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Research Article

INVESTIGATING THE DIFFERENT WIRELESS POWER TRANSMISSION SYSTEMS

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ABSTRACT
The main reason for power loss during transmission and distribution is the resistance of wires used for grid and as growing all technologies in the world, nowadays one of the efforts is trying for accessing the power without wires. Wireless power transmission systems are designed to transmit power without using wires. In this paper Wireless Power Transmission is defined in detail and some of its applications are mentioned. Also components of a Wireless Power Transmission system are explained. Different types of Wireless power Transmission Systems are mentioned and described in detail along with their advantages and shortcomings. Then a comparison is performed between different PWT systems.

Keywords: *Wireless Power Transmission; WPT; Microwave WPT; Resonance Coupling; Inductive Coupling*

INTRODUCTION
One of the major issue in power system is the losses occurs during the transmission and distribution of electrical power. As the demand increases day by day, the power generation increases and the power loss is also increased. The major amount of power loss occurs during transmission and distribution (Chunbo *et al.*, 2008). The percentage of loss of power during transmission and distribution is approximated as 26%. Figure 1 shows the power loose while using wires. The main reason for power loss during transmission and distribution is the resistance of wires used for grid and as growing all technologies in the world, nowadays one of the efforts is trying for accessing the power without wires (Naoki, 2010).
Wireless power transmission has been studied and experimented with since the first experiments by Tesla end of the 19th century and the first successful laboratory scale demonstrations during the 1960s by Brown *et al.*, (Koert and Cha, 1993).
Nikolo (1888) for the first time in the world developed the principles of his Tesla coil and began working with his ideas for poly phase systems, which would allow transmission of AC electricity over large distances. The connection would be made by electrostatic induction or conduction through plasma. Tesla firmly believed that Wardenclyffe would permit wireless transmission and across large distances with negligible losses.
But after lighting vacuum tubes wirelessly, he provided us with enough evidence of the potential and feasibility of wireless power transmission network (Chunbo *et al.*, 2008).

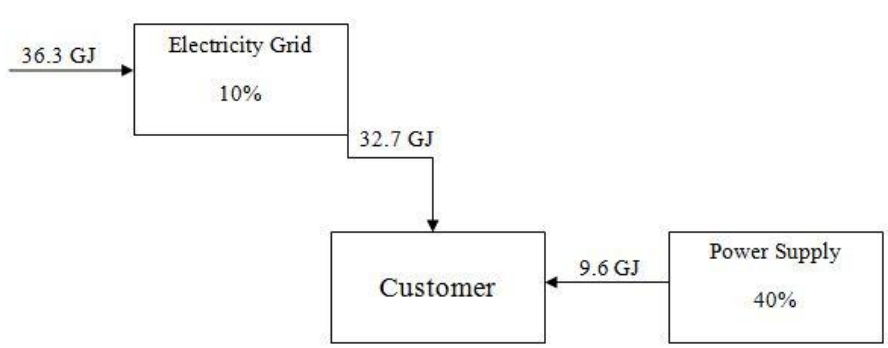

Figure 1: Power loose using wires

There are several kinds of Wireless Power Transmission (WPT); WPT via radio waves, especially via microwaves, resonance coupling, and inductive coupling. Wireless power transmission systems are designed to transmit power without using wires more efficient than transmitting it while using wires.

There could be large number of applications for wireless power systems. These systems can be used in Mobile devices such as Laptops, PDAs, Cellular Phones, Music players also they can be used in Household devices such as Vacuum Cleaners. WPT systems can be used for implementing medical devices with different purposes.

WiTricity is defined as transferring electric energy or power over distance without wires. WiTricity will ensure that the cellphones, laptops, iPods and other power hungry devices get charged on their own, eliminating the need of plugging them in. Even better, because of WiTricity some of the devices won't require batteries to operate. 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 technology. Realizing recent theoretical prediction, they are able to light a 60W light-bulb from a power source seven feet (more than 2 meters) away when there is no physical connection between the source and the appliance. The MIT team refers to their concept as “WiTricity” (Wireless Electricity).

