Wireless Power Transfer Techniquies : A Review

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Abstract—The invention of various wireless technologies are great revolution in the field of communication. Wireless technology can be used for transmission of electric power wirelessly from one end to other end. This technology will reduce the losses incurred in power transmission through wires. This paper presents the inclusive review and detailed analysis of different techniques used for wireless power transmission. In this paper, we have compared the different techniques of wireless power transmission. Advantages and disadvantages of different techniques are discussed in this paper with the other wireless power transfer (WPT) technologies.

Keywords*- wireless power transfer; strongly coupled magnetic resonances; mid-range non-radiative high-efficient power transfer*

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I. Introduction

Wireless power transfer techniques are not new us,since in the year 1889 Nikola Tesla had invented the Teslacoils by which we can transfer power wirelessly.Afterward, researches began onwireless power transfer [1].In the year 1964, William C. Brown projected a point-to-pointwireless power transfer scheme on the basic of microwave beams [2]. In the year 1968, American engineer Peter Glaser introduced a concept of a space solar power station, and furtherhe concluded that solar energy could be converted into electric energy and can be transmitted to the Earth in the form of microwaves [3]. Incredible progress took place in the solar power satellite project during the 1970s [4], which shows that human beings had grasped this electric energy transfertechnology. In the year 2007, wireless power transfer stunned the world again, the research teamof Massachusetts Institute of Technology (MIT) proposed strongly coupled magnetic resonance (SCMR), and they were able to transfer 60 watts of power wirelessly with about 40% efficiency over the distances of 2 meters [5]. Afterward, Intel and Qualcomm alsoestablished their wireless power transfer systems, whichindicated that this novel technology would soon appear in our daily life.

Up to now, wireless power transfer technology can be roughly classified into three type, the working principles,which comprise electromagnetic radiation mode, electricfield coupling mode and magnetic field coupling mode. In electromagnetic radiation mode, electric energy is converted into electromagnetic energy just like microwaves or laser beams which can be transmitted, then it can be received and converted back into electric energy by using a silicon rectifier antenna at the receiving end. Electromagnetic radiation mode is usually suitable for the long distance power transferapplications, because of its high power density and goodpositioning features, particularly for the spacepowergeneration or military applications. Nevertheless, its transferefficiency is harshly affected by themeteorological ortopographical conditions, and its impacts on living being and biological environment are irregular. Thus, wireless power transfer based on electromagnetic radiation mode is not suitable for the resident use. The principle of electric field coupling mode is basically the rearrangement of the surface charges on the object. A high-frequency and high-voltage driver source stimulates the resonant transmitter to generate a changing electric field which can couple with the resonant receiver. Energy will be delivered instantlyasearly as this coupling is set up. The transferefficiency of this mode is affected by neighboring objects [6,7], and also the transfer power is relatively low, but if correspondingtreatments are done in advance, the electric field coupling mode will findappropriate applications. According to the transfer distance, the magnetic field coupling mode can be largely classified into short-range electromagnetic induction and mid-range electromagnetic induction. The transferefficiency and power of electromagnetic induction are high, but the transfer distance is limited to few centimeters. However, the transfer efficiency and transfer power of SCMR are very less, but the transfer distance can achieve in meters to realize mid - range power transfer.

II. NEAR FIELD METHODS

2.1 Inductive Coupling

Any wireless transfer energy method based on electromagnetic field, follows the laws of Maxwell, although in case of near field methods the most important is the variation of the magnetic field that induces voltage in a secondary winding. The reason behind that isthe electromagnetic field which is always present but the derivative of the magnetic field is disregarded as too low.

The working of a loosely coupled transformer is the simplest example of induction technique. The inductively coupled coils don't need the Maxwell´s law but the sub-law of magnetic (electromagnetic) induction. The examples of this technique are Inductive battery chargers of mobile phones or electric toothbrushes. Even the induction cooker is an example of power transferred by this technique. But the main disadvantage of the method is the short range of transfer (usually up to a few centimeters).

