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A Systematic Review of Wireless Transmission System

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AMA, JAO and TAF initiated the project artificial intelligence for clean energy, under which this research belongs. Author JAO coordinates the research on wireless transmission system. Authors IAA and IGA manages the research on wireless transmission systems. Author IGA did the editing and proofreading of the manuscript. Authors MAA and DOB managed the literature searches and drafted the review. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Wireless transmission of energy has gained immense attention and importance in the heart of researchers over the years. Many attempts to make it a widely used technology have been done. However, this has not been successful or fruitful. Hence, the need for a comprehensive review of the mechanisms and techniques by harmonizing the findings of various researchers cohesively and adeptly. Thus, this review paper presents a comprehensive evaluation of the research works in wireless power transmission from the time of Andre-Marie Ampere in 1826 till date. The transmission mechanism and techniques used were concisely discussed as well as technologies

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that have incorporated wireless power transmission into their system. The study closes with a conclusive review of the challenges, and limitations faced, the application, advantages, and disadvantages, of wireless power transmission.

Keywords: Wireless power transmission; near field; far field; microwave power transmission; witricity; magnetic resonance coupling.

1. INTRODUCTION

The role electricity plays in the modern world is as important as food is to the human body. Electricity over the years has made life easy and luxurious for humans, as it is a fundamental ingredient in modern technology for the day to day activities of man. The conventional way of transmitting electricity from generating stations to the consumers' end through wired grid systems pose some challenges and limitations such as delayed communication and heavy transmission losses due to the long transmission distance. However, wireless power transmission (WPT) has gained the heart and attention of researchers as the future transmission medium of energy between the energy stations and the end consumers.

The WPT is a process of transmitting electricity from a power source through the vacuum space or the earth's atmosphere to an electrical load without the use of wired connections [1,2]. The goal of WPT is to transmit electricity from generating or distributing stations to end-user in a similar manner as mobile internet wireless communication technology is achieved. Through this, transmission loss experienced in a wired connection will be reduced and optimum power in the transmission is achieved. Several technologies have started incorporating WPT in their devices such as the wireless charging of phones and portable devices [3].

The idea of WPT is credited to Nikola Tesla who in the 1890s successfully experimented on the wireless transmission of energy at a distance of 26-miles away from the transmitting source [4]. Since then, scientists and researchers have been working assiduously to fill the research gaps in making it a widely used technology thereby eliminating the use of wired connections. Its functionality also fulfills the sustainable development goals of clean and accessible energy to our communities. This paper aims to review the existing mechanism and techniques used for wireless power transmission; as well as some recent works and developments, and technologies using wireless power transmission.

The rest of the paper is organized as follows: Section II is dedicated to the historical revolution of WPT and section III elaborates on the literature review of WPT mechanism and techniques. In section IV, a review of the recent methods and technologies in WPT was presented, and in section V, the applications, advantages, and disadvantages of WPT were highlighted. Conclusions and Recommendations are drawn in sections VI and VII respectively.

2. HISTORY OF WIRELESS POWER TRANSMISSION

The historical event of the WPT system began in 1826 when Andre-Marie Ampere developed Ampere's circuital law showing that electric current flowing through a coil produces a magnetic field [5]. Michael Faraday in 1831 further developed what is called Faraday's law of electromagnetic induction by describing the electromagnetic force induced in a conductor by a time-varying magnetic flux [6]. In 1836 Nicholas Callan worked on the transformation of electricity and invented the electric transformer also known as an induction coil [7]. Heinrich Hertz and Nikola Tesla started their analysis of wireless electricity in the 1890s [8]. In 1891 Tesla was able to use electromagnetic induction using high tension coil to demonstrate wireless transmission of power at the American Institute of Electrical Engineers (AIEE) at Colombia College [9]. In 1893 and 1894, he demonstrated wireless illumination of phosphorescent and incandescent lamps at the Columbian exposition in Chicago using Resonant inductive coupling, also referred to as "electro-dynamic induction" [9,10,11,12]. He proposed a wireless transmission signal at the National Electric Light Association in St. Louis and got his first patent for wireless transmission registered in 1897 [4,7,13].

