Different Techniques and Algorithms used in Wireless Power Transfer: A survey

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ABSTRACT: Battery back-up gadgets are having unique technological challenges likeincreased cost, high weight and minute density of power. The battery charging time of Smartphone has become a challenge because of the increased use of electricity due to the complexities of complex multimedia signal processing requirement. One excellent solution is wireless power transfer (WPT) in which the battery is charged over the air.WPT is more convenient over traditional energy supply as itnot bother of connecting wires and replacing batteries. It offers required uninterrupted power supply, so it reduces cost of battery. No need of battery disposal hence environmental friendly.In this paper we present an general idea of WPT technology that is emphasized on basic WPT technology, its types and applications.Then we discuss the comparison between different wireless charging techniques i.e., inductive and capacitive coupling, magnetic resonance coupling, microwave and light wave transmission.

IndexTerms - **Wireless charger, near field capacitive coupling (NCC), Wireless power transfer (WPT), PoWiFi, Wireless-Powered Sensor Network (WPSN).**

I. **Introduction**

WPT includes transfer of power from fixed power source to electronic implants without using physical medium. Wireless device can be powered remotely. The battery-powered devices can harness wireless power from electromagnetic field in air and then charge their batteries cordlessly even in the moving state by utilizing the WPT technique [1].WPT allow devices to move freely and remove large battery, which make devices more compact.User convenience, product durability, usage flexibility, and on-demand availability are the advantages of wireless charger. WPT can charge moving devices. It reduces the problem of battery storage for long time, its maintenance and cost of batteries. Major technical difficulties in WPT are efficiency, power loss, security, distance, Omni-directional chargingandmisalignment. Author tesla had been introduced different methods of WPT, including inductive and capacitive coupling, magnetic resonance power transmission for short range, and microwave power transmission, laser based transmission for long range [2]. The leftovers part of this paper is presented as follows: Section II will explain the working mechanism of inductive and capacitive coupling, magnetic resonant coupling, Microwave transmission and Light wave transmission. In Section III, this paper will systematically summarize literature review. Lastly, Section VI will draw conclusions and discuss about future prospects for WPT systems.

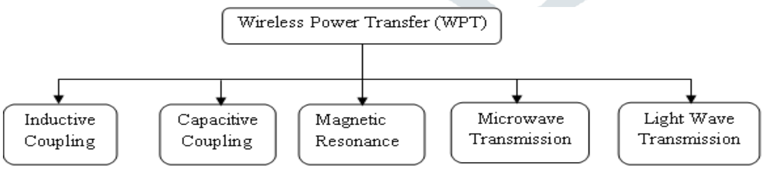


Figure.1 WPT Technologies.

II. WPT TECHNOLOGIES

A. Inductive Coupling

Magnetic induction field is used in inductive coupling as shown in Fig.2.

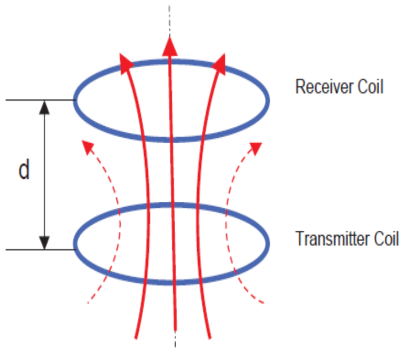


Fig.2. Inductive Coupling-based WPT

This is a near field transmission technology that holds transmission of few mm to cm [3]. Inductive Coupling is based on magnetic induction. Its efficiency is Very high more than 90%. But, it require precise transmitter - receiver coil alignment. It works on very short range and compatible with single receiver only. Applications of inductive coupling are RFID, phone, smart cards, Electric vehicle charging, etc. It follows Qi (Chee) standard. Powermat, WildCharge, Primove Delphi, GetPowerPad, etc. companiesworking on Inductive coupling [2]. The inductive coupling uses Faraday's Law and Biot-Savart's Law in WPT based theory. The magnetic field produced by an arbitrary current distribution is calculated by the Biot-Savart's Law:

$$\boldsymbol{B} = \frac{\mu_0}{4\pi} \oint \frac{I d_I \times r}{|r|^3} \qquad (1)$$

Where I is current, μ_0 is magnetic constant, d_I vector r is full displacement vector.