Various engineers and scientists worked on a better wireless energy transfer. There are registered results proposed by the Soviet electrical engineer George Babat [10] early in the 20th century, who in 1943 built an electric car supplied by wireless energy transferred from a distance. That vehicle was named "HF automobile". In 1944 he employed this operating principle in the factory where those type of electric vehicle started to be applied in practice. The motor had a nominal power of 2 KW and it ran over tarmacadam paths under which thin copper tubes were buried. The HF current (50 kHz) in those tubes induces the voltage in the receiver winding at a maximum distance of 2-3 dm. After being rectified the energy obtained in the secondary winding was used to supply the electric car. The first experiments had the efficiency of only 4% but the results were greatly improved in 1947.

In the year 1995, John Boys and Grant Covic, of the University of Auckland in New Zealand, developed systems to transfer high very high energy across air gaps and proved that power transmission by induction is practicable.

The one of the locomotive company Bombardier Transportation demonstrated the world's first tram, equipped with wireless current collection devices in place of catenaries, which named power system PRIMOVE. In this technique cables in the ground creates a magnetic field and pick-up coils converts magnetic field into electric current which charged the battery. This way of power supply is safe, because energy flow is only activated under the tram.

The Advanced Institute of Science and Technology (KAIST) in Korea developed the Online Electric Vehicle (OLEV) which is charged by induction principle from hidden inductor loops, placed in specific convenient points, i.e. at the bus stop, road intersection or vehicle parking, transmitting portions of energy for recharge when the vehicle will be situated over that particular point. This idea is illustrated in Fig. 1 taken from [9].

This type of technologies are already being used in automobile production plants and large warehouse facilities to power remote robotic floors, conveyors and vehicles [3].

2.2 Electrostatic Induction Technique

The idea of capacitive coupling was proposed by A. Rozin in 1998. The energy is transmitted between metallic plates (thus forming one or more capacitors) by the oscillation of a high-frequency electric field. At the receiver side, the battery or other electronic equipment is supplied by the transported high frequency capacitive current (being rectified). Unfortunately, to obtain a reasonable power levels this electric field must achieve too high intensity and this fact limits possible applications.

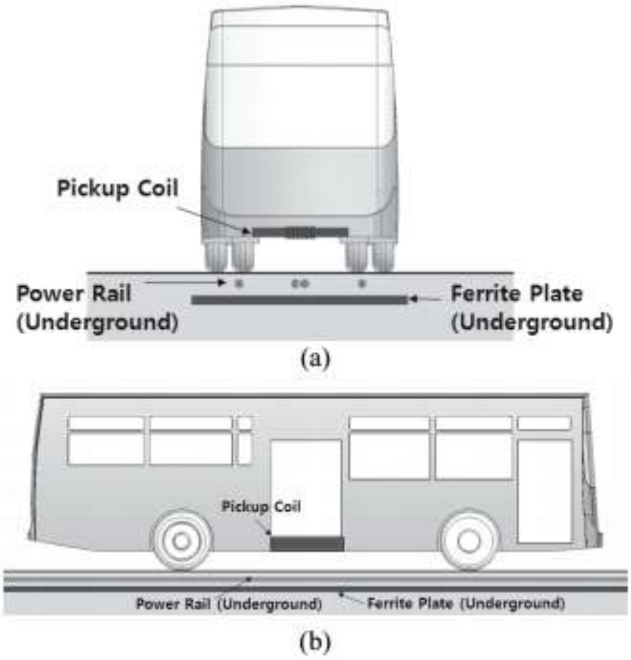
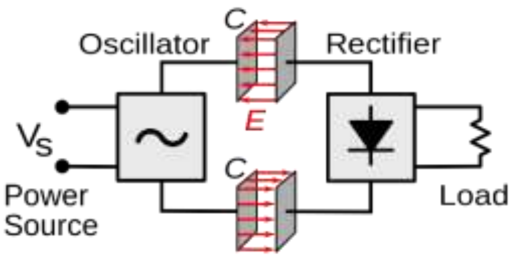