In 1899, he manufactured a resonant transformer called the Tesla loop and built a huge coil tower of about 60m in height to conduct his experiment in Colorado Springs, Colorado [14]. The tower had a copper ball positioned at the top and an iron root system of above 90m that goes underground as shown in Fig. 1. He accomplished a noteworthy achievement in his work by transmitting 100-millions volts of electricity wirelessly. His test could power 200-lights, 26-miles away from the location of his lab to illuminate a bank, and power an electric motor [15]. Tesla's idea could have been implemented on the large scale, provided he documented the outcome of his research. However, he was said to be poor in putting down notes, but only documented things he thought to be extremely fundamental or vital. Tesla sought to change the phase of electricity transmission after his discovery but was limited by timing and funding [8,16,17].

In recent years, researchers picked up interest in Tesla's idea of a wireless transmission system with several research gaps identified. It was noted that WPT holds a future as a transmission medium in the energy industry [18]. In 2007, a group of scientists from the Massachusetts Institute of Technology (MIT) led by Professor Marin Soljacic used the principle of electromagnetic induction to power a 60W light bulb from a distance of 2 meters. They carried out a mid-range wireless power transfer using resonance coupling of electromagnetic with an efficiency of about 40% [19]. In 2008, Tesla's electro-dynamic induction was reproduced by Intel and used to wirelessly power a bulb with 75% energy efficiency [20]. In 2009, Sony demonstrated a wireless electrodynamics induction powered TV set, 60 W over 50 cm [21].

2.1 Other Experimental Proofs of WPT

- In 1910, a wireless powered incandescent lamp experiment was performed using electromagnetic induction. At the bottom side, a large cylindrical shape used as the transmitter was developed using an electromagnet and a coil of wire with alternating current flowing through it. The electromagnetic field generated during transmission is then converted to electric energy to power the lamp which has been attached to the core of the wire at the top. The lamp used is similar to that of Thomas Edison lamp with a carbon filament [22].
- In Goldstone, California, 1975 a wireless high-power transmission using microwaves experiment in the tens of kilowatts was carried out and more recently in 1997 at Grand Bassin on Reunion Island [23]. These methods achieved a distance on the order of a kilometer. Under experimental conditions, the microwave conversion efficiency was measured to be around 54% [24,25,26].
- Hiroshi Matsumoto team in 1983 carried out a microwave power transmission (MPT) in space. The rocket experiment was called MINIX (Microwave Ionosphere Nonlinear Interaction experiment). They used a cooker-type 800W-2.45GHz magnetron for the microwave transmitter. In the course of their experiment, a new wave-particle interaction phenomenon was observed in the MINIX and the plasma theory supported their observations [27,28,29].
- The world's first fuel-free airplane powered by microwave energy from the ground was implemented in Canada in 1987. This system is called SHARP (Stationary High – Altitude Relay Platform) with 2.45GHz [29,30].
- In 1992, a joint collaborative group in Japan used phased array technology to perform a fuel-free flight successfully. The experiment was regarded as the MILAX (Microwave Lifted Airplane Experiment) [31].

Fig. 1. Tesla Tower on Long Island, New York [16]