The induced voltage over the receiver coil V_{Ind} is calculated by Faraday'sLaw using rate of magnetic field B change through an effective surface area S by:

$$V_{Ind} = -\frac{\partial}{\partial_t} \oint B . d_s \qquad (2)$$

The drawback of the WPT based on inductive coupling is its short distance transmission.

A. Capacitive Coupling

Capacitive coupling is Near-field (NCC) transmission based WPT scheme proposed by Rangarajan Jegadeesanand el. at in [4]. They identified that NCC can work in sub GHz frequency range. This is the capacitive scheme basically designed for improvement of efficiency and flexibility of implants. NCC work on principle of displacement currents. Itconsists of 2 conductorsTX–RX pairs at distance D, effective area A, when time-varying voltage, V(t) applied current passes through source.Magnitude of conduction as well as displacement current given in [4] as follows,

$$I_{disp} = \mathcal{E}_0 \mathcal{E}_r(\omega) A \frac{\partial \tilde{E}}{\partial_t} \qquad (3)$$

I_{disp} is representing the current displacement of plates.

$\mathcal{E}_0$ – free space permittivitybetween the two plates

$\mathcal{E}_r(\omega)$ – represent the relative permittivity based on frequency.

$$I_{cond} = \frac{V(t)\sigma(\omega)A}{D} \qquad (4)$$

I_{cond} is representing the current conduction of plates.

σ (ω) represents conductivity of the medium for pair of conductors.

User can increase efficiency of WPT by increasing electrical field rate and area between the conductors eq. (3). However, eq. (4) shows that decreasing the conduction current requires reducing the effective conductor area and the excitation voltage [4].

B. MAGNETIC RESONANT COUPLING

The range of Magnetic resonance WPT is longer than inductive coupling. It uses multicasting, to charge multiple wireless devises at a time. Efficiency of magnetic resonant is high and it is mid-range transmission. WiTricity, Intel, WiPower, PowerbyProxi, companies are working on Magnetic resonance WPT. Two electromagnetic subsystems are available in magnetic resonant coupling system. These subsystems are having same natural resonance frequency. The efficient power transfer is enabled by it [5]. A standard RLC circuit represents such system. It consists of a resistor, a capacitor and an inductor as shown in Fig. 3.

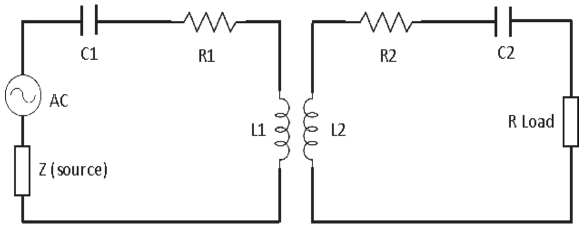


Fig.3. Circuit of Magnetic Resonant Coupling

Firstly source excited the transmitter coil and then transmitter is magnetically coupled with the receiver coils. Power transfer efficiency is determined by the resonator's Q-factors and the strength of mutual coupling as:

1) The resonator's Q-factors (Q) [5].

2) The strength of mutual coupling (M) [6] [7].

The Q factor is defined by:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{\omega_0 L}{R} \qquad (5)$$

Where resonant frequency denoted by $\omega_0 = \frac{1}{\sqrt{LC}}$. A lower Q indicates high energy loss and vice versa.

Mutual inductance calculated by:

$$M = k\sqrt{L_1} \times L_2 \qquad (6)$$

Where k is the coupling coefficient determined by the distance between transmitter and receiver coils, L1, L2 are the inductance, C1, C2 are the capacitance, R1, R2 are the resistance of the receiver coils and the transmitter. The load resistance is RLoad.

Magnetic resonant coupling is can transfer power over long distance than the inductive coupling approach. It is irradiative. It don't required line of sight. It has almost not harmful to anyone. The magnetic coupling WPT is sensitive to alignment. When multiple devices are charging, the problem to adjust the resonance frequency is more difficult [8].

