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A Review Of Wireless Power Transmission

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ABSTRACT

In the present article some of the latest advances and the concept of transmitting power without wires are reviewed.The methods applied for the wireless power transmission such as - induction, electromagnetic transmission, radio and microwave and evanescent wave coupling are discussed here. Furthermore, the various technologies available so far for wireless transmission of electricity and the need for a wireless system of energy transmission is presented.The study also focuses on the latest technologies, merits, demerits and economical aspects in this field.

I. INTRODUCTION

One of the major issues in power system is the losses during the transmission and distribution of electrical energy. As the demand increases day by day, the power generation increases and the power losses during transmission is also increased. In the present electricity generation system more than half of our resources are wasted due to the various reasons particularly during transmission. The resistance of the wire used in the electrical grid distribution system causes a loss of 26-30% of the energy generated. This loss implies that the present system of is only 70-74% efficient. We have to think of Hence, an alternate technology to transmit and distribute the electricity is to developed [3].Using a wireless system for the transmission of electricity is a prominent method to increase the efficiency.

Wireless power transmission(WPT) is the method of transmitting the power from one place to another without the means of wires through atmosphere or vacuum. This can be used for applications where either an instantaneous amount or a continuous delivery of energy is needed, but where conventional wires are unaffordable, inconvenient, expensive, hazardous, unwanted or impossible. There are various methods of power transmission which are discussed further in the following sections

II . WIRELESS POWER TRANSMISSION

A. TESLA THEORY

Nikola Tesla, the father of wireless, invented the radio. He conceived the idea of wireless power transmission and demonstrated the transmission of electrical energy without wires that depends upon electrical conductivity as early as 1891[2].In 1893, Tesla demonstrated the illumination of vacuum bulbs without using wires for power transmission at the World Columbian Exposition in Chicago. The Wardenclyffe tower shown in Figure 1 was designed and constructed by Tesla mainly for wireless transmission of electrical power rather than telegraphy [1].

Tesla wanted to make use of the Niagara Falls to transmit electricity from this Tower to the whole globe without wires using the Ionosphere [1]. The most popular concept known is Tesla Theory in which it was firmly believed that Wardenclyffe, as shown in figure 1, would permit wireless transmission and reception across large distances with negligible losses [2]. But it was so unfortunate that people of that century was not in a position to recognize his splendid work.

Fig.1. 187-foot Wardenclyffe Tower (Tesla Tower)

III. METHODS OF WIRELESS POWER TRANSMISSION

A. MICROWAVE METHOD (MPT)

Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range.

COMPONENTS OF MPT

William C. Brown, the pioneer in wireless power transmission technology has designed, developed a unit and demonstrated to show how power can be transferred through free space by microwaves. The concept of Wireless Power Transmission System is explained with functional

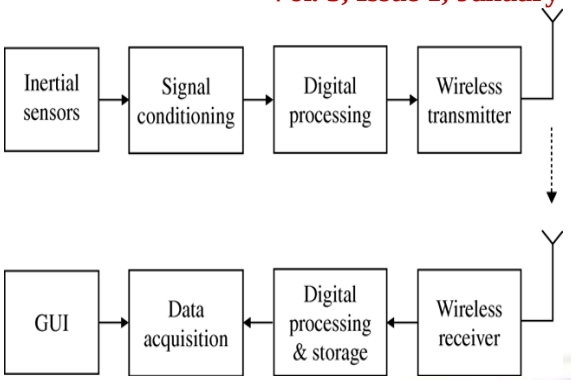

Fig 2. Flow and components of Wireless power System

block diagram shown in Figure 2 [3]. In the transmission side, the microwave power source generates microwave power and the output power is controlled by electronic control circuits. The wave guide ferrite circulator which protects the microwave source from reflected power is connected with the microwave power source through the Coax Waveguide Adaptor. The tuner matches the impedance between the transmitting antenna and the microwave source. The attenuated signals are then separated based on the direction of signal propagation by Directional Coupler. The transmitting antenna radiates the power uniformly through free space to the rectenna.