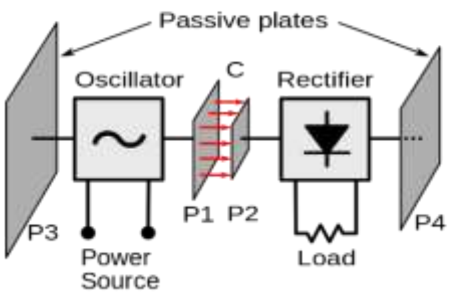
Fig. 1 OLVE and its power transfer system: (a) side view and (b) front view

In the capacitive coupling or electrostatic induction, the dual of inductive coupling, power is transmitted by electric fields between the metal plate electrodes. The transmitter and receiver electrodes form a capacitor, with the intervening space used as the dielectric. An alternating voltage generated by the transmitter is applied to the transmitting plate, and the fluctuating electric field induces an alternating voltage on the receiver plate by electrostatic induction, because of this an alternating current starts flowing in the load circuit. The amount of power transferred increases with the increase in frequency and the capacitance between the plates, which is proportional to the area of the smaller plate and inversely proportional to the separation.

Capacitive coupling has the application practically in a few low power applications, because the very high voltages on the electrodes required to transmit substantial power which can be hazardous,and can cause unpleasant side effects such as harmful ozone production. Furthermore, in contrast to magnetic fields, electric fields interacts strongly with most materials, which includes the human body, due to dielectric polarization. Superseding materials between or near the electrodes can absorb the energy, in case of humans possibly of causing excessive electromagnetic field exposure. However apart from these disadvantages the capacitive coupling has a few advantages over inductive coupling. The electric field is mainlylimited between the capacitor plates, reducing interference, whereas inductive coupling requires heavy ferrite flux confinement cores. The alignment required between the transmitter and receiver are less critical. Capacitive coupling has recently been applied to charge thebattery powered portable devices and is being considered as a resources of shifting power between substrate layers in integrated circuits.



(a) Bipolar



(b) Unipolar

Fig. 2 Capacitive wireless power system

2.3 Magnetic resonance coupling

The method of inductive coupling is not effective when transmitting energy at increased distance and a huge amount of energy is lost in the form of resistive losses. If the primary and the secondary coils are involved in resonating circuits at the same frequency, substantial power can be transferred over that larger distance and the losses are lower. Actually, the resonant method was used by N. Tesla for his energy transfer experiments.

The magnetic resonance coupling take place when two resonant loops exchange energy through the oscillations of their magnetic fields. In that case all the surrounding impedances have much higher value compared to the good resonant coupling that compensates the positive and negative reactance.

The equations that defines the energy transfer process at the high-frequency magnetic resonance are different from the equations ofthe inductive coupling at lesser frequencies and shorter distance, although both processes apply resonance. For example, the lightly magnetic coupling is described by differential equations with piece-wise constant coefficients [1]. In magnetic resonant coupling the equations mostly consider strong resonance and fully shaped sinusoidal currents and voltages. At the high-frequency of operation some new important parameters appear in theequations, for example attenuation factor, characteristic impedance, etc. With the increased frequency of operation, the scattering matrix parameters appear as more convenient [6].

III. FAR FIELD METHODS

Using far field methods we can achieve longer ranges, often multiple kilometer ranges, where the distance is much largeras compared to the diameter of the device(s). The main reason for longer ranges with radio wave and optical devices is that the electromagnetic radiation in the far-field can be made as smaller as the shape of the receiving area (using high directivityantennas or highly directed laser beams). The maximum directivity for antennas is physically limited by diffraction.

Generally, visible light (from lasers) and microwaves (from purpose-designed antennas) are the forms of electromagnetic radiation best suited to energy transfer.

The dimensions of the components may be decided by the distance between transmitter and receiver, the wavelength and the Rayleigh criterion, used in standardradio frequency antenna design, are also applies to lasers. Airy's diffraction limit is often used to determine an approximate spot size at a random distance from theaperture. Electromagnetic radiation faces less diffraction at shorter wavelengths (higher frequencies); for example, a blue laser is diffracted less than a red one.