C. MICROWAVE TRANSMISSION

Microwaves technology of WPT is used for long distance transmission. Applications like satellite on solar power, charging wireless devices, drone aircraft powering works on microwave transmission technique [9]. Microwave waves are far field WPT technique. It works on long rangeintegration with wireless communication. It is flexible to use and support power multicasting for mobile devices. RFID, IoT devices and Wireless sensor are main applications of microwave. Its efficiency is low and having health and safety problem. PowerCast, Ossia and Energouscompanies work in this epoch. WPT system with RF/microwave generator is shown in Fig.4 on base station and harvesting node.

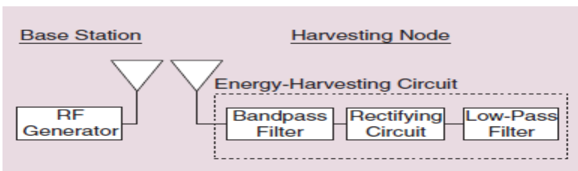


Fig.4. WPT system with RF/microwave generator

An important issue in the development of WPT technology is improving power transmission efficiency. An electromagnetic radiation requires waveguide, microwave source, transmitting and receiving antenna. Initially the energy is transmitted to the waveguide from the microwave source. While transferring energy from the transmitter side electromagnetic wave are uniformly emitted by the transmitter antenna. This microwave energy is collected by the receiving antenna by using silicon-controlled rectifier diode. This energy is converted into direct current. The high efficiency is advantage of electromagnetic radiation. This efficiency is maintained for long distance. It has radiation concerns often. For transmission it requires the line of sight.

D. Light waves Transmission

Light waves are used on long distance with high energy concentration through laser radiation. Laser radiation is compact in size. It does not hamper the existing electronics devices or communication system. It require accurate receiver focusing. Laser radiation is harmfulto livelihood and vulnerable to cloud, fog, and rain. LaserMotive works in Laser waves [2]. Fig.5 gives laser light Transmission in WPT from transmitter side to receiver side.

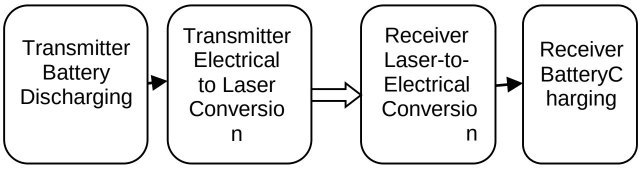


Figure.5. Laser light Transmission in WPT

III. LITERATURE SURVEY:

WPT technique designed and invented by Nikola Tesla. He proposed Wardenclyffe Tower. This tower used to transfer electrical energy in short distance communication [2]. Inductive, magnetic resonance and microwave radiation are the three important techniques of the wireless charger, which are reviewed in case of their advantages, disadvantages, effective charging distances, and applications wireless charger technique. The Qi and Alliance wireless charging standards of for Wireless Power are also discussed in this paper [10].

In Wireless Power Sensor Network (WPSN) electric energy is wirelessly transfers power to a sensor node. In WPSN testbed the Real-life multi-antenna is used. Algorithm for adaptive duty cycle control, energy beam forming and channel estimation of receive power is proposed [11]. The power is received as per the distance between antennas and the sensor node. They studied parameters like efficiency of energy harvesting of the energy harvesting board, gain of beam forming and efficiency according to the distance. It increases receive power 6 times higher than regular receiver. The RF energy transfer efficiency is linearly increasing with the number of antennas when the energy beam forming is applied. Its effective distance is 2.6 m.

In [12] author Vamsi Thalla designed a new novel technique name as PoWiFi. Power over Wi-Fi is a modified device of existing Wi-Fi. In general in wireless technology, battery problem is a major problem during communication. Many sensor nodes are having limited battery backup for communication. Energy is very important parameter in wireless communication. So, to solve this energy consumption problems author proposed PoWiFi device that transmit power over Wi-Fi for packet transmission to the destination end. Using this technique user can easily charge sensor nodes or communication devices. PoWiFi build up of a Wi-Fi transmitter that transmits power to multiple devices simultaneously and energy-harvester that receives power to increase life span of the nodes. Author face challenges like, power requirements of implants and Wi-Fi protocol may have mismatch, energy leakage and collision of packets during transmission. Transmission efficiency of PoWiFi is achieved by optimizing rectifier's voltage and network's throughput. Packets are transmitted concurrently to enhance performance. Collision between the packets during transmission doesn't effects on system. This neither affect TCP / UDP throughput of data transmission nor to neighboring Wi-Fi network. Harvester uses matching network to balance power requirement of implants and Wi-Fi protocol. Multiple powering devices are used to harvest power i.e. PoWiFi cluster [12].

