WiTricity: A Wireless Energy Solution Available at Anytime and Anywhere

Shahbaz Ali Khidri[1], Aamir Ali Malik[2], Shakir Hussain Memon[3]

Department of Electrical Engineering, Sukkur Institute of Business Administration, Sukkur, Sindh, Pakistan

[1]shahbazkhidri@outlook.com, [2]aamir.malik@iba-suk.edu.pk, [3]shakir.hussain@iba-suk.edu.pk

Abstract – Electrical power is vital to everyone and is a clean and efficient energy source that is easy to transmit over long distances, and easy to control. Generally, electrical power is transmitted from one place to another with the help of wires which introduce losses and a significant amount of power is wasted in this way. As a result, the efficiency of the power system is significantly affected. In order to overcome these problems, a low-cost, reliable, efficient, secure, and environmental friendly wireless energy solution is presented in this research paper. The concept of transferring power wirelessly in 3D space was first realized by Nikola Tesla when he gave the idea to transmit the power without the help of wires over large distances using the earth's ionosphere. In this research paper, magnetic resonance method which is non-radiative in nature is introduced for wireless power transmission and the electrical power is transmitted wirelessly over a distance of 10 feet with an overall efficiency of 80%. The method introduced in this paper is environmental friendly and has a negligible interaction with exterior forces/objects.

Keywords – Electrical power, energy source, long distance power transmission, wireless power transmission, magnetic resonance, non-radiative, power system efficiency.

I. INTRODUCTION

An interesting aspect about the energy in "Electrical form" is that neither it is so available directly from nature, nor it is required to be finally consumed in that form [1]. Still, it is the popular form of energy since it can be used cleanly in any home, work place, or factory [2]. Generally, electrical power is transmitted from one place to another with the help of conventional copper cables and current carrying wires which introduce significant losses and much amount of power is wasted in this way. As a result, the efficiency of the power system is highly affected and the overall performance of the power system is degraded. The efficiency of the conventional power transmission system can be improved by using the quality material but this introduces a significant increment in cost. As the world has become a global village because of technological advancements, people don't like to interact all the time with the conventional wired power system for charging their electrical/electronic devices and for other purposes because it's much complicated, time consuming, and dangerous as there is always a chance of getting electric shock. The conventional wired power system is shown in figure 1.

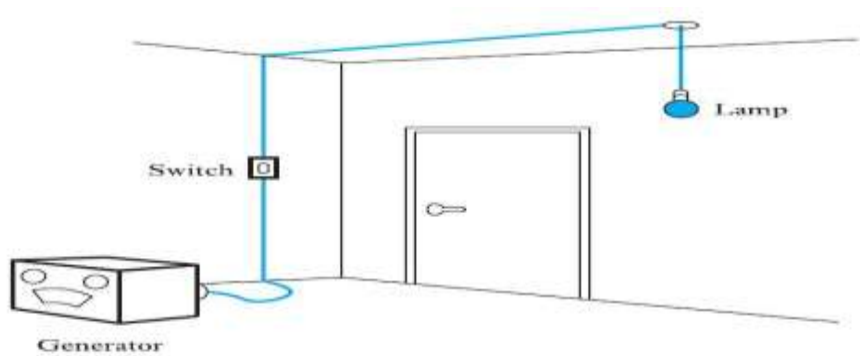

Figure 1 Conventional Wired Power System

In order to get rid of all these problems and hurdles, an alternative solution must be presented or created which must be efficient, reliable, safe, cost-effective, and environmental friendly. Nikola Tesla was the first person who gave the idea of transmitting electrical power over large distances using the earth's ionosphere without the help of conventional copper cables and current carrying wires [3].

Nikola Tesla designed a magnifying transmitter to implement wireless energy transmission by means of the disturbed charge of ground and air method [4]. The magnifying transmitter is shown in figure 2.