In the receiving side, a rectenna receives the transmitted power and converts the microwave power into DC power.The rectifying circuit consists of Schottky barrier diodes which converts the received microwave power into DC power.

B. ELECTROMAGNETIC TRANSMISSION

Lasers generate phase-coherent electromagnetic radiation at optical and infrared frequencies from external energy sources by preferentially pumping excited states of a “lasant" to create an inversion in the normal distribution of energy states. Photons of specific frequency emitted by stimulated emission enter and are amplified as standing waves in a resonant optical cavity. The most efficient DC-to-laser converters are solid-state laser diodes commercially employed in optic and free-space laser communication [8].Alternatively, direct solar-pumping laser generation has a major advantage over conventional solid state or gas lasers, which rely on the use of electrical energy to generate laser oscillation since the generation of electricity in space implies automatically a system level efficiency loss of roughly 60%. To generate a laser beam by direct solar pumping, solar energy needs to be concentrated before being injected into the laser medium. The required concentration ratio is dependent on the size of the laser medium, the energy absorption ratio and the thermal shock parameter (weakness of the material to internal stress caused by a thermal gradient). But it has many drawbacks such as:

1. Conversion to light, such as with a laser, is moderately inefficient
2. Conversion back into electricity is moderately inefficient, with photovoltaic cells achieving 40%-50% efficiency
3. This method requires a direct line of sight with the target.

However, it is argued that due to recent advances in direct solar pumped lasers,laser-based wireless power transmission concepts should be matured further in order to represent a credible alternative.

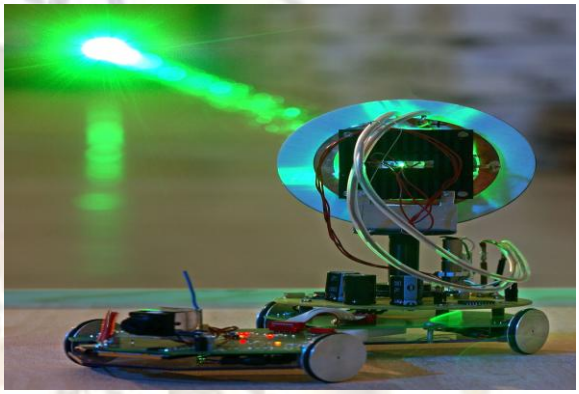

fig. 3: fully laser powered autonomous rover.

C. INDUCTIVE COUPLING

Inductive coupling uses magnetic fields that are a natural part of current's movement through wire. When electrical current moves through a wire, it creates a circular magnetic field around the wire. Bending the wire into a coil amplifies the magnetic field. The more the loops the coil makes, the bigger the field will be generated. When the coil of wire is introduced in the magnetic field already generated, the field can induce a current in the wire. In general in inductive coupling method, it consists of two coils of wire which are close enough to each other such that they act like a weakly coupled air-core transformer. Coiling must be tight to achieve high efficiency.

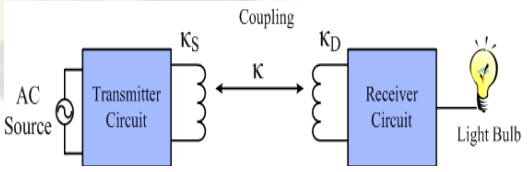

Fig 4.Induction Coupling Block Diagram

D. RESONANCE INDUCTIVE COUPLING (EVANESCENT WAVE COUPLING)

It is a combination of inductive coupling and resonance.Resonance improves the efficiency by tunneling magnetic field to a receiver coil which

resonates at the same frequency.When resonant coupling is used the two inductors are tuned to a mutual frequency and the input current is modified from sinusoidal to non sinusoidal rectangular or transient waveform so as to drive the system more aggressively.

