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Wireless Power Transmission Using Resonant Coupling and Induction

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Abstract

The paper presents the idea to transfer power wirelessly, without use of any physical contact between source and load. Wireless power technology offers the promise of cutting last cords, allowing user to wirelessly charge the mobile through air. We present the idea of magnetically coupled resonator for Wireless Power Transfer (WPT) which has cited promising results. Here a circuit model is presented along with the system key concepts such as frequency splitting over the operating distance (critical coupling), and behaviour of the system as it becomes under coupled. We have also shown several points relating to history of wireless power transfer along with the present day senario of power transmission and also some of the developmental changes in WPT.

This paper provides a view on the evolution of wireless power transmission with its advantage, disadvantage and applications of WPT in different fields.

Index Terms— *Wireless Power Transfer (WPT), Magnetically Coupled Resonator, Frequency Splliting etc.*

1. Introduction

Wireless power is not a new technology. Different incarnations have been in development for over 130 years when Hertz (in 1886) performed a successful experiment with wireless energy transfer [1].The area of wireless power transmission is very interesting. The technology is in its infancy but the overall benefits from its maturation could be significant to society as a whole. World population is expected to continue to grow exponentially. We live in a world that is rapidly progressing toward newer and greater levels of convenience, connectivity and freedom. This is the age of the wireless power and communications revolution, where everything from handheld consumer electronics to home appliances to transportation is incorporating wireless technologies to create new levels of convenience, interaction and monitoring. While tremendous progress has been made because of technologies including Bluetooth,Wi-Fi, radio frequency (RF), Ultra Wide Band (UWB) and global positioning systems (GPS), one last tether has kept consumers from making the leap to a completely wireless lifestyle – the power cord. In research conducted by the Alliance for Universal Power Supplies, consumer demand for “simplicity, a better charging experience and convenience,” along with manufacturing, usability, waste and environmental concerns surrounding the billions of power adapters that are produced and shipped each year globally, have created a surge of interest in wireless power solutions. All of these trends point to an energy demand that will grow at even a larger rate. Wireless power transmission could one day allow us to generate solar power on a satellite and beam it down to Earth, transmit power to a water treatment plant for a disaster relief operation or power a flying communication relay station from a terrestrial station. There are a few engineering hurdles yet to overcome to make this technology viable to today’s investors, but with the rising demand for energy and the rapid improvements being made it is just a matter of time before wireless power transmission becomes an industry of its own.

2. History

The discussion of wireless power transmission as an alternative to transmission line power distribution started in the late 19th century. Both Heinrich Hertz and Nicolai Tesla theorized the possibility of wireless power transmission. Tesla demonstrated it in 1899 by powering fluorescent lamps 25 miles from the power source without using wires[2][3]. Despite the novelty of Tesla’s demonstration and his personal efforts to commercialize wireless power transmission, he soon ran out of funding because it was much less expensive to lay copper than to build the equipment necessary to transmit power through radio waves.

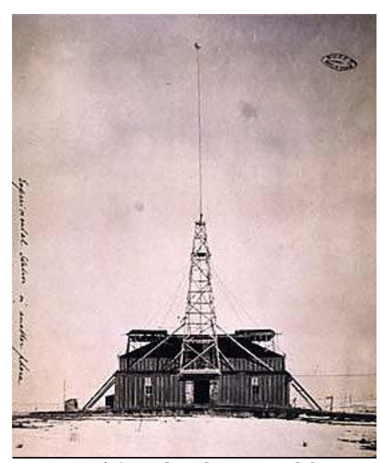

Fig. 1. Tesla’s Colorado springs lab

William C. Brown contributed much to the modern development of microwave power transmission which for many reasons dominates research and development of wireless transmission today. In the early 1960s brown invented the

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rectenna which directly converts microwaves to DC current. He demonstrated its ability in 1964 by powering a helicopter from the solely through microwaves. "In 1982, Brown (Raytheon) and James F. Trimer (NASA) announced the development of a thin-film plastic rectenna using printed-circuit technology that weighed only one-tenth as much as any previous rectenna" [4]. This new, lighter weight rectenna led to the development of the Stationary High Altitude Relay Platform (SHARP). Latter this technology is used in World's first fuel free airplane powered by microwave energy from the ground in 1987 at Canada.