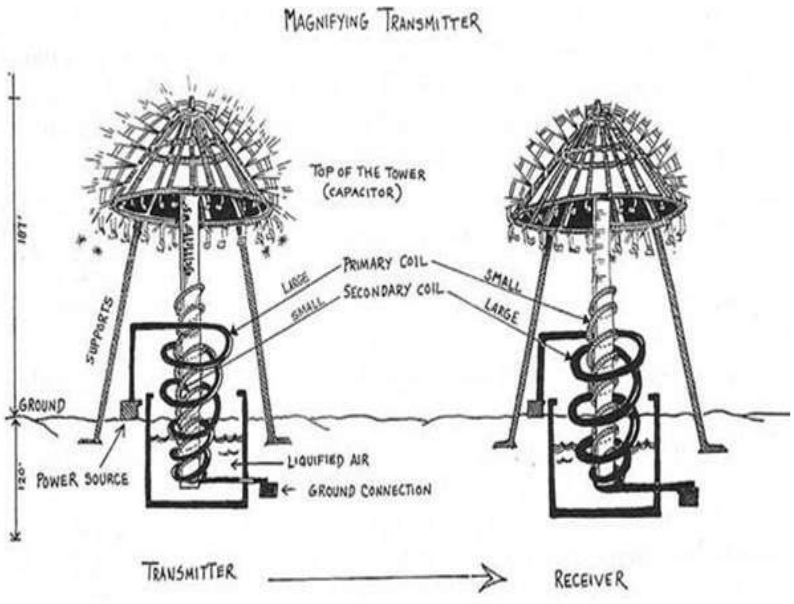

Figure 2 Magnifying Transmitter

In this research paper, a low-cost, reliable, efficient, secure, and environmental friendly wireless energy solution is presented and is based on magnetic resonance method which is non-radiative in nature. The electrical power is transmitted wirelessly over a distance of 10 feet and an overall efficiency of 80% is achieved by utilizing this technique.

This research paper is based on 5 sections. Section II is based on literature review and reviews the existing techniques and methods for wireless power transmission. Section III is based on the methods and techniques which we have used for wireless power transmission and describes our contribution. Section IV is based on results and reflects the results obtained from carried out research work. Section V is based on conclusions and concludes the research paper with the important suggestions and factual findings from the carried out research work.

II. LITERATURE REVIEW

Several techniques and methods are available for wireless power transmission. The common methods are given as:

1. Wireless Power Transmission using Magnetic Induction

This method for wireless power transmission is non-radiative in nature and works on the principle of mutual induction which states that when two coils are inductively coupled and electrically isolated and if current in one coil is changed uniformly then an electromotive force gets induced in the other coil [5]. In this way, the energy can be transmitted from one place to another without using the conventional wires. However, there are few limitations and this method is not a proper method for wireless power transmission because of several factors including shorter range (a few mm if any), lower overall efficiency, and tight coupling [6]. The care must be taken in positioning the coils for proper operation. Many industries are using this method in their products. The magnetic induction method is widely used in electric toothbrushes, wireless cell phone chargers, and pace makers [7, 8]. The efficiency and the operating range of this method can be improved to a considerable level by enhancing the resonance.

2. Wireless Power Transmission using Electromagnetic Radiations

This method for wireless power transmission is radiative in nature and not widely used because the transmitted power is dissipated in all directions and at the end, insufficient amount of power reaches at the receiver.

This method is widely used for the transmission of information wirelessly over large distances.

3. Wireless Power Transmission using Optical Techniques

This method for wireless power transmission uses lasers to transmit energy from one place to another. The energy which is to be transferred is in the form of light which is converted into electrical form at the receiver end. This method uses directional electromagnetic waves so the energy can be transmitted over large distances [9]. This method for wireless power transmission is not suitable when the receiver is mobile because proper line-of-sight is needed. For proper operation, no object should be placed between transmitter and receiver. Complicated tracking techniques can be used in mobility condition but at the end, the cost of the power system is increased to a significant level.

4. Wireless Power Transmission using Microwaves

This method for wireless power transmission uses microwave frequencies for transmitting energy from one place to another. The energy can be transmitted over large distances using radiative antennas [10]. The efficiency of this power system is higher at greater distances as compared to other wireless power transmission systems but this method is not environmental friendly and is unsafe and complicated because microwave frequencies at higher power levels can potentially harm people. Proper care must be taken when using method at higher power levels. Energy in tens of kilowatts has been transmitted wirelessly using this method [11]. In 1964, a model of microwave powered helicopter was presented by Brown [12]. In 1997, this method has been utilized for wireless power transmission in Reunion Island [13].