The remainder of the paper is organized as follows:

The components of the wireless power transmission systems are defined in Section 2. In Section 3 wireless power transmission using Microwave is and its advantages are explained. Wireless power transmission using strongly coupled magnetic resonance is described in detail in Section 4.In Section 5, Wireless Power Transmission system using inductive coupling, its advantages and shortcomings are explained. A compression is performed between these different systems for wireless power transmission in section 6. Finally, conclusions are presented in Section 7.

Components of WPT System

The Primary components of Wireless Power Transmission are Microwave Generator, Transmitting antenna and Receiving antenna (Rectenna).

A. Microwave Generato

The microwave transmitting devices are classified as Microwave Vacuum Tubes (magnetron, klystron, Travelling Wave Tube (TWT), and Microwave Power Module (MPM) and Semiconductor Microwave transmitters (GAAS MESFET, GAN PHEMT, SIC MESFET, ALGAN/GAN HFET, and INGAAS). Magnetron is widely used for experimentation of WPT. The microwave transmission often uses 2.45GHz or 5.8GHz of ISM band. The other choices of frequencies are 8.5 GHz (Alanson *et al.,* 2010.), 10 GHz (Chunbo *et al.,* 2008) and 35 GHz (Tesla, 1904). The highest efficiency over 90% is achieved at 2.45 GHz among all the frequencies (Tesla, 1904).

B. Transmitting Antenna

The slotted wave guide antenna, micro strip patch antenna, and parabolic dish antenna are the most popular type of transmitting antenna. The slotted waveguide antenna is ideal for power transmission because of its high aperture efficiency (> 95%) and high power handling capability.

C. Rectenna

The concept, the name ‘rectenna’ and the rectenna was conceived by W.C. Brown of Raytheon Company in the early of 1960s (5).The rectenna is a passive element consists of antenna, rectifying circuit with a low pass filter between the antenna and rectifying diode. The antenna used in rectenna may be dipole, Yagi – Uda, microstrip or parabolic dish antenna. The patch dipole antenna achieved the highest efficiency among the all. The performance of various printed rectenna is shown in Table I. Schottky barrier diodes (GaAsW, Si, and GaAs) are usually used in the rectifying circuit due to the faster reverse recovery time and much lower forward voltage drop and good RF characteristics (Sheik *et al.,* 2010).

Wireless Power Transmission via Microwave

Wireless Power Transmission (WPT) is a technology in which there is no wire for charging a battery for high power users or any battery for tiny power users via the WPT. WPT systems have different characteristics. One of the earliest demonstrations of wireless energy transfer was the use of microwave radiation to power a small helicopter in 1964 (Brown, 1984).

This experiment contained the basic elements of microwave power transmission: a source of electromagnetic radiation, and a microwave receiver with a DC rectifier to transform the microwave energy into DC electrical power.

Since then, efforts have been made to increase the efficiency, power, and range of microwave transmission. Brown (1961) published the first paper proposing microwave energy for power transmission, and in 1964 he demonstrated a microwave-powered model helicopter that received all the power needed for flight from a microwave beam at 2.45 GHz (Brown *et al.*, 1961) from the range of 2.4GHz – 2.5 GHz frequency band which is reserved for Industrial, Scientific, and Medical (ISM) applications (Anand and Sanjay, 2010). The characteristics of the WPT via radio wave are based on the technologies and system design of wireless communication. It uses an antenna for a transmitter and a rectenna, rectifying antenna, for a receiver in the WPT via radio waves. Therefore, it seems the efficiency is low because it uses radiation of radio wave to transmit the power. Rectenna conversion efficiencies exceeding 95% have been realized.

Power beaming using microwaves has been proposed for the transmission of energy from orbiting solar power satellites to Earth and the beaming of power to spacecraft leaving orbit has been considered. However, the efficiency can increase close to 100 % via radio waves. The WPT via radio waves is most versatile WPT for applications from short range to long range with higher efficiency.

Figure 2 shows an artist's depiction of a solar satellite that could send electric energy by microwaves to a space vessel or planetary surface and in figure 3 a conceptual image of solar power station/satellite is shown.