A physics research group, led by Prof. Marin Soljacic, at the Massachusetts Institute of technology (MIT) demonstrated wireless powering of a 60W light bulb with 40% efficiency at a 2m (7ft) distance using two 60cm-diameter coils in 2007.
In 2008, Intel reproduced the MIT group's experiment by wirelessly powering a light bulb with 75% efficiency at a shorter distance. MIT team experimentally demonstrates wireless power transfer, potentially useful for powering laptops, cell phones without any cords. Imagine a future in which wireless power transfer is feasible: cell phones, household robots, mp3 players, laptop computers and other portable electronics capable of charging themselves without ever being plugged in, freeing us from that final, ubiquitous power wire. Some of these devices might not even need their bulky batteries to operate.

A team from MIT's Department of Physics, Department of Electrical Engineering and Computer Science, and Institute for Soldier Nanotechnologies (ISN) has experimentally demonstrated an important step toward accomplishing this vision of the future. Realizing their recent theoretical prediction, they were able to light a 60W light bulb from a power source more than two meters away, there was no physical connection between the source and the appliance. The MIT team refers to this concept as "**WiTricity**"[5]

Fig. 2. WiTricity

3. Basic Principle

The basic principle of an inductively coupled power transfer system is shown in Figure 3. It consists of a transmitter coil L1 and a receiver coil L2. Both coils form a system of magnetically coupled inductors. An alternating current in the transmitter coil generates a magnetic field which induces a voltage in the receiver coil. This voltage can be used to power a mobile device or charge a battery.

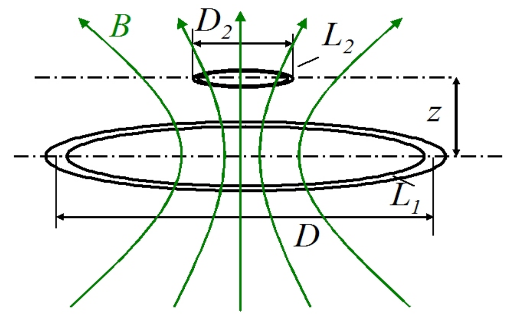

Fig. 3. Typical arrangement of inductively coupled power transfer system.

The efficiency of the power transfer depends on the coupling (k) between the inductors and their quality (Q). (See also Figure of merit). The coupling is determined by the distance between the inductors (z) and the ratio of D2 /D.The coupling is further determined by the shape of the coils and the angle between them (not shown).[6]

4. Transfer Efficiency

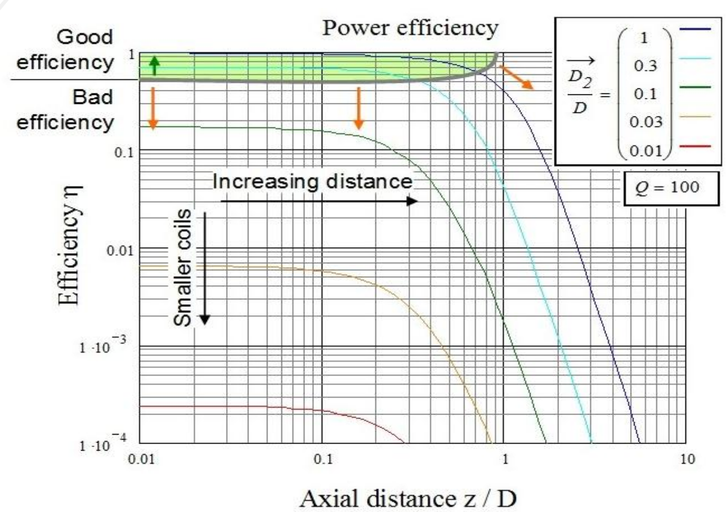

Fig. 4. Power efficiency for an inductive power transmission system consisting of loop inductors in dependence on their axial distance z with size ratio parameter.(for Q=100)

Fig. 4 shows the calculated optimal efficiency of a system according to Fig. 3 with an assumed quality factor of 100.

Dimensions for these calculations have been scaled to the larger diameter coil 'D', which can be either the transmitter or receiver. The values are shown as a function of the axial distance of the coils (z/D). The variable is the diameter of the smaller coil D2.

The figure shows that:

• The efficiency drops dramatically at larger distance (z/D > 1) or at a large size difference of the coil (D2/D < 0.3)

• A high efficiency (>90%) can be achieved at close distance (z/D < 0.1) [8].

This shows that inductive power transmission over a large distance, e.g. into a space, is very inefficient. Today, we cannot afford to waste energy for general power applications by using such a system. On the other hand, the figure shows that inductive power transmission is competitive with wired solutions under close proximity settings. Wireless proximity power transmission combines comfort and ease of use with today's requirements for energy saving.