5. Wireless Power Transmission using Electrodynamic Induction

This method for wireless power transmission is non-radiative in nature and is environmental friendly. Two resonance objects can exchange energy when they possess same frequency [14]. The higher efficiency can be achieved when the transmitting range is medium. This method is popular method for wireless power transmission because no alignment of transmitter and receiver is needed so this method has a higher placement freedom. In 2007, researchers from Massachusetts Institute of Technology (MIT) utilized this method and powered a 60W light-bulb wirelessly at a distance of 7 feet with an overall efficiency of 40% [15]. In 2008, Intel used the same method and powered a 60W light-bulb wirelessly at a shorter distance with an overall efficiency of 75% [16]. In 2008, the same method was used by Lucas Jorgensen and Adam Culberson belonging to Cornell University and a successful experiment of wireless power transmission at a shorter distance was performed [17]. In 2011, Mandip Jung Sibakoti and Joey Hambleton belonging to Cornell University performed the same experiment and powered a 40W light-bulb wirelessly at a shorter distance [18].

III. IMPLEMENTATION OF WIRELESS POWER TRANSMISSION USING MAGNETIC RESONANCE

The block diagram of wireless power transmission using magnetic resonance is shown in figure 3.

Figure 3 Block Diagram of WPT using Magnetic Resonance

Magnetic resonance is a low-cost, reliable, efficient, secure, and environmental friendly method for wireless power transmission.

The energy in "Electrical form" can be transmitted from one place to another over medium ranges with the help of magnetic field when the frequencies of source resonator and device resonator are equal. This method is non-radiative in nature and has a negligible interaction with exterior forces/objects. Different steps involved in magnetic resonance based wireless power transmission are shown in figure 3.

In first step, an alternating current (AC) is supplied to the power system which is usually 240V. In second step, the alternating current (AC) is converted into the direct current (DC) using rectifiers. This step is ignored when a direct current (DC) supply is provided to the power system. When used for high power applications, few errors may occur so a power factor corrector may be needed for high power applications. In third step, the direct current (DC) obtained from the rectifier is converted into a radio frequency (RF) voltage waveform because the source resonator operates on a radio frequency (RF) voltage waveform. This conversion is done using a high speed and highly efficient operational amplifier. The amplifier used here has a very high frequency response. In fourth step, an impedance matching network (IMN) is used for efficient coupling of the high speed operational amplifier output and the source resonator. In fifth step, the magnetic field is generated by the source resonator. In sixth step, the generated magnetic field excites the device resonator and an energy build up process takes place. Here, the energy is transferred without the help of wires with the help of magnetic field. In seventh step, an impedance matching network (IMN) is used again for efficient coupling of the device resonator and the load. In eighth step, the radio frequency (RF) voltage waveform is converted into the direct current (DC) using rectifiers because the load operates on a direct current (DC) supply. In ninth and final step, the load is powered with the direct current (DC) supply. So, the energy is efficiently transmitted wirelessly from the source to the load with the help of magnetic resonance.

In this research work, a successful experiment of wireless power transmission over a distance of 10 feet is performed with an overall efficiency of 80%. It is observed that a large amount of energy can be obtained from resonators because of their oscillating nature. So with a weak excitation force, a useful amount of energy can be obtained which is stored in resonators. The efficiency of a resonator is based on its quality factor often represented by "Q". The quality factor depends upon the resonant frequency and the internal losses of the resonator. So, a resonator with lower losses has a higher quality factor and a higher efficiency. A simple electromagnetic resonator is shown in figure 4

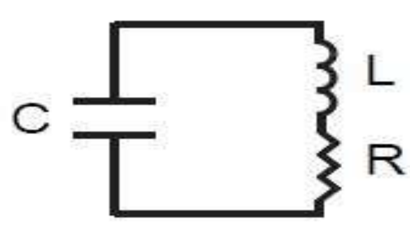

Figure 4 Electromagnetic Resonator

For this research work, resonators with a high quality factors are used in order to obtain a better and desirable efficiency. It is possible for resonators to exchange energy with the help of magnetic field when they are placed closer to each other. Two coupled resonators exchanging energy are shown in figure 5