The Rayleigh criterion shows that any radio wave, microwave or laser beam will spread and become weaker and diffuse over distance; with the increase in the transmitter antenna or laser aperture compared to the wavelength of radiation, the more focused beam and the less it will spread as a function of distance (and vice versa). Smaller antennae also suffer from excessive losses due to side lobes. Though, the concept of laser aperture considerably differs from an antenna.

Typically, a fewer aperture much larger than the wavelength induces multi-moded radiation and mostly collimators are used before emitted radiation pairs into a fiber or into space.

Eventually, beam width is physically determined by diffraction due to the dish size in relation to the wavelength of the electromagnetic radiation used to make the beam.

The power points are calculated by combining the above parameters together, and adding in the gains and losses because of the antenna characteristics and the transparencyand dispersion of the medium through which the radiation passes. That process is known as calculating a link budget.

3.1 Microwave power transmission

According to this method, energy can be transmitted by a well-focused microwave energy beam. The complete process consists of three essential parts: a converter from conventional energy to microwave, a transmitting antenna, and a combination of receiving and converting unit called "rectenna". In this method, microwaves are sent at a much larger distance.

One of the pioneers of microwave power transmission was William Brown who in 1964 demonstrated a microwave beam that powered a helicopter model [7]. One possible application of the Wireless Power Transmission via microwave electromagnetic emission is the Solar Power Stations idea [8]. In 1968, Peter Glaser suggested placement of large solar panels on a geostationary orbit to collect and convert sunlight into microwaves, beamed afterwards to a large antenna on the Earth, to be converted into conventional electrical power. In the 70s this thematic was forgotten mainly because of the technological difficulties and the cold war adversary problems.In recent years the industrial activities in this field are already in revival again. In 2009, the US Corporation Solaren signed a contract with the California Energy Company to supply 200 MW of electric power produced in space from the beginning of 2016. In comparison to the laser transmission, microwave transmission is more developed, and more efficient, but the diameter of the antenna is to be some kilometers, thus increasing the health and safety risks caused by the focused microwave radiation.

3.2 Laser beamed power transmission

The long-distance wireless power transmission can be realized by converting electricity into laser emission. The laser beam may be focused on a solar panel which transforms it into electricity with an efficiency level of 40-50%. Laser is ideal for power transmission at a distance: it provides a coherent, almost non divergent beam with high energy density, thus allowing smaller diameter of the antenna.

Unfortunately, certain disadvantages reduce the benefit of laser: the imperfection of existing technologies leads to the loss of the most of energy during the transformation of the laser beam into electric power. Before making the method effective, more efficient solar cells must be developed. Another significant drawback of laser is safety: the danger of hitting any object in the area of the beam. On the other hand, laser energy transmission allows much higher energy densities, a slighter focus of the beam and smaller emission and receiver diameters in comparison with microwave energy transmission.

Laser beaming is already used successfully in models and prototypes developed by specialized companies, e.g. LaserMotive. This Seattle-based company developed a space elevator prototype supplied by a laser beam (about 1 kW) to lift 50 kg.

In September 2003 with a laser beam centered on its panel of photovoltaic cells a model plane made the first flight of an aircraft powered by an infrared laser beam inside a building at NASA Marshall.

IV. POWER TRANSMISSION BY LASER

Another technique is the wireless power transmission using laser beam which acts as a source. Thelaser beam of high intensity is incident from some specific distance to the load end. Depending on the range and intensityof the beam Laser method is used for small distance applications. This process is similar to the solar cells photovoltaic generation technique which uses the solar energy of the sun light and converts it into electricity. At the load end highly efficient photo voltaic cells are used that converts light energy in to the electrical energy.

Recent experiments have shown that the wireless power transmission through laser beam is 50 percent efficientthan the other methods but by using improved technology of laser photovoltaic cells receivers the efficiency could beincreased. Different stages of process are described further.The laser source transmits the laser beam through an efficient lens. The lens is used to focus the beam of the laser to the specific place where the receiver is present. The laser receiver contains a series of highly efficientphotovoltaic cells which receives the laser beam and then convert them into electrical energy. The load which is attached to the photovoltaic cells which after being energized through laser beam convert light energy of laser beam into electrical energy [12]. Laser power transmission isshown in Fig. 3 as following.