A capacitance plate which can hold a charge attaches to each end of the coil. As electricity travels through this coil the coil begins to resonate. Its resonant frequency is a product of the inductance of the coil and the capacitance of the plate [4]. Unlike multiple layer secondary of non-resonant transformer single layer solenoids with closely spaced capacitor plates on each end as shown in figure 5 is used as transmitter and receiver.

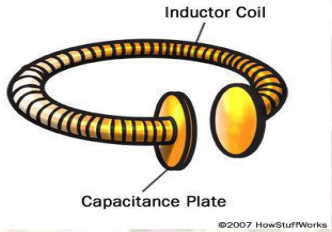

Fig.5 Transmitter and receiver [4]

IV. CURRENT TECHNOLOGIES IN THE FIELD OF WPT

A. SOLAR POWER SATELLITES (SPS)

It is a gigantic satellite designed as an electric power plant orbiting the earth which uses wireless power transmission of space based solar power. The SPS satellites would be put in high earth orbit at geosynchronous location. It consists of mainly three segments; solar energy collector to convert the solar energy electrical energy which can be either photovoltaic cells or solar thermal turbine; a DC-to-microwave converter for which microwave oscillator like klystrons, magnetrons can be used and the transmitiing antenna which transmits the microwaves to the earth's receiving antenna [5].

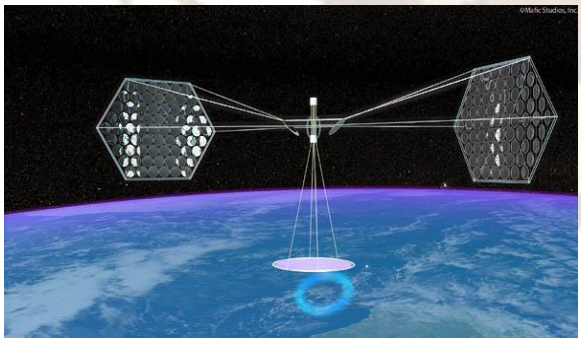

Figure 6. Solar Power Satellite (SPS) [3].

The SPS targeted for commercial launch in 2030 is capable of a power output equivalent to a 400-MV thermal plant unit and able to supply electricity at a price similar to that of publicly supplied power [6]. Generating a microwave beam using so many panels requires power transmission technology with high precision phase control at a target level of less than 10^0 for economic viability and safety. Mitsubishi Heavy Industries is developing two transmission-control technologies:the position and angle correction (PAC) and parallel methods [6]. In the PAC method, the unique position gap of each panel is estimated by comparing the reaching-phase angle of pilot-signal from Earth,and the microwave beam phase angle is corrected accordingly. In the parallel method, microwave phase modulation occurs at each panel. When the phase-modulated microwave is compared to a reference signal at the rectenna, the resulting phase deviation is equivalent to the modulation frequency output. Based on this principle, the phase deviation for each panel is corrected individually.

B. WITRICITY

Witricity, standing for wireless electricity, is a term coined by MIT researchers, to describe the ability to provide electricity to remote objects without wires. Witricity is based upon coupled resonant objects to transfer electrical energy between objects without wires. Two objects of the same resonant frequency tend to exchange energy efficiently [7]. A child on a swing is a good example of mechanical resonance**.** According to the theory, one coil can recharge any device that is in range of the coil, as long as the coils have the same resonant frequency.

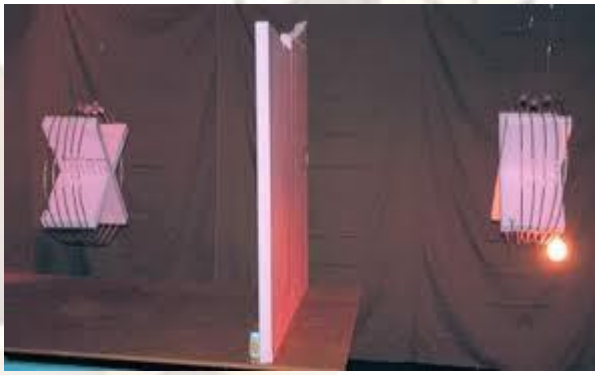

Fig. 7 Experiment at MIT for WPT.