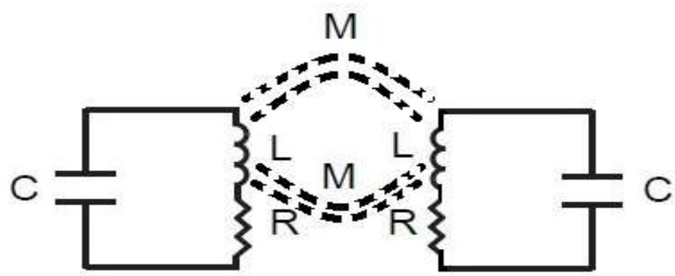

Figure 5 Coupled Resonators

The coils used for wireless power transmission in this research work have the radius of approximately 74cm and are designed to have the resonant frequency range of 8.5MHz – 12.5MHz. For frequency matching, a tunable high frequency oscillator is designed using operational amplifiers having the tunable frequency range of 5.5MHz – 14.5MHz. Along with a tunable high frequency oscillator, a power amplifier is used for assuring the reasonable amount of power which is to be transferred to the load at the receiver side.

The creative visualization of wireless power transmission using magnetic resonance is shown in figure 6, figure 7, and figure 8.

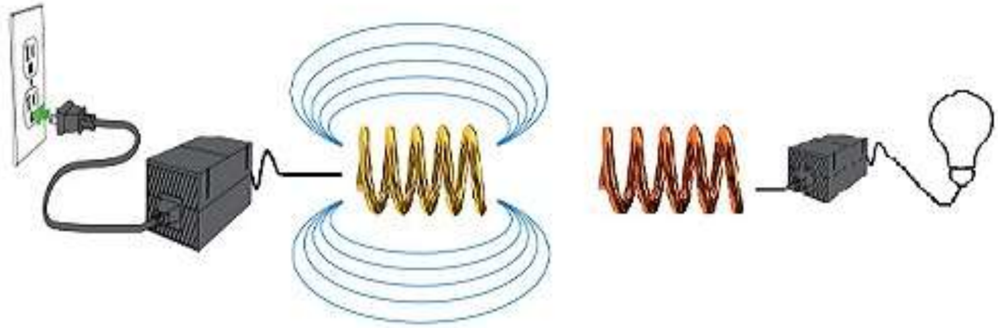

Figure 6 Powering the Source Resonator

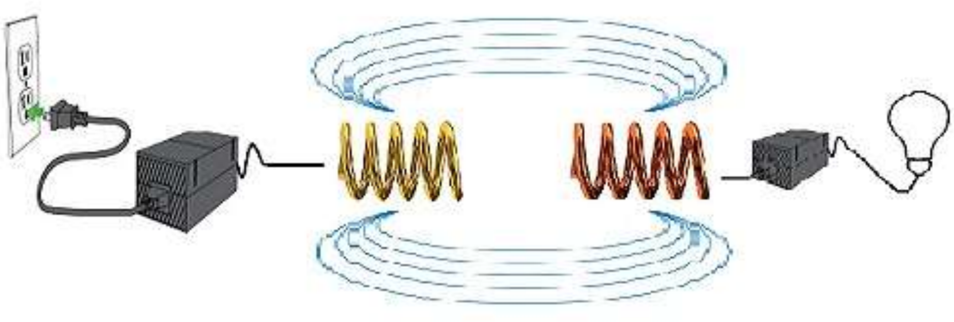

Figure 7 Energy Build Up Process in the Device Resonator due to the Source Resonator

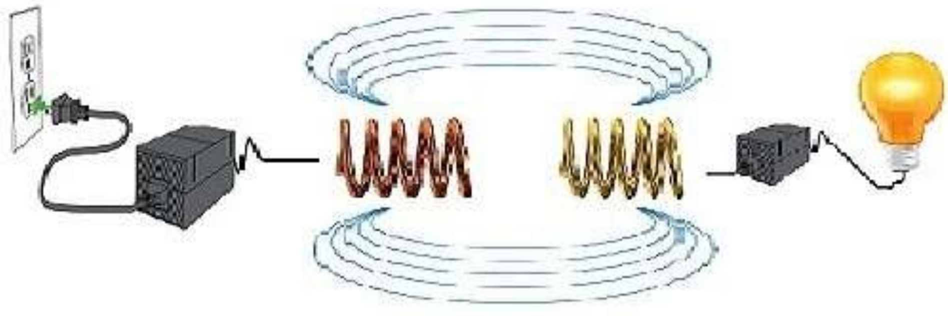

Figure 8 Powering the Load

The creative visualization shows that the energy is transmitted from the source to the load in three steps.