- In [32] a system used to transfer a large quantity of energy across small air gaps was developed in 1993 [33]. This system was used for the moving crane and the AVG non-contact power supply in Japan [34].
- Series of ground to ground MPT experiments were carried out by power companies and universities [35].
- NASA Dryden Flight Research Center in 2003 used a laser beam to power a lightweight unmanned model plane. A control system was used to keep the laser pointed at the plane and photocells from a beam of infrared light from a ground-based laser-generated small model plane motor which was powered by electricity [36].
- Managed Energy Technologies of the U.S organized the demonstration of a long-range MPT on one of the Island of Hawaii in May 2008. This demonstration also included the wireless transmission of energy [37].
- The University of Korea Advanced Institute of Science and Technology (KAIST) researchers developed an electric transport system that is called Online Electric Vehicle (OLEV). They powered the vehicle wirelessly using cables via non-contact magnetic charging that are kept under the surface of the road. This technique was implemented to manage traffic congestion and also improve energy efficiency by reducing its consumption. In 2009, they successfully supplied power to a bus over a distance of 12cm and recorded 60% efficiency [38].
- An American Physicist inventor Hatem Zeine, demonstrated WPT using a phased array antenna to deliver electrical power up to 30feet in 2013 at the same radio frequencies as Wi-Fi [39,40].
- The first mid-field radio frequency (RF) transmitter of WPT was certified by the Federal Communication Commission (FCC) in 2017 [41].

3. LITERATURE REVIEW

The transmission mechanism for WPT can be classified by distance from the electromagnetic field source under two categories: The Near-Field and the Far-Field [42].

3.1 Near Field Technique

The near field transmission techniques (also known as non-radiative) can transmit power at a relatively short distance with high transfer efficiency [43]. It uses only capacitive and inductive coupling to transmit power over a short-range/distance which is within a few diameters of the transmitting coil. The magnetic field serves as the transmission medium between the transmitting coil and the receiving coils to transmit energy as shown in Fig. 2 [44]. The transfer energy efficiency drops if the iron core is removed and the two magnetic coils are separated from each other [45]. Since near field transfer frequency is usually at 50 or 60Hz, there is practically no interference with TV, radio, or Wi-Fi signal. Although, concerns have been on its implication to human health. However, the larger percentage of the human body composition is non-magnetic, so they interact very weakly with the magnetic field [44,46].

Near-Field technique has several advantages such as low production cost, compact structural design, safety, and reliability. This method is used in several applications including charging of portable devices like wireless phones charging and electric toothbrushes, RFID tags, mp3s, universal wireless power pad, etc. [47,48]. Types of Transmission mechanism under the Near Field technique:

1. Electromagnetic Induction Coupling
2. Electromagnetic Resonance Coupling
3. Electric Field Coupling

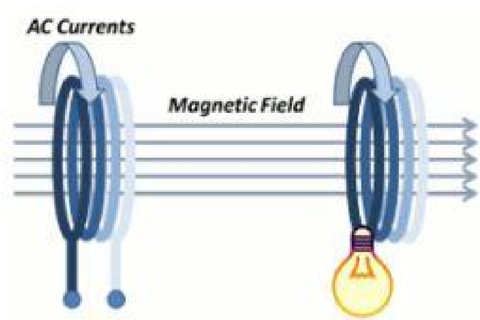

Fig. 2. Transferring energy through magnetic field coupling between two coils with identical resonant frequency [44]

3.1.1 Electromagnetic induction coupling

Electromagnetic induction coupling is the most widely used wireless power technology in commercial products. It is used in inductive charging stands for cordless appliances used in wet environments such as electric toothbrushes [49] and shavers, to reduce the risk of electric shock [50]. It operates on the principle of mutual inductance in a transformer to transfer energy between two coils (transmitting and receiving coils). Transformers operate on this principle where no physical contact exists between the two coils but induces power electromagnetically as shown in Fig. 3 [51].

When an alternating current (AC) is passed through the transmitting coil, an oscillating magnetic field (B) is created according to Ampere's law [52]. As the magnetic field passes through the receiving coil, it induces an alternating electromotive force (voltage) by Faraday's law of induction [53] and creates an alternating current at the receiver [54,55]. The induced AC is either rectified to a direct current (DC) by adding a rectifying circuit to the receiver coil or used directly to power the load. The transmission efficiency increases with the frequency [55] and the mutual inductance between the two coils [54] which both depend on the geometry of coils and the distance between them [56]. Another application area is in the transcutaneous recharging of biomedical prosthetic devices implanted in the human body, such as insulin pumps and cardiac pacemakers, to eliminate wire passing through the skin [57] [58]. It is also used to either charge or power transit vehicles like trains and buses [49,59].