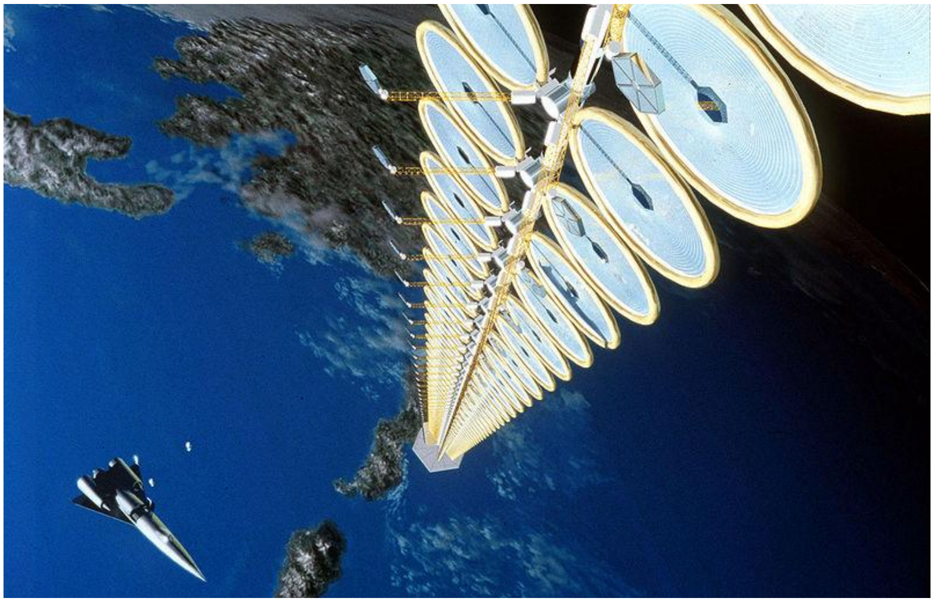

Figure 2: Solar Satellite sending electric energy by microwaves to a space vessel or planetary surface

Microwave electricity transmission has several advantages; using microwaves power level is well below international standard and the frequency is upto 2.45 GHZ of the Micro Beam. With using Microwaves for transmitting power, no air or water pollution is created and during generation, power can be beamed to the location where it is needed and there is no need for invest in a large electrical grid.

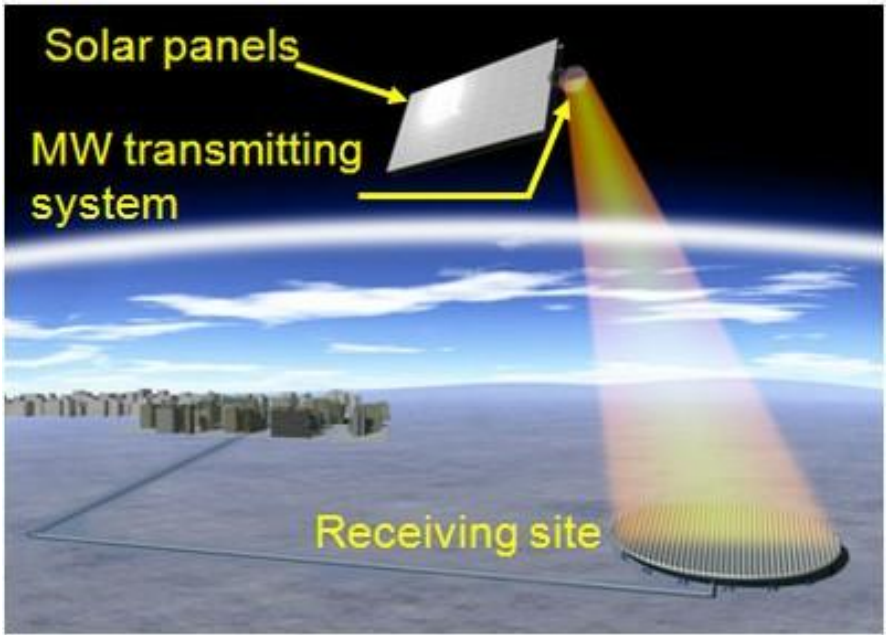

Figure 3: Conceptual image of solar power station/satellite

Wireless Power Transmission using Strongly Coupled Magnetic Resonance

One of the wireless power transmission systems is based on using coupled resonant objects. Two resonant objects of the same resonant frequency tend to exchange energy efficiently, while interacting weakly with extraneous off-resonant objects. Coupled Mode Theory (CMT), Haus (1984) provides a simple and accurate way of modeling the system and gives a more understanding of what makes power transfer efficient in a strongly coupled rejoin.

