Operating range**	Long-range		Short-range		Mid-range	
2	**Methods of Power transmission and frequency range**	Radio Frequency (RF) / Microwave (300 MHz to 300 GHz)	Laser (up to10 times of THz)	Inductive Coupling (10 kHz to 1 Mhz)	Capacitive Coupling (Low -Frequency and High Frequency	Inductive resonance coupling	Capacitive resonance coupling
3	**Efficiency (η)**	Very low		high		Medium	
4	**Merits**	1. It is useful for portable devices. 2. It can be transmitted for long distances, generally from meters to kilometers.		1. Up to 95% of efficiency for the distance from mm to few centimeters. 2. Power should transfer through the metallic element.		1. At once, Charging is possible for many devices. 2. Efficiency is high for some centimeters to meters.	
5	**Demerits**	1. Harmful to neighboring materials and human beings due to radiation. 2. If Omni-directional, the efficiency is low. 3. It requires to transfer the power, end to end connection.		1. Powerful interaction with the human body and materials. 2. Induction of Eddy current is possible in a metallic element. 3. The requirement of the coupling area is large.		1. .Cost and switching losses are high due to high operating frequency.	

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