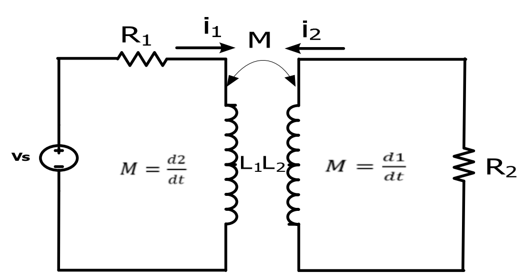

Fig. 3. Transformer mutual inductance circuit diagram

$$M = \frac{\mu_\circ \mu_r N_1 N_2 A}{\ell} \quad (1)$$

where:

$\mu_\circ$ is the permeability of free space $(4\pi \times 10^{-7})$
μ_r is the relative permeability of the soft iron core
N is in the number of coil turns
A is in the cross-sectional area in m^2
ℓ is the length of the coil in meters
L is the coil inductance

$$M_{12} = \frac{N_2 \Phi_{12}}{I_1} \quad (2)$$

$$L_1 = \frac{\mu_\circ \mu_r N_1^2 A}{\ell} \text{ and } L_2 = \frac{\mu_\circ \mu_r N_2^2 A}{\ell} \quad (3)$$

$$M^2 = L_1 L_2 \quad (4)$$

$$M = \sqrt{L_1 L_2}\, H \quad (5)$$

The strength of the magnetic field is directly proportional to the amount of current that passes through a conductor.

$$B = \frac{\mu_\circ I}{2\pi r} \quad (6)$$

where B is the magnetic field in Tesla,
I is the current in the inductor
r is the Radius of the inductor

3.1.2 Electromagnetic resonance coupling

Tesla discovered the use of resonance coupling for WPT in his experiment in the 1890s, but the possibilities of using resonance to increase transmission range have just started gaining ground [60]. The principle of a strong magnetic resonance coupling was proposed by a group of researchers at MIT in 2007 as a solution to the mid-range WPT [19,61]. Energy is transferred by magnetic fields between two resonant circuits (tuned circuits), one in the transmitter and one in the receiver at the same resonance frequency [49]. Each circuit consists of a capacitance plate to hold a charge and is added to the end of a pair of coupled coils [62].

The continuous flow of electric current through the transmitting coil makes the coil resonate, thus generating a magnetic field around it. Therefore, the resonance frequency is the frequency at which the amplitude of the waves produced in the system is maximum. This can be attained by varying different parameters affecting the gain of the voltage produced within the coils such as the Q-factor [63,64]. Electromagnetic resonance coupling has considerably better power efficiency and can go several meters as compared with the inductive coupling WPT. The resonance between the coils can significantly increase the coupling and the energy transfer similarly to the way a sounding trumpet can cause a nearby trumpet to vibrate. This is because the two trumpets have the same resonance frequency.

A major drawback of the resonant coupling theory occurs when the two resonant circuits are tightly coupled at close ranges, the resonance frequency of the system will become varying and split into two resonance peaks [65,66]. With this, the maximum power transfer at the original frequency no longer takes place and the oscillator frequency must be tuned to the new resonance peak [67,68].

Resonance coupling is widely used in modern inductive WPT. It is envisioned for an area of wireless power coverage. A coil in the wall or ceiling of a room might be able to wirelessly power lights and mobile devices anywhere in the room, with reasonable efficiency (Wilson, 2014). An environmental and economic benefit of wirelessly powering small devices such as clocks, radios, music players, and remote controls is that it could drastically reduce the 6 billion batteries disposed of each year, a large source of toxic waste and groundwater contamination [69].