The basic principle behind this system is that, if two resonant circuits tuned at same frequency then their near fields (consisting of evanescent waves coupled by means of evanescent wave coupling) then due to this evanescent wave coupling standing wave developed between inductors, which can allow energy to transfer from one object to other within time. Evanescent wave coupling is a process by which electromagnetic waves are transmitted from one medium to other by means of evanescent exponentially decaying electromagnetic field. Electromagnetic evanescent waves have been used to exert optical radiation pressure on small particle in order to tap them. In order to achieve Efficient Power transfer there are some ways used for tuning parameter of given system so that it is operated in strongly coupled rejoin. Coupled Mode Theory (CMT), Haus (1984) provides a simple and accurate way of modeling the system and gives a more understanding of what makes power transfer efficient in a strongly coupled rejoin. CMT said that when two resonators have equal frequencies then, when resonator 1 is excited at t = 0 and $a_1= 1$ and resonator 2 is unexcited i.e. $a_2 = 0$, then phases of two solutions evolve at different rate, and after time $t= \pi/2k$ all of excitation will be transferred to other resonator. For CMT the needful condition is that $k << \omega_{1,\ 2}$. Here $\omega_{1,\ 2}$ are individual Eigen frequencies.CMT gives following set of differential equation by analyzing system as:

$a_m(t) = –(iw_m – \Gamma_m).a_m(t) – \sum_{m \neq n} ik_{nm}.a_n(t) + F_m(t)$(1)

The diagram which shows two objects, one is denoted by Source (S) and Device (D) is as shown in figure 4 (9). The coupling coefficient (20) k_{SD} and k_{DS} are dependent on each other. $k = k_{SD} = k_{DS}$, here k is related to transfer of energy between two oscillator. The Q factor which is used to determine the rate at which energy loses for above system is:

$Q = 2\Pi\frac{energystored}{powerdissipatedpercycle}$(2)

Figure 5 shows a diagram of a wireless power system using magnetically coupled resonators (Haus and Huang).

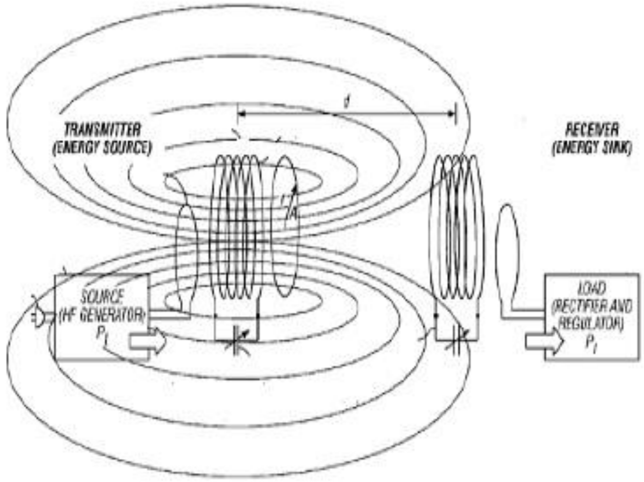

Figure 4: Block diagram of magnetic wave based wireless power transmission system

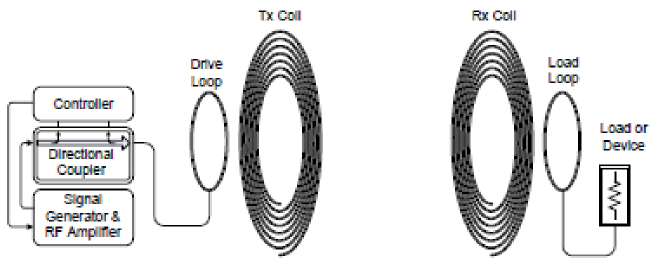

Figure 5: Sketch of the magnetically coupled resonant wireless power system consisting of a RF amplifier, on the left, capable of measuring the forward and reflected power. A two element transmitter, made of a signal turn drive loop and high Q coil, wirelessly powers the receiver on the right

It is possible to transfer energy over distance up to 8 times the radius of coils with nearly 40% efficiency. Also it is found that efficiency; received power and coupling coefficient are decreases with increase in distance between two resonators (Anand *et al.*, 2010). Magnetically coupled resonant structures offer a unique set of benefits as well as design challenges when used for wireless power transfer. One of the remarkable results is the existence of the 'magic regime', where efficiency remains nearly constant over distance, as long as the receiver is within the operating range of the transmitter. This is not the case for conventional far-field and near-field wireless power systems, whose efficiencies decline sharply with range (Alanson *et al.*, 2010).