In first step as shown in figure 6, the source resonator is powered with the help of an alternating current (AC) supply. In second step as shown in figure 7, the energy build up process takes place with the help of magnetic field when the source resonator and device resonator having same frequencies are coupled. In third step as shown in figure 8, the load is powered with the help of direct current (DC) supply which is transmitted wirelessly from the source.

IV. RESULTS AND DISCUSSIONS

In this research work, we were able to power a 40W light-bulb wirelessly over a distance of 10 feet with an overall efficiency of 80%. A significant change in the efficiency of the wireless power transmission system was observed when the distance between the source resonator and the device resonator was varying. A decrement in the intensity of light was observed with the increment in the distance. However, the overall efficiency of the designed wireless power transmission system was better and desirable. The results obtained from the designed wireless power transmission system when placed in the parallel and the perpendicular configuration are shown in figure 9 and figure 10 in form of charts respectively.

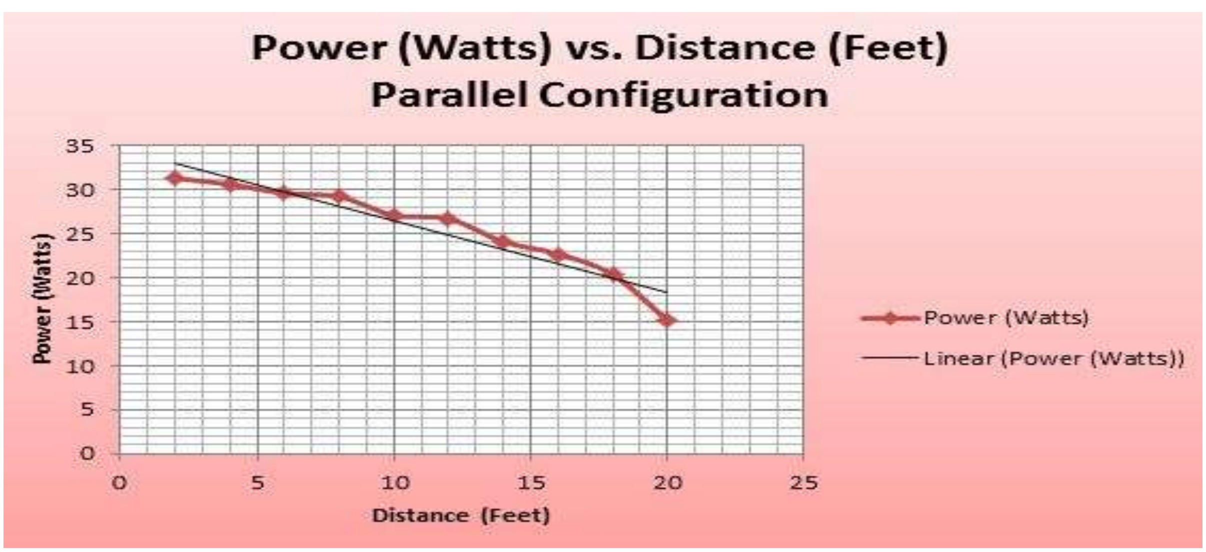