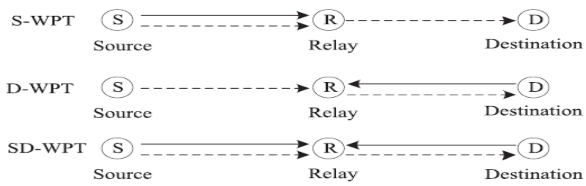


Fig.6. Three basic WPT schemes

In [13] C. Zang consider a half-duplex wireless powered relay system consist of a source (S), a relay (R) and a destination (D) as shown in Fig.6. They proposed Source WPT (S-WPT) Scheme, Destination WPT (D-WPT) Scheme, Joint Source and Destination WPT (SD-WPT).

In S-WPT scheme, only the source with transmits power P_t transfers energy to the relay. In most related literatures, WPT is performed by the source. Thus, in S-WPT scheme, the harvested energy at the relay is

$$E_r^S = \eta\alpha T\left(\frac{P_t|h|^2}{Kd_1^m}\right) \qquad (7)$$

Where m presents the path loss factor, E is the conversion efficiency of energy harvesting circuit, and K is the power loss at the reference distance.

The path loss of RF signals propagation is considered in Destination WPT (D-WPT) Scheme [13].The energy transferred by source not always good if the relay is closer to the destination. Therefore, in destination WPT scheme, the destination tries to transmit RF signals to recharge the relay. Then, similarly, the harvested energy at the relay is

$$E_r^D = \eta\alpha T\left(\frac{P_t|g|^2}{Kd_2^m}\right) \qquad (8)$$

In Joint Source and Destination WPT (SD-WPT) Scheme, the RF signals are simultaneously transmitted by source and destination to the relay throughout the first phase. For 0 <δ< 1,

$$E_r^{SD} = \eta\alpha T\left(\frac{\delta P_t|h|^2}{Kd_1^m} + \frac{(1-\delta)P_t|g|^2}{Kd_2^m}\right) \qquad (9)$$

The relay is recharged by WPT. Message from one source to particular destination is transmitted by cooperative information relaying. The left time slot (1- α)T is separated into two sub-phases with equal period due to the Decode-and-Forward scheme [13]. (Fig.7)

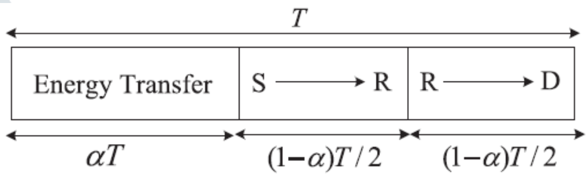


Fig.7. Transmission time schedule

SUMMARY OF ADVANTAGES AND DISADVANTAGESOF DIFFERENT WPT TABLE:

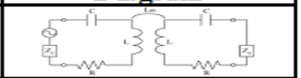
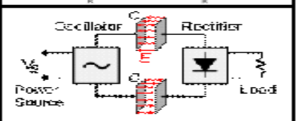
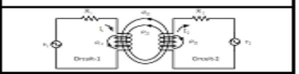
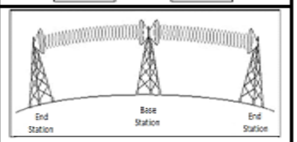
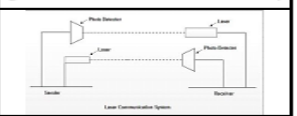
WPT Category	Advantages	Disadvantages	Basic Circuit Diagram
Inductive Coupling	Simple, Safe, and high transfer efficiency in short distance	Short transmission distance, needs accurate alignment.	
Capacitive Coupling	High sensitivity, high transfer efficiency, good frequency response, high input impedance.	Short distance, non linear behavior, temperature sensitive, output impedance depends upon the frequency	
Magnetic Resonant Coupling	Long transmission distance, No radiations	Difficult to adjust resonant frequency for multiple devices	
Microwave Transmission	Long effective charging distance typically from tens of meters, up to several kilometers; suitable for mobile applications	Not safe when the RF density exposure is high; low charging efficiency	
Light Transmission	Self-aligning, multiple-Rx charging, high power, compact size, EMI-free, SWIPT-ready; suitable for mobile applications	Range Up to 10 m, LOS required; low charging Efficiency, Not safe	