5. Resonant Coupling

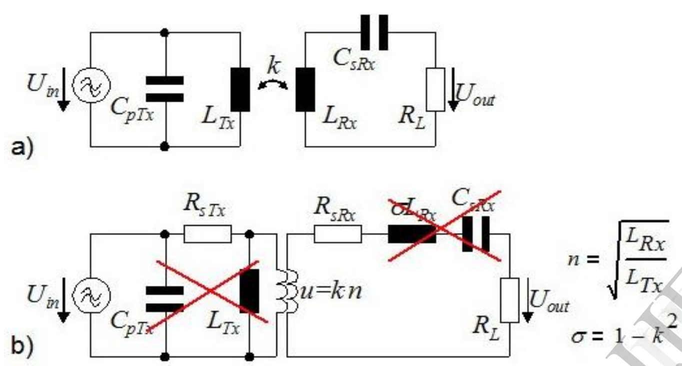

Fig. 5. Circuit diagram of Wireless Power System with resonant capacitors.(a) General circuit diagram (b) Equivalent circuit diagram with magnetizing and stray inductance

From the beginning of inductive power transmission, resonant circuits are used to enhance the inductive power transmission. Already Nicola Tesla used resonances in his first experiments about inductive power transmission more than hundred years ago. Especially for systems with a low coupling factor, a resonant receiver can improve the power transfer.

Resonant power transmission is a special, but widely used method of inductive power transmission and is limited by the same constraints of magnetic fields emissions and efficiency. To understand the effect, it can be compared to mechanical resonances. Consider a string tuned to a certain tone as mechanical resonator [10]. Even a far away and low level sound generator can excite the string to vibration, if the tone pitch is matched. Here, the resonator in the receiver consists of the receiver inductance and a capacitor. Also the transmitter can have a resonator. The general arrangement is illustrated in Fig. 5. The transmitter and receiver coils LTx and LRx can be considered as weakly coupled transformer. For this, an equivalent circuit diagram consisting of magnetizing and stray inductance can be derived, as shown in 6b. In this diagram, also the resistances of the windings are shown. The diagram shows clearly, that the resonant capacitors cancel out the stray inductance in the receiver and the magnetizing inductance in the transmitter. Now, the only remaining limit for the power transmission is the winding resistances of the coils, which impedance is one or two orders of magnitude lower than that of the inductances. Therefore, for a given generator source, much more power can be received.

6. Advantages

6.1 The electrical energy can be economically transmitted without wires to any terrestrial distance, so there will be no transmission and distribution loss.

6.2 At a certain time with a single module we can charge more than one equipment with in range like mobile phones, camera, tooth brush etc…

6.3 The power failure due to short circuit and fault on cables would never exist in the transmission.

6.4 An electrical distribution system, based on this method would eliminate the need for an inefficient, costly, and capital intensive grid of cables, towers, and substations.

6.5 System would reduce the cost of electrical energy used by the consumer.

6.6 It will change the senario with landscape of wires, cables, and transmitting towers.

6.7 Power theft would be not possible at all.

7. Disadvantages

7.1 Cost for practical implementation of WPT to be very high.

7.2 The other disadvantage of the concept is interference of microwave with present communication systems.

7.3 Effiency decreases as the range of WPT increases.

8. Applications

8.1 One of the major applications of wireless power transfer is wireless mobile phone charging which is growing exponentially with time.

8.2 It has also the wide applications in medical industries like Pacemakers, Cardiac Defibrillators, Deep Brain Neurosimulators, Gastric Simulators etc. can be wirelessly powered in the body

8.3 Used to charge the battery operated vechiles wirelessly during its parking.

8.4 Mobility - user device can be moved easily within the wireless range.

8.5 Different home appliances can also be powered by using wireless power transfer.

8.6 Moving targets such as fuel free airplanes, fuel free electric vehicles, moving robots and fuel free rockets. The other applications of WPT are Ubiquitous Power Source (or) Wireless Power Source, Wireless sensors and RF Power Adaptive Rectifying Circuits (PARC).

9. Conclussion

Wireless power systems are constantly evolving as more and more practical options for conveniently charging smartphones and other mobile devices. This concept offers greater possibilities for transmitting power (by increasing frequency) with negligible losses and ease of transmission than any invention or discovery have ever made. The energy-saving advantages arise from (i) the reduction of the standby power and (ii) the reduction of manufacturing and transportation energy of unnecessary wired power adapters.Besides the energy savings aspects, the potential reduction of huge amount of electronic waste arising from the reduction of the number of conventional power adapters also contributes greatly to environmental protection in the long run. User experience is the key factor that drives technology development, paving the way for safer and more convenient devices accompanying us in everyday life.

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