Figure 9 Power vs. Distance Chart for Parallel Configuration

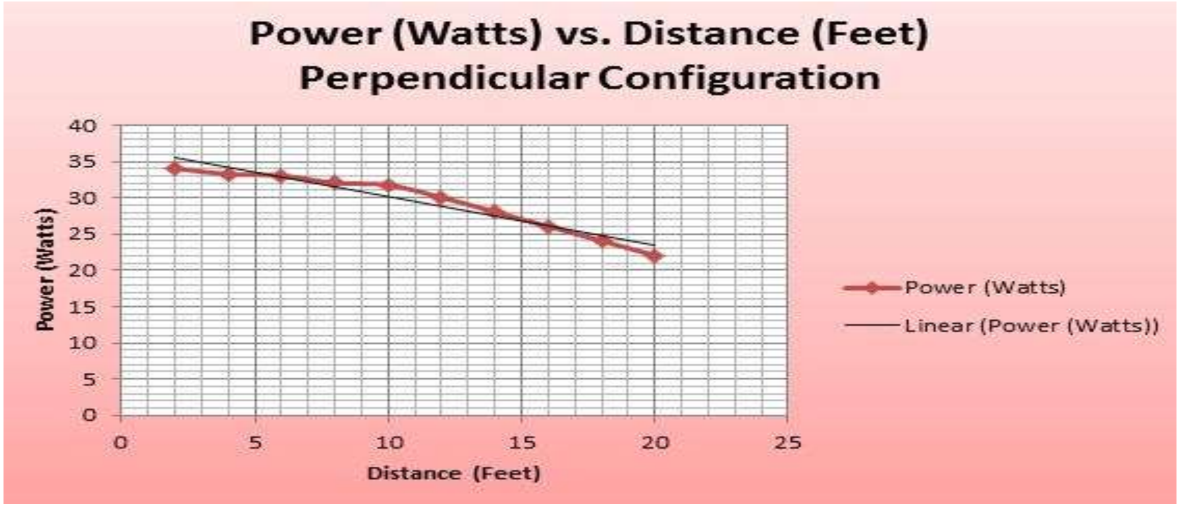

Figure 10 Power vs. Distance Chart for Perpendicular Configuration

Different values of power in watts with respect to distance in feet are shown in figure 9 and figure 10 for the parallel and the perpendicular configuration respectively. It is observed from these power values that the intensity of light decreases when the distance increases. However, sufficient amount of power is obtained wirelessly over a distance of 10 feet with an overall efficiency of 80%. A change in the resonant frequency was also observed when the distance was increased gradually due to the imperfect match in the resonant frequencies of coils. So, the frequency was properly adjusted at different intervals of measurement for obtaining maximum power and better efficiency. Overall, the results obtained from the carried out research work were desirable.

The chart in figure 11 shows the relationship between the efficiency of the designed wireless power system and the distance when the parallel configuration is used and the chart in figure 12 shows the relationship between the efficiency and the distance when the perpendicular configuration is used.