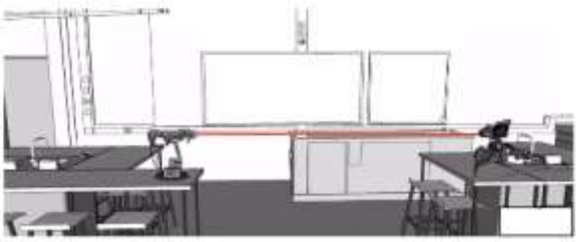


Fig 3. Wireless Power Transmission through Laser322

V. COMPARISION OF POWER TRANSMISSION METHODS

Methods presented in preceding subsections are compared briefly in this subsection. Each and every method has its own advantages and disadvantages includingcost, range and health hazards. Comparison is summarized in table 1.

Table 1. Comparison of Different Methods

Magnetic Resonance Method	Microwave Method	Laser Method
It is economical as the equipment used is cheap and easily available	Relatively expensive as compared to other methods	Implies same economic conditions of mutual inductance
Useful for implementation of the small distance applications	This method implies for long distance applications	Useful for small distance but could be used for longer distance when high distance beam is involved
It is safe from biological point of view	Injurious for health because of high frequency rays	This method is also injurious to human health

VI. ADVANTAGES DISADVANTAGES & APPLICATIONS

We could eliminate the present system of high power transmission lines, towers and substations, which is inefficient and costly way of energy transmission, by wireless power transmission.This will lead to a worldwideefficient and cheap transmission system. The price of the transmission and receiving power would reduce for the daily users and the large scale reduction of power tariff would be easily noticeable. The loss of transmission will be decreased and the power couldeasily be transferred toany place regardless of the geographical conditions. Powerfailures due to short circuit and faults can be minimized [12]. It will make the system more effectiveand environment friendly.The natural calamities such as earthquakes,floods, landslides or tornados would not become the reason for power cuts and damages to the system. The usage of land for the installation of the system would completely be removed. As Dr. Neville of NASA states “You don’tneed pipes, cables,or copper wires to receive power. We can send it to you like a mobile phone call where you want it, when you want it, in real time” [14].

In terms of portability, this system is very grander toany other existing system. However, the most importantconcern remains the organic impacts. But according to thesafety studies and research it indicates clearly that the radiation level attained by the wireless power transmission is very close or marginally higher than the radiation of cellularphones or not ever greater than microwave oven coverage. Therefore, public exposure of wireless power transmission will be within the acceptable limits [13].

Disadvantages of wireless power transmission systeminclude very high initialcost for the system's practicalinstallation.Since in this technique microwaves are used for the transmission then the line of sight becomes the basic need. Any sort of obstacle in the line of sight could in fact stop the transmission. The microwave power transmission can cause high intervention problemsfor telecommunication infrastructure. As the energy will beavailable freely in the air energy; chances of the theft will be increased.

Due to the introduction of different recent technologies like cellular phones, laptops automated systems androbotics,the portability and accessibility has become mainobjectiveof scientific research and development. Toachieveportability, suitability and the demand of recentdeveloping technologies; wireless power transmission canplay an important role. It has immense applications whichwilldecrease the cost of power systems by reducing the wiresand towers. It will save the cost of equipment’s and labor cost.System complication will be reduced and efficiency will beenhanced. There are many applications in contextof smart grid like electrical vehicle charging etc.

VII. CONCLUSION

The wireless power transfer of is considered one of the most attractive new technologies and does have its place in future. Even though this technology is still not widely applied for high level of electric power and large distance, there are symbols that the research in this direction is demanding and has never stopped.

Comparing the wireless energy transfer to the classical electrical energy transport by high voltage lines, a contactless technology is capable not only of cutting down the construction expenses of power lines, but also of providing unconventional solutions, e.g. capable of switching the highest power supplied to one point of the Earth to another point on the Earth in the shortest possible time. All this will save money, time, material, and natural resources.

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