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Management of Highly Resonant Wireless Power Transmission

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Abstract : A non-radiative energy transfer or witricity , based on 'strong coupling' between two coils separated physically by medium range distances is discussed to realize efficient wireless energy transfer.the distances between the two coils can be larger than the characteristic size of each resonator.non radiative energy transfer between two coils is facilitated through resonance.the discussed system operates as a traditional inductive coupling device when the operating frequencies are not resonant frequencies. Mathematical analysis has been carried out to facilitate the quantitative comparison. Compared with typical magnetic inductive coupling energy transmission device , the efficiency of the proposed system is quite high. The investigations indicate that this system is feasible to use wireless energy transfer technology to recharge batteries particularly in implant device.

Keywords: Wireless Power Transmission, Resonant, Electricity, Transmission

INTRODUCTION

We all are dependent on electricity. From necessity to luxury, electricity gratifies all our needs. Cell phones, laptops, television, health care etc all our powered by electricity. All the electrical equipments that we use in our daily lives are provided with electrical power with the help of wires. These wires have also become a part of our lives. Despite of the fact that we are using wires for a very long time and that too without complaints, wires do have some shortcomings. For e.g. Wires limit the distance to which the electricity could be transmitted. Also they form the most fault prone equipment of the device posing spark hazards and dangers of being electrocuted. Hence transmitting power through air was thought of and researched for.

BACKGROUND AND OUR NEEDS

The idea of transmitting power wirelessly has been present over a century with Nikola Tesla's pioneering experiments to be the stepping stones. He wanted to bypass the grid system and thought of transmitting electricity through the earth's ionosphere. However the project was abandoned due to technical and financial reasons. Also the embodiments (incarnation) of the Nikola Tesla's power scheme (such as Tesla's coil) involved high amounts of electric field which posed safety hazards. Later new methods were developed, one of which included transmitting electric power through far field techniques. This method involved electromagnetic fields of some frequency through which energy is sent. At high frequency ends, an optical technique that uses lasers to send power via a collimated beam of light to a remote detector is used. The remote detector receives the photons that converted to electrical energy. Efficient transmission over large distance is possible .However complicated pointing and tracking mechanisms are needed .Moreover objects that come in between the transmitter and the receiver may cause harm. Similar caveats (limitation) about safety and system complexity are involved in the radiative approaches that involve microwave techniques. These techniques besides having the above mentioned disadvantages also radiate harmful electromagnetic waves into the surroundings. With the limitations of the far field techniques, near field techniques with non radiative approach were thought for e.g. transfer of power in a transformer can be considered to be a wireless transfer of power that employs the principle of electromagnetic induction.

Nonetheless, the primary coil and the secondary coils have to be kept in a close proximity of each other i.e. they should have high coupling between them. Also there must be careful positioning between the primary and the secondary for proper operation. With so many technologies developed, yet the technology that could cater to all our needs was yet not developed. Scientists were researching for such a technology that could transmit electricity over mid range distances (the distance between the objects between which transfer is taking place should be greater than the size source and the receiver), with non radiative approach providing us more freedom from positioning and alignment.

WITRICITY-THE PRESENT SCENARIO

With the above mentioned needs in mind, a group of researchers at MIT (USA) in 2007 were able to power a 60 W light bulb wirelessly over a distance of 7 feet with 40 % efficiency. They used self resonating coils in a strongly coupled near field regime (establishment) and named it Witricity. The basic idea is that in systems of coupled resonances, there may be a general strongly coupled regime of operation. If one can operate in this regime in a given

system, the energy transfer is expected to be very efficient. Mid-range power transfer implemented this way can be nearly Omni directional and efficient, irrespective of the geometry of the surrounding space, and with low losses into most off-resonant environmental objects.
The above considerations apply irrespective of the physical nature of the resonances. In the work done by the research team from MIT (USA), they worked on magnetic resonances. This implies that the interaction between the objects occurs predominantly through the magnetic fields they generate. Magnetic resonances are particularly suitable for everyday use because biological tissues and most common materials do not interact strongly with magnetic fields, which help make the system safer and more efficient. So essentially witricity employed strongly coupled regime in the system of two coupled magnetic resonances by exploring non- radiative (near field) magnetic resonance induction at MHz frequencies.