3.1.3 Electric field coupling

Electric field coupling (also called capacitive coupling or electrostatic coupling) uses an electric field for the transmission of power between two electrodes (anode and cathode) forming a capacitance for power transfer [70]. Energy is transmitted by the electromotive force through the electric fields between the transmitter and receiver electrodes which form the capacitor, with the separating space as the dielectric [54,71]. The generated alternating voltage is applied to the transmitting plate and the electric field induces an alternating potential at the receiver plate by capacitive coupling (electrostatic induction), which causes the flow of an alternating current to the load circuit. Several factors contribute significantly to the increase in power transfer, such as the frequency [72], the square of the voltage, and the capacitance between the plates, which is directly proportional to the area of the smaller plate and inversely proportional to the separation [54].

Transmitting a high amount of power using capacitive coupling can be hazardous and can cause side effects such as noxious ozone production, because of the very high voltage on the electrodes [73]. Hence, the capacitive coupling has only been used for small power application such as some portable device batteries, biomedical implants, and substrate layers in integrated circuits use electric field coupling techniques for wireless power transfer for charging [74].

3.2 Far-field Technique

The far-field technique is used for long-distance WPT using beams and electromagnetic radiation to transmit large amount of energy. The higher the wavelength, the larger the antennas must be to achieve sufficient directionality during transmission. The maximum directivity for antennas is physically limited by diffraction. An antenna with a dimension of several meters to several kilometers is highly required for use since the speed of light in the air is about $3 \times 10^8 ms^{-1}$. Therefore, the corresponding wavelength used will be about one meter long [75,76]. Thus to transmit to smaller objects, an electromagnetic with a shorter wavelength must be used. Also, it has potential health implications to humans if the radiation is not directly transmitted from the source to the receiver. Its application includes wireless powered drone aircraft and solar power satellites [77,78,79]. Three transmission mechanism in existence under this technique are:

1. Microwave Power Transmission
2. Laser Power Transmission
3. Radio Wave Power Transmission

3.2.1 Microwave Power Transmission (MPT)

Nikola Tesla in the 1980s' constructed a large power tower called the Wardenclyffe Tower as a concept used for large distance MPT [7]. William C Brown pioneered the WPT technology using microwave technology [80]. He designed a unit and demonstrated how power can be transferred using microwave antennas. However, the major limitation in the development of microwave over the years is the health implications that microwave radiation has on human health. This is because the intensity of the electromagnetic radiation is much higher than the standard radiation for the living environment (usually lesser than $0.4W/m^3$) [81]. A microwave power transmission system has three major parts which are: the microwave generator, transmitting antenna, and receiving antenna (rectenna). The concept of WPT is explained using the functional blocks as shown in Fig. 4 [82].

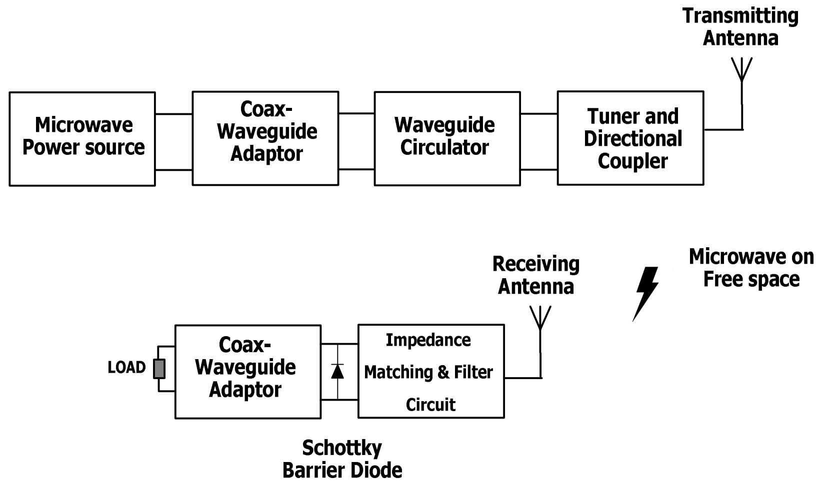

Fig. 4. Block Diagram of power transmission using microwave [82,83]