The system developed by MIT uses two copper coils, each a self-resonant system, as shown in fig.7. One of them, attached to the power source which is a sending unit. It fills the surrounding space with a non-radiative magnetic field. The non-radiative field mediates the power exchange with the other, receiving coil, specially designed to "resonate" with the field. With such a design, power transfer still has a limited range. But researches expected that power levels more than sufficient to run a laptop can be transferred over room-sized distances, even when environmental objects

completely obstruct the line of sight between the two coils [7].

V. RECENT INVENTIONS AND RESEARCHES

A. IMPLANTABLE BIOMEDICAL APPLICATIONS

Biomedical implants require a clean and medically safe source of energy to perform the operation. Early implants such as pacemakers sourced their power from small lithium ion battery which had some drawbacks like limited battery life which causes the impracticality, health risks and expense of operating on patients. While this solution allows for the operation of the implantable device without a wire connecting the internal and external circuitry which avoids the usage of lithium ion battery for the implants.

For implanted devices, wireless power and data transmission is preferred to avoid changing battery frequently through surgery so as to reduce the cost and the risks in the surgery. The external power and signal transmission module as shown in Figure.8 transmits the power and data to the implanted devices in the human body through a wireless link of inductive coupling. The implanted devices interact with the targeted tissues and cells for biological prosthesis, health monitoring and advanced biomedical treatment such as pain control, mood regulation and remote microsurgery. These bio-information and operation can be monitored and controlled through a handheld device [9]. Among the technologies used for the wireless power transmission inductive coupling method is the mostly used for the biomedical implantation.

The external power transmission module consists of one power amplifier and a primary inductive coil. The power receiving block of the implanted device consists of the secondary inductive coil, matching network, rectifier and low drop-out regulator. The primary and the secondary coils are designed to have a resonant frequency.The conventional efficiency-boosting technique adds a capacitor C_t to form the resonance at power carrier frequency. The rectifier is used to convert the differential alternating voltage signal (AC) appearing across the two terminals of secondary coil into a direct voltage signal (DC). To obtain a stable DC supply, one low drop-out voltage regulator (LDO) is followed after the rectifier to provide a regulated DC output to power the entire implanted device [9].

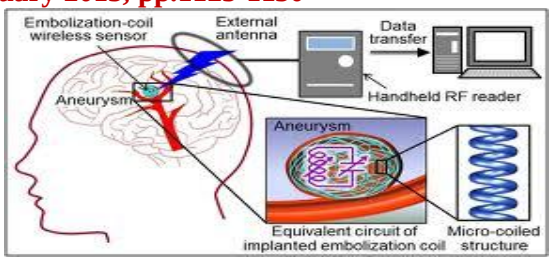

Fig. 8 block diagram of wireless biomedical Implantation

B. POWER WITHOUT THE CORD

Researchers at the Fraunhofer institute for ceramic technologies and systems IKTS in Hermsdorf succeeded in wirelessly transmitting power from a portable transmitter module to a mobile generator module the receiver,shown in figure.9 .The cylindrical shaped transfer module is so small and compact that it can be attached to a belt. The transmitter provides an electric current of over 100 mW and has a range of about 50cm.So that, the receiver can be placed almost anywhere in the body [10].

In the transfer module, a rotating magnet driven by an EC motor generates a magnetic rotator field. A magnetic pellet in the receiver connects to the alternating exterior magnetic field and as a result, is set in rotation itself. The rotational movement is transformed into electricity, thus the power is produced right in the generate module. With magnetic coupling, power can be transported through all non-magnetic materials, such as biological tissue, bones, organs, water, plastic or even a variety of metals. Moreover , the magnetic field produced has no harmful side effects on humans. It does not even heat up tissue.Because the modules available as prototypes are scalable in term of range, size and performance capacity, they can be used for more than medical technology applications. They can also supply power wirelessly to hermetically sealed sensors- such as those inside walls or bridges [10]. With this portable device, we can remotely supply power to implants, medication dosing systems and other medical applications without touching them.

