Design of Wireless Power Transfer System for Charging of Electronic Gadgets

Lala Bhaskar¹, Pradeep Kumar², Kishore Naik Mude³

¹ Amity Institute of Information Technology, Amity University Uttar Pradesh
² Amity School of Engineering and Technology, Amity University Uttar Pradesh
³ Systec R&D, Porto, Portugal

E-mail: lbhaskar1@amity.edu

Abstract. Wireless charging of gadgets is one of the new emerging technologies in the world at present moment. The most common method used is wireless power transfer by using the method of inductive coupling. Wireless power transfer is one of the simplest and inexpensive ways of charging as it eliminates the use of conventional copper cables and current carrying wires. The inductive coupling technique is used since currently it is the easiest method of wireless power transfer because of high efficiency and large amount of the energy transferred. Its versatility and range of applications the power transferred will be used to charge a battery with the aid of additional circuitry. This research work focuses on the study of wireless power transfer for the purpose of transferring energy at maximum efficiency within a small range or in the near field region. The motivation to this proposed design model is contact less mobile device charging about 5cm-100cm distance range, which can be used to charge the mobile electronic devices like mobile phones, laptops, smart phones wirelessly. This proposed design is very helpful in the pandemic situation to charge electronic gadgets contactless as well wirelessly in the hospitals, public transports like metro stations, educational institutions, and in office communication systems.

1. Introduction

Wireless Power Transmission (WPT) is about transferring electricity over a distance without using wires, this distance may vary according to its application. It is most efficient for short distances but techniques for long distance transmission have also been developed. Wireless Power Transmission has been researched for over a century with initial demonstrations from Nikola Tesla in the 1890s. The potential to reduce or eliminate the need for wires and batteries in devices has been alluring to manufacturers and consumers who are tired of carrying accessories along with their portable devices. Applications of this field are also in remote areas where it is difficult or hazardous to provide wired power. While various techniques for WPT exist, only a few are considered efficient enough to be economically feasible. These techniques have several applications making it important to study them to identify techniques that are efficient and economically feasible. Wireless Power Transmission (WPT) has seen major breakthroughs in the past decade since its first demonstration by Nikola
Tesla in the 1890s through the creation of Tesla Coil. He used a radio frequency resonant transformer to transmit electricity by producing high voltage and high frequency alternating current through the transformer. However, the energy transmission could be demonstrated only over a short distance. Between 1899 and 1900, Tesla discovered Terrestrial Stationary Waves which he considered as one of his great discoveries. According to Tesla Memorial Society of New York, “by this discovery he proved that the Earth could be used as a conductor and would be as responsive as a tuning fork to electrical vibrations of a certain frequency. He also lighted 200 lamps without wires from a distance of 25 miles (40 kilometers) and created man-made lightning.” [1,3] On the basis of this, he designed the Wardenclyffe Tower or Tesla Tower in 1901 to conduct experiments on long distance wireless power transmission. However, due to the lack of funds and debt, this project was abandoned in 1906.

Wireless power transmission was, once more, a topic of research in 2007 when WiTricity, an MIT initiative was successful in transferring power over 2m. After this, there was an increase in studies on WPT and different ways to improve the efficiency as well as the distance of transmission. Large companies such as Samsung and Apple have been able to develop coils for efficient wireless charging. They have been able to commercialize it and effectively use it to charge some of their devices like mobile phones, watches as well as wireless earphones. A future application is the use of WPT in space missions. Since there are huge risks related to the use of electrical wires in space, WPT will be an efficient alternative. Study conducted by (G. V. Ramos et al.) found that WPT is a reliable alternative to electrical connectors however an advanced design is required for practical use.[2] These designs would be highly specific to the area of use (such as launch vehicles, rovers, etc.) Qi (pronounced as chee) is a consortium, which standardizes the specification (for example frequencies at which a device may operate, designs of transmitters, etc.) for transferring power wirelessly using inductive coupling. It was established in 2008 with limited specifications for up to 5W (released in 2009) of power transfer. They have since released more versions, expanding their coverage areas for up to 30W (version 1.2.3). Consortium members are also developing standards to provide 30 - 60 W power for laptop charging. Its kitchen standard provides a wide range of power (200-2,400 W) to kitchen appliances. Qi also has a certification program conducted by independent authorized test labs that test products for properties such as safety, interoperability, and usability prior to being allowed to use the Qi certified logo. [7] There are news items indicating that Apple is seriously considering removing wires entirely from its phones/devices thus providing ample space for other important features. These changes are likely to provide a significant impetus to universal adoption of WPT.