At the transmitting side, the reflection from the microwave is protected by the waveguide circulator and it is connected to the microwave power source through the coax-waveguide adaptor. The impedance between the transmitting antenna and the microwave source is matched by the tuner and the directional coupler uses the direction of the propagated signal to separate the attenuated signals. The microwave power is transmitted through the transmitting antenna at a high frequency ranging from 1GHz to 1000GHz [63,84]. Common types of transmitter antennas are slotted waveguide, microstrip patch, parabolic dish antennas, traveling wave tube (TWT), klystron, and magnetron [85,86]. Slotted waveguide antennas are used for high power loads because of their high efficiency, while magnetron is highly preferred by researchers because it is relatively cheap and efficient.

At the load end, the microwave received is converted back into dc power using a unit called rectenna [7]. The rectenna extracts microwave energy and convert it back to electrical energy and is extensively used in microwave power transmission. It consists of an RF diode and a dipole antenna connected across the dipole elements [87]. The AC induced in the antenna is rectified by the diode to produce a dc power for the load. According to [88], the power efficiency of an MPT system is said to be 76%. The output impedance of a signal source is made equal to the rectifying circuit by the input impedance matching and filter circuit.

3.2.2 Laser power transmission

The laser beam is thrown from a distance to the load end at a high frequency and intensity. The process of energy transmission is similar to the solar cells photovoltaic generation principle which takes energy from the sunlight and converts it to electricity. Laser power transmission operates by using highly efficient photovoltaic cells at the load end to receive the laser beam from the transmitter, energize the laser light and convert it into electric energy. Research organizations such as Nassau, Entech, etc. are working on making laser power transmission a working principle at a large scale [7]. Previous research and implementations have shown that laser power transmission has an energy efficiency of 50% as compared to other methods. However, several propositions have been made that the efficiency could be increased by using advanced technology of laser photovoltaic cell receivers [89].

Energy is transmitted from the laser source through an efficient lens. This lens converges the beam of the laser to the specific location where the receiver has been positioned. The receiver is made up of a series of highly efficient photovoltaic cells that receive the transmitted beam and convert it into electric energy to energies the load. This technology was used with a rover to explore the presence of ice at the bottom of the craters of the moon where no sunlight is available. Other applications include powering of extra-terrestrials reveres and aircrafts providing power to a satellite orbiting the earth, power transmission to inaccessible locations. Laser power transmission is shown in Fig. 5 [84,90,91].

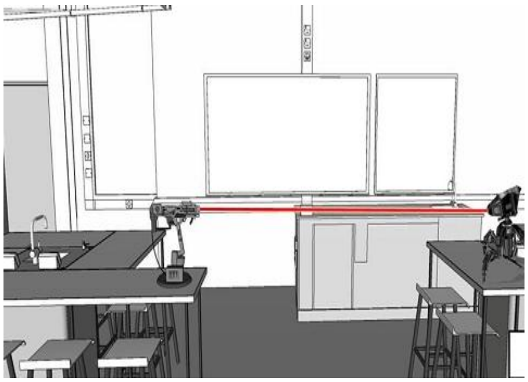

Fig. 5. Wireless power transmission through laser

3.2.3 Radio wave power transmission

Radio wave power transmission operates almost the same way that microwave power transmission operates except that the transmitting signal is not converter to microwave, but is transmitted as radio frequency (RF) beams. The transmitter transmits the RF signals at a specific frequency across the space powered from either an ambient or international power sources. The receiver at the other end is built into one or more devices, captures the frequency, and converted it back to electric energy to power the device. Previous research works show that a distance of 30-meters and above can be achieved via this method. Wireless Radio Frequency can be used to power several devices such as laptops, remote sensors, Wi-Fi, etc. [7,89].