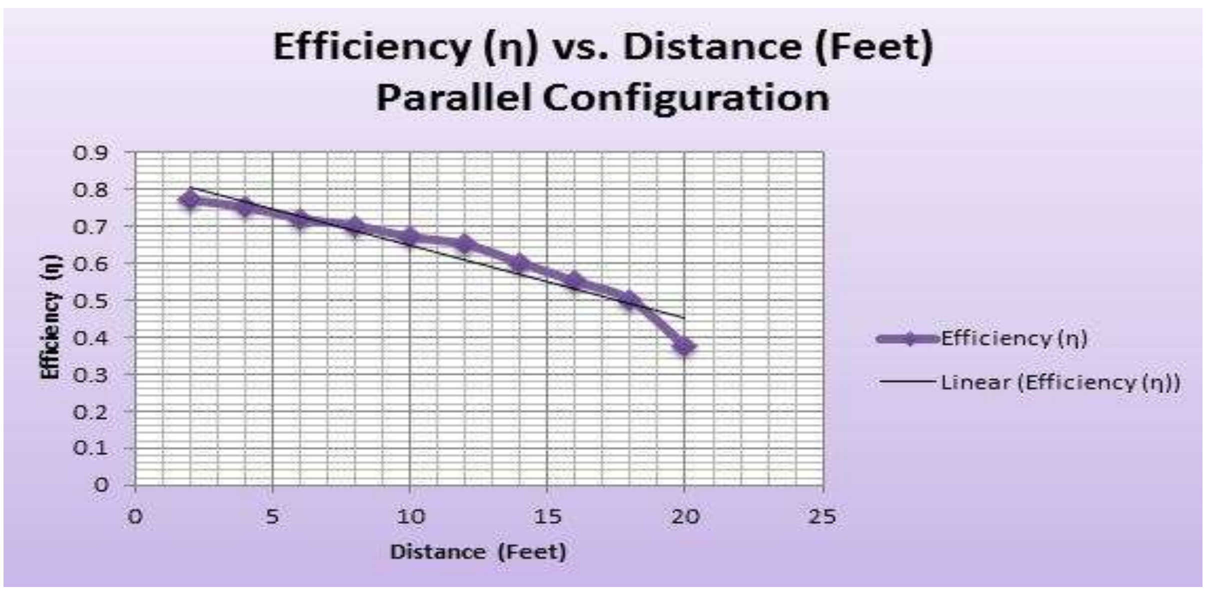

Figure 11 Efficiency vs. Distance Chart for Parallel Configuration

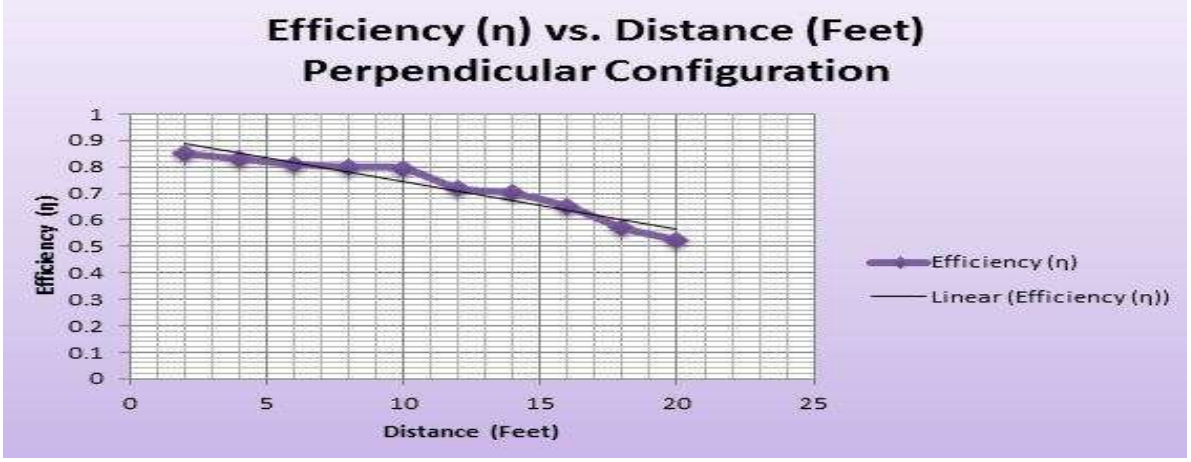

Figure 12 Efficiency vs. Distance Chart for Perpendicular Configuration

The efficiency is decaying with an increment in the distance as shown in both charts in figure 11 and figure 12.

This shows that the performance of the designed system is better when the source resonator and the device resonators are closer to each other and the performance starts degrading when the distance between the source resonator and the device resonator gets increased. It is observed that the efficiency and the performance of the wireless power system decreases when the distance between the source resonator and the device resonator increases for parallel as well as perpendicular configuration.

This wireless power transmission system is suitable for medium transmitting ranges so better efficiency can be achieved at moderate distances.

V. CONCLUSIONS AND FUTURE RECOMMENDATIONS

A successful experiment of wireless power transmission over a distance of 10 feet with an overall efficiency of 80% is carried out in this research work. The designed wireless power transmission is a low-cost, reliable, efficient, secure, and environmental friendly. The designed power system has a negligible interaction with exterior forces/objects. The designed wireless power transmission system can be used in various areas of application. In the area of consumer electronics, the designed system can be used to wirelessly power the home and industry appliances including television, cell phone, room lightings, laptop, propeller displays and clocks, etc. In the area of medical sciences, the presented system can be used to power heart assist pumps, pacemakers, infusion pumps, etc. The presented system can be used to efficiently charge the electric vehicles. The wireless power transmission system can also be used in military and can be used to power military robots, vehicles, and other necessary equipment of a soldier.

In future, a significant research can be carried out in the area of wireless power. Reduced size wireless power transmission systems with better efficiency over large distances can be developed. Efficient wireless power transmission systems can be designed in future to transmit tens and thousands of KW power over hundreds of miles with maximum efficiency and performance.

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