At the first glance, such power transfer resembles the usual magnetic induction .however, a non resonant induction is very inefficient unless two coils share a core with high magnetic permeability or are very close to each other.
Also, operating on resonance is necessary but not sufficient to achieve good efficiency at mid range distances. Although many of Tesla's works that are available today(RFID tags, radio receivers etc) also rely on resonance ,yet their efficiencies are not very good at mid range distances. Operation in the strong coupling regime, for which resonance is a precondition, is what makes the power transfer efficient.
As witricity is based on wireless energy transfer between two resonating coils in strongly coupled regime of magnetic resonance it is also called highly resonant-wireless power.
Since the invention of electricity, there has been a keen interest in the area of wireless power transmission. Delivery problems and issues of convenience in the wire transmission have stimulated interest in this technology. In the initial period of 20th century, an attempt was made to transmit electricity wirelessly [1]. After several researches in this area, in 2007, a new method for wireless power transmission, based on resonant coupling method [2], was developed at Massachusetts Institute of Technology. The method is called Witricity. The new technique has found many application areas. The usage of witricity in medical area is illustrated in [3]-[4]. The effect of using more than one resonator with different specifications in transfer system was investigated in [5]-[6]. It is shown that the misalignment of resonators does not have a significant effect on the transfer [7]. The possibility of transfer by using a relay resonator is shown in [8]. Wireless sensor networks with multi resonators are an example of the application of witricity in daily life [9]. An MIT study also reported that magnetic resonant coupling using a non-radiative mid-range field can be used for wireless power transfer [10]. This scheme, "witricity", has been tested to be feasible and efficient in non-medical cases. In their experiment, they lit up a 60W bulb 2 meters from the power source with efficiency up to 40%. Although their experiment was successful in transmitting power in non-medical applications, their resonant coil design is not feasible for transmitting power to medical devices due to its large size and inflexibility. Based on witricity, Liu et al., 2009 [6] develop their wireless power transfer system (WPT) and cells for recharging medical implants and powering worn devices. Their experiment has shown that the WPT system proposed is effective in transferring power efficiently to implanted and worn devices.
Ho et al. [11] reported the study on a topical mode of energy transmission using resonant technique, commonly known as Witricity (short form of wireless electricity). In this paper, a wireless energy transfer system based on Witricity technology for power transmission and recharging of electrical devices is studied. In order to showcase its performance, comparable traditional inductive magnetic coupling model is built. Experiment and simulation results are reported to demonstrate the effectiveness and characteristics of the proposed method. In summary, the feasibility of this system is demonstrated using practical measurements in order to make meaningful performance comparisons.
Detailed theoretical and numerical analyses reveal that Witricity is efficient and practical for mid-range wireless energy exchange. Unlike conventional inductive coupling methods, there are only very small energy dissipations in off-resonant objects for systems working on Witricity principle [12]. Zhang et al. 2010 [13] have shown that one or more relay resonators can be added to the witricity system to extend power transfer range, increase efficiency, and allow a curved transmission path in space. This system has great potential in civic and military applications to build up a wireless energy transfer network.
In the work, Zhang et al. 2009 [14] have utilized strongly coupled magnetic resonance to transfer power wirelessly for the operation of medical sensors and implantable devices. The basic physical principle of this technique has been explained using coupled mode theory. New versions of source and device resonator designs have been presented. In the paper [15], the effect of various frequencies on wireless power transmission is investigated. Energy transfer efficiency for multi transmitter and receiver condition is also presented. When there is a relay resonator between transmitter and receiver, it is shown that the efficiency increases.

In the work [16] an investigation has been made to know how the efficiency changes when the characteristic impedance changes for single frequency and for several wave types. They have also emphasized single transmitter and double receiver conditions. The paper [17] introduces wireless technologies for use with robotic endoscopes in the gastrointestinal tract. The technologies include wireless power transmission (WPT), wireless remote control (WRC), and wireless image transmission (WIT). WPT is based on the electromagnetic coupling principle, powers active locomotion actuators and other peripherals in large air gaps. The paper [18] addresses the recent technological comprehensive developments in the area of communication and environment monitoring in underground coal mines. It points out the suitability of application of recently developed wireless sensor network for this purpose as proposed by different researchers all over the world.