4. REVIEW OF RECENT TECHNOLOGIES IN WIRELESS POWER TRANSMISSION

Over the years, researchers have focused their attention on ways of increasing the efficiency of wireless power transmission for far distances. In 2007, MIT researcher proposed the idea of using a strongly coupled magnetic resonance to transmit power over a large distance [61]. They experimentally demonstrated an efficient non-radiative power transfer over a distance up to 8-times the radius of the coils. The experiment consists of two self-resonant coils which depend on the interplay between the distributed capacitance and the distributed inductance to achieve resonance. The source coil is coupled inductively to an oscillating circuit while the receiving coil is coupled inductively to a resistive load at the same frequency. As the coil resonates, the charge and the current density profiles are $90^{\circ} or \frac{\pi}{2}$ out of phase with each other. This means that when the real part of one coil is at maximum the real part of the other is at zero. Equally, the energy contained in the coil is at definite points in time completely due to the charge and at other points, it is completely due to the current. The effective inductance (L) and capacitance (C) using the electromagnetic theory is given as [61].

$$L = \frac{\mu}{4\pi|I_{\circ}|^2} \int \int dr dr' \; \frac{J(r).J(r')}{|r-r'|} \quad (7)$$

$$\frac{1}{C} = \frac{1}{4\pi\varepsilon_{\circ}|q_{\circ}|^2} \int \int dr dr' \; \frac{p(r).p(r')}{|r-r'|} \quad (8)$$

The spatial current $J(r)$ and charge density $p(r)$ are obtained respectively from the current and charge densities along with the isolated coil, in conjunction with the geometry of the object. The system was given a resonance frequency of $f_{\circ} = 10.56 \pm 0.3 \text{ MHz}$, which is about 5% of the measured resonance at 9.90MHz. It was used to power a 60watts load and a 40% efficiency over a distance excess of 2meters were recorded. However, the limitation of their work was seen in the low efficiency of the power transmitted as the total power loss was 10% more than half the overall power transmitted. Also, all the necessary information such as the design theory was not disclosed nor presented [61,92,93].

In [94], the author worked on the limitations of MIT researchers [61] by using the magnetically coupled-resonator as the intermediate circuit between the transmitting and the receiving coil. They considered the use of two coupled resonators facing each other and tried to match them with the external circuits that are neither more nor less than a modified 2-stage bandpass filter.

Yuki Endo and Yasuo Furukawa in [95] focused their works on obtaining over 100 high Q factor as a requirement in the power transmission resonance circuit by using high precision adjustment of the resonance frequency. They proposed a circuit by which a set resonance frequency can be sustained without applying complicated control in a high Q resonance circuit named Automatic Tuning Assist Circuit (ATAC). They concluded based on their experimentation that power transmission was possible when the transmitting side ATAC circuit was effective, even though the transmitting frequency did not match that of the resonance frequency. Although there exists power loss at the side whose frequency was lower than the resonance frequency as a result of the ATAC circuit not satisfying the condition of zero voltage switching (ZVS). They discovered that when the ATAC circuit is placed at the receiving side, it proves to be highly effective. Hence they proposed that by using soft switching technologies, higher transmission efficiency will be achieved. In [96], Masataka Ishihara et al analyzed the ATAC circuit as proposed by [94] and explained the effectiveness of the ATAC for improving the robustness of the performance of the repeater when the frequency splitting phenomenon occurs.

Several technologies have incorporated the use of WPT as a working part of their systems, some of which are explained below:

4.1 WiTricity

WiTricity Corporation was founded in 2007 to commercialize a new technology for wireless electricity. This technology uses the principle of coupled resonant objects [94]. Resonance is a property that exists in many different physical systems as a natural frequency at which energy can most efficiently be added to an oscillating system. Resonant coupling occurs when the natural frequencies of the two systems, a source, and a receiver are approximately the same. WiTricity power source and receiver devices are specially designed magnetic resonators that efficiently transfer power over large distances via the magnetic near-field. It provides a unique solution of all sizes and power requirements [19].