Inductive Couple Wireless Power Transmission

Inductive coupling does not have the need for large structures transfer power signals. Rather, inductive coupling makes use of inductive coils to transfer the power signals. Due to the use of coils rather than the antenna, the size of the actual transmitter and receiver can be made to fit the situation better. The tradeoff is for the benefit of custom size, there will be a poor gain on the solenoid transmitter and receiver.

Inductive coupling also offers several advantages over other options that are as follows:

A. Simple Design

The design is very simple in theory as well as the physical implementation. The circuits built are not complex and the component count is very low too.

B. Lower Frequency Operation

The operating frequency range is in the kilohertz range. This attribute makes it easy to experiment and test in breadboard. Furthermore there is low risk of radiation in the LF band.

C. Low Cost

The entire system is designed with discrete components that are readily available. No special parts or custom order parts were necessary for the design. Thus we were able to keep the cost of the entire system very low.

D. Practical for Short Distance

The designed system is very practical for short distance as long as the coupling coefficient is optimized**.** The design also offers the flexibility of making the receiver much smaller for practical applications.

Inductive coupling also has some shortcomings that need to be addressed.

A. High Power Loss

Due its air core design the flux leakage is very high. This results in a high power loss and low efficiency.

B. Non-directionality

The current design creates uniform flux density and isn't very directional. Apart from the power loss, it also could be dangerous where higher power transfers are necessary.

Compression between Different WPT Methods

There are several kinds of Wireless Power Transmission (WPT); WPT via radio waves, especially via microwaves, resonance coupling, and inductive coupling. There is no need for any wire to charge a battery for high power users or any battery for tiny power users via the WPT. There are several kinds of WPT, WPT via radio waves, especially via microwaves, resonance coupling, and inductive coupling. The characteristics of the WPT are shown in Table 1 (Naoki, 2010).

Table I: Comparison of different WPT methods

WPT Systems	Waves	Resonance Coupling	Inductive Coupling
Field	Electric field	Resonance	Magnetic field
Method	Antenna	Resonator	Coil
Efficiency	Low to high	High	High
Distance	Short to long	Middle	Short
Power	Low to high	High	High
Safety	Electric field	Non (Evanescent)	Magnetic field
Regulation	Radio wave	Under discussion	Under discussion

WiTricity will ensure that the cell phones, laptops, iPods and other power hungry devices get charged on their own, eliminating the need of plugging them in. Even better, because of WiTricity some of the devices won't require batteries to operate. As it is shown in Table 1, the method used in Microwaves WPT systems is Antenna. In WPT using Resonance Coupling Resonator is used and in Inductive Coupling WPT Coil is the used method. Microwave WPT systems can be low or high efficient for both short and long distances while Resonance Coupling WPT systems have high efficiency for middle distances and Inductive Coupling WPT systems are with high efficiency for short distances.

Conclusion

The percentage of loss of power during transmission and distribution is approximated as 26%. Wireless power transmission systems are designed to transmit power without using wires. In This paper an investigation is performed on different types of Wireless power Transmission systems. There are several kinds of Wireless Power Transmission (WPT); WPT via radio waves, especially via microwaves, resonance coupling, and inductive coupling. In this paper these methods are explained in details. There could be large number of applications for wireless power systems such as Mobile devices, Household devices or for implementing medical devices with different purposes. Components of a Wireless Power Transmission system are Microwave Generator, Transmitting Antenna and Rectenna that are described. Then a comparison is performed between different PWT systems that shows Microwave WPT systems can be low or high efficient for both short and long distances while Resonance Coupling WPT systems have high efficiency for middle distances and Inductive Coupling WPT systems are with high efficiency for short distances.

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