WITRICITY TECHNOLOGY: SYSTEM DESCRIPTION

Across an application space that ranges from power levels from less than a watt to multiple kilowatts, a wireless energy transmission system based on HR-WPT often has a common set of functional blocks. A general diagram of such a system is given:

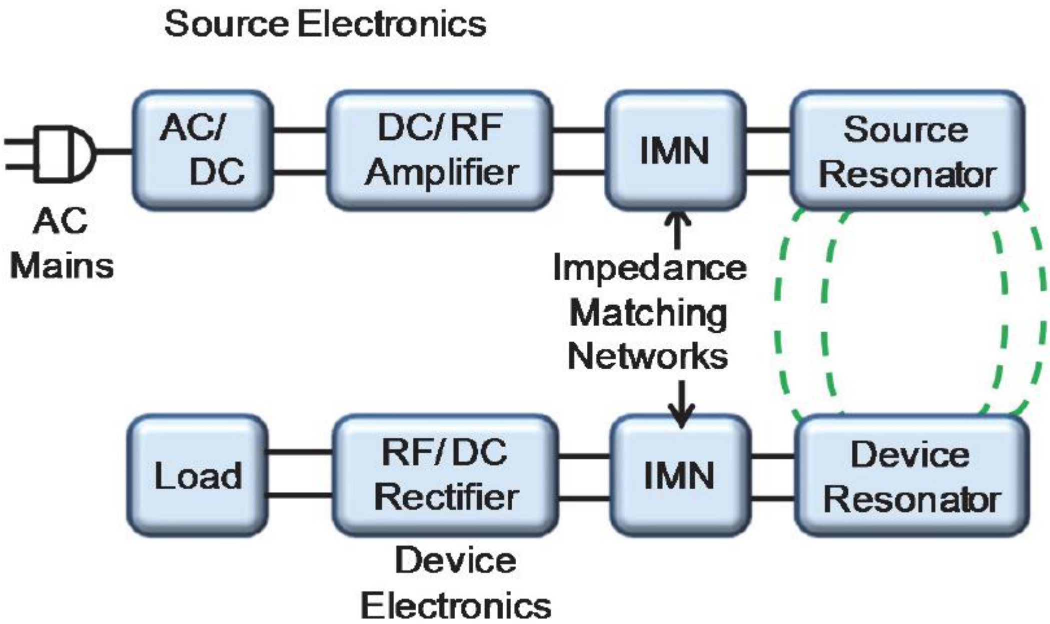

Figure 3.1.1 Witricity diagram

The system electronics consists of the following components:

SOURCE ELECTRONICS

a. AC power source
b. AC to DC conversion block
c. RF amplifier(along with the function generator)
d. Impedance matching networks on the source side
e. Source resonator

DEVICE ELECTRONICS

a. Device resonator
b. Impedance matching networks on the device side
c. DC to AC conversion block
d. Load

Progressing from left to right in the top line of the diagram we have the source electronics.

The input power to the system is usually either wall power (AC mains) which is converted to DC in an AC/DC converter block, or alternatively, a DC voltage directly from a battery to other DC supply. A high efficiency switching amplifier converts the DC voltage into an RF (Radio Frequency) voltage waveform that along with a function generator are used to drive the source resonator. Usually a class D or class E switching amplifier is suitable in many applications. Often an impedance matching network (IMN) is used to efficiently couple the amplifier output to the source resonator while enabling an efficient switching amplifier operation.

The IMN serves to transform the source resonator impedance, loaded by the coupling to the device resonator and output load, into such impedance for the source amplifier.

The magnetic field generated by the source resonator couples to the device resonator ,exciting the resonator and causing energy to build up in it. This energy is coupled out of the device resonator to do useful work, for e.g. directly powering the load or charging a battery.

A second IMN may be used here to efficiently couple energy from the resonator to the load. It may transform the actual load impedance into effective load impedance seen by the device resonator which more closely matches the loading for optimum efficiency. For loads requiring DC voltage, a rectifier converts the received AC power back to DC.

BENEFITS OF USING WITRICITY TECHNOLOGY

1. Make devices more convenient and thus desirable to purchasers by eliminating the need for a power cord or battery replacement.
2. Make devices more reliable by eliminating the most failure prone component in most electronic systems- the cords and connectors
3. Make devices more environmentally sound by eliminating the need for disposable batteries. Using grid power is much less expensive and more environmentally sound than manufacturing, transporting and using batteries based on traditional electro chemistries
4. Make devices safer by eliminating the sparking hazard associated with conductive interconnections and by making them watertight and explosion proof by eliminating connector headers and wires that run through roofs ,wall and other barriers

5. Reduce system cost by leveraging (increase in the force obtained by using the lever) the ability to power multiple devices from a single source resonator.

FUNCTIONAL BENEFITS OF USING HIGHLY RESONANT WIRELESS POWER TRANSFER

• Flexibility in the relative orientations of the source and device during operation. This flexibility opens the application space as well as makes systems easier and more convenient to use.
• A single source can be used to transfer energy to more than one device ,even when the devices have different power requirements. For e.g. instead of having separate charger for each mobile in the family , one can have a charging surface that handles all of them at once.
• Because of the ability to operate at lower magnetic coupling values the sizes of the source and the device resonator are not constrained to be similar.
• The distance range of efficient energy transfer can be extended significantly through the use of resonant repeaters that enable the energy to "hop" between them.