Table 1.WPT COMPARISON TABLE

LITERATURE REVIEW TABLE:-

PAPER NO.	SYSTEM PROPOSED	TECHNIQUE/ALGORITHM USED	Advantages & Disadvantages	PARAMETERS ACHIEVED
[14]	Multiband and broadband WPT on conformal strongly coupled magnetic resonance (CSCMR)	1. Achieve planar compact WPT systems. 2. Designs can be scaled &altered to cover different frequencies. 3. Compatible with different WPT standards. 4. Efficiently transmit power in different bands.	1. Short range20 to 70 mm 2. Energy loss in broad casting.	1. Dual-band CSCMR 2. Three-band CSCMR 3. Broadband CSCMR. 4. Resonators with different radii.
[15]	Electric and Magnetic Coupling Mixed	1. Distance increases due to combine effect of Electric and Magnetic Coupling. 2. At various transmission distances total coupling coefficients are realized. 2. Frequency splitting is gives stable output power.	1. Operating distance ranging from 40 to 170 mm	1. Transfer coefficient S_{21} 2. Weak and normal coupling at I/O ports. 3. Resonant frequency 4. Distance
[16]	Frequency diversity in a broadband WPT network and distributed charging control	1. voting-based distributed charging control 2. Maximize network lifetime	1. Distance few centimeters 2. Complicated	1. Transmission block time allocation 2. Sub-channel allocation 3. CSI and BSI Feedback 4. Performance
[17]	Harvesting Wireless Power	1. Wireless Power Transfer Systems 2. Diode Rectifier Behavior 3. RF Energy-Harvesting Principles 4. Energy-Harvesting Circuit Characterization	1 .Efficiency is nonlinear 2. Depends on the input power level.	1. Threshold and reverse-breakdown voltage. 2. Energy-harvesting efficiency 3. Impedance matching 4. Device parasitic
[18]	Using Bluetooth Low Energy (BLE), introduces a Fuzzy Logic Controller (FLC)	1. Fuzzy-Based Algorithm for Home Energy Management 2. Fuzzy Logic Controller	1. Satisfy peak load demand of customer. 2. Packet delivery ratio improved 3. Ease-of-use	1. Inference rules 2. Peak load reduction comparison 3. Load of the appliances ratio during peak hours. 4. Electricity consumption cost
[19]	Distributed laser charging (DLC).	1. Transmitting approximately 2 W of power up to a distance of about 10 m. 2. Use infrared and ultraviolet lasers	1. Self-Aligning 2. Concurrently Charging 3. No power leak	1. DLC-aided infrastructure-based network 2. DLC-based ad-hoc network.

Table 2: Literature Review

IV. CONCLUSION AND FUTURE WORK:

Wireless charging technology is still in early childhood, but it can no longer be seen as science fiction - they need extensive research in terms of realistic mobile electronics devices.In this paper, we summarize WPT technology, types and applications.We compare the most important wireless charging techniques i.e., inductive coupling, capacitive coupling, magnetic resonance coupling, microwave and light wave transmission.We have discussed some new trends that can play an important role in converting WPT.Detailed information about important technical details for various sections is added in Table1. The transmission distance will be the one important aspect for researchers for future study.Main challenge of the WTP system is security of energy. A real WPT system should securelypass the energy over a long distance in wireless rather than the wired charging approach. However, loosely coupling effect influence in a long distance for electromagnetic and laser transmission WPT systems. Energy loss is transmission and in broadcasting is another era of study.

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