Electrical vehicles are gradually replacing conventional combustion engines and this serves as the current research focus WiTricity. The organization is working on mass-producing new batches of electric vehicles to be charged wirelessly at the car park or on the highway using the principle of strongly coupled magnetic resonance coupling. Their products are designed to meet the safety standards and regulations for highway vehicles. The efficiency of the transmitted power can exceed 95% when the distance between the transmitter and the receiver is relatively close to each other. Although, the position of the receiver has a significant impact on transmission efficiency. They are designing their system to be position adaptive and also transmit through walls or obstacles. [95].

4.2 Qi Technology

The Qi technology allows charging at a distance of a few centimeters at most and uses small inductance to transmit power at higher frequencies. Portables devices are placed on the charging pad to ensure that the receiver stays within the range of the magnetic field to achieve a high power transfer efficiency. With these limitations at hand, the Qi uses multiple resonators (repeaters) arrays to create a larger charging area [96,97]. Although, the wireless charger gets warm during charging due to the operating frequency heating the conducting materials. This technology incorporates a limited communication protocol in other to limit the power consumption of the multiple coils. This makes it possible for the receiver to take as much power as needed to get fully charged. Additionally, the charger can modify its power output to that of the receiver and can also switch to standby mode once the device is fully charged or when no device is placed on it. Despite technological advancement, wireless charging has not been as efficient as a wired charger [98,99,100,101].

4.3 Alliance for Wireless Power (A4WP) Technology

This technology is based on reference power transmitting and receiving resonators without the use of a wired connection [102]. It allows multiple devices to be charged by different power specifications from the same transmitter at the same time. It enables the device to be charged without necessarily lining-up with the coil because it uses larger electromagnetic fields rather than small inductor coils. It has the advantage of allowing chargers to be embedded in the objects where the magnetic field can emit energy from the object despite the barrier [103,3].

4.4 Power Matters Alliance (PMA) Technology

Power Matters Alliance (PMA) is a forward-thinking organization where a better power paradigm for battery-equipped devices using wireless charging technology has been functional. The organization has experienced rapid growth since its inception in 2012. PMA's growth and success are attributed to the dedication, commitment, and hard work of the workers and the uniqueness of their approach to making wireless charging abundant in places where it is needed the most [104].

5. APPLICATIONS OF WIRELESS POWER TRANSMISSION, ADVANTAGES AND DIS-ADVANTAGES

WPT finds application in several areas or fields. Some of them are listed below [47,88,105].

1. Field of electronics
2. Medical devices
3. Electric Vehicles
4. LED Lightening
5. Defense System

5.1 Advantages

1. Through WPT, electricity becomes accessible to places where a wired connection cannot be implemented.
2. Transmission efficiency is higher in wireless transmission than in wired transmission [47].
3. It is easy to use and easily integrated since the need for clustered wired cable is eliminated
4. It is more reliable, convenient, and environmentally friendly.
5. It can transmit power to many directions simultaneously

5.2 Disadvantages

1. The cost of WPT installation is high
2. There is a tendency of having interference between the microwave transmission and the wireless communication networks
3. Microwave transmission poses a risk to human health

6. CONCLUSION

A review of the WPT system techniques has been presented. In this paper, the development of the WPT system, the transmission techniques, mechanism, the latest technologies using WPT, and the areas of application was discussed. Remote areas with limited or no access to the energy grid will benefit immensely from this technology. With the development of WPT, transmission through wired cables will gradually fade out. Researchers are working on deploying this technologies to areas such as wireless powered smart city, wireless control of drone to extinguish a fire, wireless powered train, wireless Solar Power Satellite, and in the area of robotics. Hence WPT systems hold a future in the transmission sector of the global energy system.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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