APPLICATIONS OF HIGHLY RESONANT WIRELESS POWER TRANSFER

1. Consumer electronics- electronic goods like laptop PCs, cell phones can be wirelessly charged using this technology. There is no need for the device to be placed in close vicinity of the source or be proper aligned to the source. There can be hindrances between the source and the device and still the energy transfer can take place without affecting the efficiency of the energy transfer.
2. Medical devices-with the help of witricity technology, the medical devices such as heart assist pumps, pacemakers and infusion pumps can be efficiently powered. Using highly resonant wireless power transfer, such devices can be efficiently powered through the skin and over distances much greater than the thickness of the skin, so that power can be supplied to devices deeply implanted within the human body. The HR-WPT technique eliminates the need for drive lines that penetrate the human body and for surgical replacement of primary batteries.
3. Electric vehicles- wireless charging systems are being developed for rechargeable hybrid and battery electric vehicles. These systems already deliver 3.3 KW at high efficiency over a distance of 10 cm-20 cm (typical vehicle ground clearances). It is expected that wireless charging will vastly improve the charging experience for electric vehicle owners, making such vehicles even more attractive to consumers.
4. LED lighting- LED(light emitting diodes) lights can be directly powered with wireless electricity ,eliminating the need for batteries in under cabinet task lighting and enabling architectural lighting designers to create products that seemingly float in mid air with no power cord.
5. Defense systems-designers of defense systems are able to utilize wireless charging to improve the reliability, ergonomics and safety of electronic devices. Helmet mounted electronics, including night vision and radio devices can be powered wirelessly from a battery pack carried in the soldier's vest, eliminating the need for disposable batteries or a power cord connecting the helmet to the vest mounted battery pack.

LIMITATIONS OF WITRICITY TECHNOLOGY

Although highly resonant wireless power transfer of power provides efficient transfer of power over mid range distances, following shortcomings were noticed

• The resonance frequency changes as the coupling factor changes and the maximum efficiency of power transfer system occurs at the resonance frequency. However when this wireless power transfer system is applied in the MHz range(which allows smaller antennas), the usable frequency range is bounded by the industrial scientific medical band. The ISM band dictates the usable frequency range for purposes other than communication. According to the ISM band, the usable frequency ranges are extremely narrow. As a result ,to apply this technology in restricted frequency ranges such as the MHz range , the frequency of the power source must be fixed at a usable range and the system has to be tuned so that its resonance frequency matches the frequency of the power source. For this purpose impedance matching networks are used that make the system bulky.

• For applications like charging of mobile phones etc. the size of the device resonator required is to be compact. For this it is required to use high resonant frequencies. However the use of high frequencies is limited by the ISM band. Hence there is a compromise between the size and the frequency in such cases.

THE FUTURE SCOPE

With such wide ranging space ,the use of resonance to enhance wireless power transfer will be prevalent in many areas of life in coming years. Electronic companies are already developing the necessary core components that will help to speed the introduction of the technology into more cost constrained applications. This will stimulate additional creative ways in which the technology could be applied , not only bringing convenience to some everyday tasks such as battery charging , health care etc but also enabling uses in ways only limited by one's imagination. The market for some specialty applications has already started(e.g.medical applications), while application to automotive charging is rapidly developing and industry leaders are meeting to discuss standardization of vehicle charging infrastructure . for mobile electronics, a consortium of companies has already developed a common specification for traditional inductive charging. Standard developing organizations are developing interoperability (ability of a system to work with or use the parts and equipments of another system) guidelines for highly resonant wireless power transfer to ensure that the mobile devices from different vendors can charge anywhere in a common wireless ecosystem. As these efforts progress, it is expected to see wireless power technology deployed in these and many more applications that improve our convenience, towards which, science always works.

CONCLUSIONS

Witricity technology based on efficient power transfer between two resonating coils under strongly coupled regime was invented by a group of scientists at MIT(USA) in 2007. This technology has opened new avenues for transferring of power over mid range distances effectively without having disadvantages of far field and near field techniques.

Due to complex system that wires create and associated hazards, witricity poses a new future. With the advent of this technology, it is hoped that many new gates of improvements in electrical engineering will open.

We can hope for safer, reliable and economical energy transfer. The sparks and related hazards can be eliminated. We can also hope for further inventions in this technology so that electricity thefts can be prevented. Also with more of grid power being used rather than traditional electro chemistries, the electronic waste generated (due to the batteries) can be reduced to a large extent.