Figure 1 The Block Diagram of WPT System [14]
2. Wireless Power Transfer System Design

In a WPT system using IPT, the AC voltage provided to our homes is first converted to DC supply using a Full Wave Rectifier with Capacitor Filter. This provides us with a regulated DC supply. This DC supply is considered as the source of the driving circuit. The transmitter coil is fed with AC at the requisite frequency through the oscillator using a DC source. The DC source is required to be converted into high frequency AC because at high frequency the quality factor increases, which then increases the transmission efficiency of the system. This high frequency AC supply is then provided to the transmitter coil. When an alternating current passes through a coil, it induces an alternating magnetic field around it. This leads to a flux linkage between the transmitter and the receiver coils. The stronger the flux linkage, the greater is the strength and hence the efficiency of transmission. The magnetic flux then induces an EMF (Electromotive Force) in the receiver coils through Mutual Inductance and by Lenz Law it generates a current which opposes the change produced by the magnetic field. According to Faraday’s Law, “The magnitude of voltage is directly proportional to the rate of change of flux.” The generated AC is converted to DC through a Full Wave Rectifier with a Capacitor Filter. This steady DC supply is still a high voltage supply and hence, it is then regulated through a voltage regulator to receive the required voltage as per the device requirement. This DC supply is fed to the device (load). Hence, power is transferred wirelessly. A basic Wireless Power Transfer system for Inductive Coupling and Resonant Inductive Coupling needs a Source, an Electronic Oscillator, a Transmitter Coil, a Receiver Coil, a Full Wave Rectifier with a Capacitor Filter, a Voltage Regulator and a Load. More coils may be added between the transmitter and receiver coils to increase the distance of transmission of power. These coils are known as Intermediate Coils. The following are the basic components of a Wireless Power Transfer System:

**Source:** The source provides power or energy to a given circuit. In case of an IPT or RIC system, a DC power source is used. This source provides AC at a high frequency to the transmitter coil.

**Electronic Oscillator:** The oscillator is a circuit that produces a continuous, repeated, alternating waveform without any input.[11] It converts DC source to an AC waveform of the required frequency [8]. In this case, a high frequency output is required to increase the quality factor which increases the efficiency of power transmission. Royer Oscillator is usually used in WPT systems as it can generate maximum frequency of oscillations at the required frequency [9], has a low cost and is less bulky and smaller in size as compared to other oscillators.[12]
Transmitter Coil: Transmitter Coil is an inductive coil which is used to generate a magnetic field. The strength of this can be increased using greater number of coil turns, this can affect the distance of effective transmission[4].

Receiver Coil: Receiver Coil is an inductive coil similar to that of the transmitter coil. This utilizes Faraday’s Law of Induction and Lenz Law, generating a current in it. An increase in the number of coils, increases the efficiency of power transmission.

Full Wave Rectifier with a Capacitor Filter: The Full Wave Rectifier converts the incoming AC supply (from the Receiver Coil) to a DC supply. However, the DC supply received is variable and hence to smoothen the variable DC supply we use an additional capacitor to the rectifier.[6] This generates a steady DC output. A similar arrangement may be needed to generate a DC source from an AC power source at the transmitter end.

Voltage Regulator: The Voltage Regulator generates a fixed output voltage of a pre-set magnitude that can remain constant irrespective of changes to its input voltage or load conditions.[13] A voltage regulator is required to maintain a constant output as required by the device (load).

Load: Load is the part of the circuit that uses the power. In case of WPT systems, the load is the device to which the power is being provided wirelessly. In this, paper we are limiting the devices to appliances which do not consume much power (<40W).

3. WPT System Hardware Implementation

In this paper, the primary coil is designed with 160 turns and the secondary coil is designed with 150 turns. The primary and secondary coil diameter is 15cm. An amended form of the original Wheeler formula for an Archimedean spiral coil has been used to calculate the geometric parameters of the spiral coil from the estimated value of self-inductance[10,11]. Figure 3 shows the representation of an Archimedean spiral.