Hence If witricity technology booms, it will definitely bring convenience to our lives, towards which science always works.

REFERENCES

[1] N. Tesla, "Apparatus for transmitting electrical energy", United States Patent Office (1119732), United States of America, 1914.

[2] A. Karalis, J.D. Joannopoulos, M. Soljacic., "Efficient wireless nonradiative mid-range energy transfer", Annals of Physics, Vol. 323: pp.34-48, 2008.

[3] X. Liu, F. Zhang, S.A. Hackworth, R.J. Sclabassi, M. Sun, "Modeling and simulation of a thin film power transfer cell for medical devices and implants", Circuits and Systems, 2009. ISCAS 2009. IEEE International Symposium, Taipei, pp. 3086-3089, 2009.

[4] F. Zhang, X. Liu, S.A. Hackworth, R.J. Sclabassi, M. Sun, "In vitro and in vivo studies on wireless powering of medical sensors and implantable devices", Life Science Systems and Applications Workshop, 2009. LISSA 2009. IEEE/NIH, Bethesda, pp. 84-87, 2009.

[5] F. Zhang, X. Liu, S.A. Hackworth, R.J. Sclabassi, M. Sun, "Wireless energy delivery and data communication for biomedical sensors and implantable devices", Bioengineering Conference, 2009 IEEE 35th Annual Northeast, Boston, pp. 1-2, 2009.

[6] X. Liu, F. Zhang, S.A. Hackworth, R.J. Sclabassi, M. Sun, "Wireless power transfer system design for implanted and worn devices", Bioengineering Conference, 2009 IEEE 35th Annual Northeast, Boston, pp. 1-2, 2009.

[7] F. Zhang, S.A. Hackworth, X. Liu, C. Li, M. Sun, "Wireless power delivery for wearable sensors and implants in body sensor networks", Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, Buenos Aires, Argentina, pp. 692-695, 2010.

[8] F. Zhang, S.A. Hackworth, W. Fu, M. Sun, "The relay effect on wireless power transfer using witricity", Electromagnetic Field Computation (CEFC), 2010 14th Biennial IEEE Conference, Chicago, pp. 1, 2010.

[9] M.K. Watfa, H. Al-Hassanieh, S. Salmen, "The road to immortal sensor nodes", Intelligent Sensors, Sensor Networks and Information Processing, 2008. International Conference, Sydney, pp. 523-528, 2008.

[10] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljacic, "Wireless power transfer via strongly coupled magnetic resonances," Science, vol. 317, pp. 83–86, Jul. 2007.

[11] Ho S. L., Wang J., Fu W.N., and Sun M., "A Comparative Study Between Novel Witricity and Traditional Inductive Magnetic Coupling in Wireless Charging", IEEE Transactions on Magnetics, Vol. 47, No. 5, pp.1522-1525, May 2011

[12] Karalis A., Joannopoulos J. D., and Soljacic M., "Efficient wireless non-radiative mid-range energy transfer," Ann. Phys., vol. 323, pp. 34–48, Jan. 2008.

[13] Zhang Fei, Hackworth Steven A., Fu Weinong, Li Chengliu, Mao Zhi-Hong, and Sun Mingui, "The Relay Effect on Wireless Power Transfer Using Strongly Coupled Magnetic Resonances", IEEE Transactions on Magnetics 2010.

[14] Zhang Fei, Hackworth Steven A., Fu Weinong, Li Chengliu, Mao Zhi-Hong, and Sun Mingui, "In Vitro and In Vivo Studies on Wireless Powering of Medical Sensors and Implantable Devices", 2009 IEEE/NIH Life Science Systems and Applications Workshop (LiSSA 2009), pp 84-87.

[15] Gundogdu A. E., and Afacan E., "The Effect of Frequency, Multi Resonator and Relay Resonator Conditions on Wireless Power Transmission", Wireless Telecommunications Symposium (WTS), 2012, pp.1-5.

[16] Gundogdu A. E., and Afacan E., "Some Experiments Related to Wireless Power Transmission", 2011 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference, pp.507-509.

[17] Gao P., Yan G., Wang Z. and Liu H., "Wireless technologies for robotic endoscope in gastrointestinal tract", Journal of Medical Engineering & Technology, Volume 36, Issue 5, 2012, pp. 242-250.

[18]. Dohare Yogendra S, Maity Tanmoy, Das P. S. and Paul P. S., Wireless Communication and Environment Monitoring in Underground Coal Mines – Review, IETE Technical Review Volume 32, Issue 2, 2015, pp. 140-150.