![Figure 3](image_url)

Figure 3 Physical representation of Archimedean spiral (a) 3-D view [15] (b) Cross-sectional view

The expression for inductance is given as: 

\[ L = \frac{N^2 A^2}{(30A - 11D_i)} \]

Where \( A = \frac{D_o + N(W + S)}{2} \)

From Figure 3 it is obvious that \( D_{out} \) is the outer diameter, \( D_{in} \) is inner diameter, \( S \) is the spacing between turns and \( W \) is the diameter of the wire used for making the coil.
Figure 4 shows the design of wireless power transfer system for charging of electronic gadgets. The proposed design able to charge the mobile devices wirelessly. The distance between the primary coil and secondary coil is varied from 5cm to 100cm. The power received in secondary coil able to charge the mobile electronic gadgets. Figure 5 shows the top view of the output power received in secondary coil up to the distance of 100cm.

Figure 6 shows the mutual inductance between the two coils decreases as the distance between the primary and secondary coils increases due to the reason that coupling coefficient decreases as the distance between coils increases. The maximum power transferred is 45.6W. The output power received in secondary coil is in the range of 5W-45.6W and is best suited for charging of portable electronic devices.
4. Conclusion

The Design of Wireless Power Transfer for office communications is successful for charging the electronic gadgets up to 100cm distance between the primary and secondary coil. The distances between transmitter coil and receiver coil is increased from 5cm to 100cm and observed the power output received in the secondary coil carrying enough power to charge the systems like Laptops, monitors, mobile phones, printers which are widely used in the office communication systems. The distance between the primary and secondary coil is further increased by having the intermediate coils between the primary and secondary coils.

5. References

[1] M. G. L. Roes, J. L. Duarte, M. A. M. Hendrix and E. A. Lomonova, “Acoustic Energy Transfer: A Review,” IEEE Trans. on Industrial Electronics, vol. 60, no. 1, pp. 242-248, Jan. 2013.

[2] Y. Hu, X. Zhang, J. Yang and Q. Jiang, “Transmitting electric energy through a metal wall by acoustic waves using piezoelectric transducers,” IEEE Trans. on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 50, no. 7, pp. 773-781, July 2003.

[3] A. Sahai and D. Graham, “Optical wireless power transmission at long wavelengths,” in Proc. International Conference on Space Optical Systems and Applications, Santa Monica, CA, 2011, pp. 164-170.

[4] S. Sasaki, K. Tanaka and K. Maki "Microwave Power Transmission Technologies for Solar Power Satellites," in Proc. of the IEEE, vol. 101, no. 6, pp. 1438-1447, June 2013.

[5] L. Summerer and O. Purcell, "Concepts for Wireless Energy Transmission via Laser," 2008.

[6] J. Dai and D. C. Ludois, "A Survey of Wireless Power Transfer and a Critical Comparison of Inductive and Capacitive Coupling for Small Gap Applications," IEEE Transactions on Power Electronics, vol. 30, no. 11, pp. 6017-6029, Nov. 2015.

[7] G. a. Covic and J. T. Boys, “Inductive Power Transfer,” Proc. IEEE, vol. 101, no. 6, pp. 1276–1289, 2013.

[8] N. Tesla, “High frequency oscillators for lectro-therapeutic and other purposes,” in Proc. IEEE, vol. 87, no. 7, pp. 1282–1292, 1999

[9] S. Y. R. Hui, "Magnetic Resonance for Wireless Power Transfer [A Look Back]," IEEE Power Electronics Magazine, vol. 3, no. 1, pp. 14-31, March 2016.

[10] H. A. Wheeler, "Simple Inductance Formulas for Radio Coils," in Proceedings of the Institute of Radio Engineers, vol. 16, no. 10, pp. 1398-1400, Oct. 1928.

[11] H. A. Wheeler, "Inductance formulas for circular and square coils," in Proceedings of the IEEE, vol. 70, no. 12, pp. 1449-1450, Dec. 1982.

[12] S. S. Mohan, M. del Mar Hershenson, S. P. Boyd and T. H. Lee, "Simple accurate expressions for planar spiral inductances," in IEEE Journal of Solid-State Circuits, vol. 34, no. 10, pp. 1419-1424, Oct 1999.

[13] Lala Bhaskar, Pradeep Kumar, Kishore Naik Mude “Wireless Power Transfer to Low Power Devices” 1st International Conference on Advances in Information Technology (ICAIT), pp 522-524, July, 2019

[14] Lala Bhaskar, Pradeep Kumar, Kishore Naik Mude “Simulation Analysis of Wireless Power Transfer for Future Office Communication Systems” International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol 8, Issue-9S, July 2019

[15] Kunwar Aditya, Sheldon S. Williamson “Design Guidelines to Avoid Bifurcation in a Series-Series Compensated Inductive Power Transfer System” IEEE Transactions on Industrial Electronics, vol.66, no.5, May2019