Fig.9 wireless power transmitter designed by Fraunhofer institute for ceramic technologies [10].

VI. LATEST EXPERIMENTS

A. JAPAN'S EXPERIMENT

Japan is now planning to perform a kW-class microwave power transmission experiment in the range around 50 m as shown in Figure.10. It will be the first experiment in the world as a high power and long-range microwave transmission experiment with a capability of retro-directive beam control [11].The microwave transmitter consists of 4 individual panels,which are movable to each other to simulate antenna motion in orbit. Each panel, 0.6m x 0.6m, has an array consisting of hundreds of transmitting antennas, receiving antennas for the pilot signal, phase controllers, and power systems. The power level from each panel will be several hundreds of watts, totally one kW level, at 5.8 GHz. The frequency of the local oscillator in each panel is synchronized by a master oscillator. The phase of local oscillator in each panel is adjusted by a Rotating Element Electric Field Vector (REV) method so as that the power at the receiving site gets maximum. In the demonstration experiment , the output dc power will be several hundreds of watts from the rectenna.

Fig.10 wireless power transmission on ground [11].

B. MORE EFFICIENT WPT

In 2007, MIT researchers announced that they had discovered a novel way of transmitting electricity without the use of wires. by which they were able to produce a power of about 60watts [7]. Now, the researchers have demonstrated that the system's efficiency at transmitting energy improves significantly when it is used to charge multiple devices at the same time [12]. A number of other companies have independently begun to develop similar wireless power systems, including large companies such as microchip maker Intel ® and electronics giant Sony® because this type of wireless power transmission produces a greater power of about 100 watts.

The team that carried out on the recent work- Kurs, Moffat and Soljacic found that when powering two devices at once, which individually could achieve less than 20% efficiency in power transfer, the combined efficiency climbed to more than 30% . the two receiving coils resonate with each other as well as with the transmitting coil, and help to reinforce the strength of the magnetic field. Researchers says that the efficiency should continue to rise as more devices are added, climbing toward a theoretical limit of 100% [12]. The amount of power transmitted in the latest experiment was on the order of 100 watts, but researchers says that is only limited by the amplifier used for the transmitting coil, and easily can be increased.

VII. FUTURE ASPECTS

A. SPS RESEARCH IN CHINA

China's first SPS research started in the late 20th century. In the new millennium, when the energy issue became a constraint on sustainable development in China, the China Academy of Space Technology (CAST) submitted to the government a "Necessity and Feasibility Study Report of SPS" [13]. The CAST SPS research team conceives that there are four imperative sections for SPS development in china:launching approach, in-orbit construction, high efficiency solar conversion and wireless transmission. Except for launch, the other aspects do not seem to be insurmountable issues for China in the upcoming years.

Based on China's SPS scenario, there are 5 steps to achieving the first commercial SPS system. In 2010, CAST will finish the concept design; while the industrial level testing of in-orbit construction and wireless transmissions could be finished in 2020. the first 100kW SPS demonstration at LEO is expected to be finished by 2025; and in 2035, the 100mW SPS will have electric generating capacity. Finally in 2050, the first commercial level SPS system will be in operation at GEO [13].

Fig.11 China's research on Solar Power Satellites (SPS)

VIII. MERITS AND DEMERITS

A. MERITS

1. It has been predicted that by 2030, the world needs 30TW power from renewable energy sources and solar energy alone has the capability of producing around 600TW.The levels of CO_2 gas emission can be minimized and brought under control. Thus the problem of global warming will be solved to a great extent.

2. The system would reduce the cost of electrical energy used by the consumer and rid the landscape of wires, cables, and transmission towers. The electrical energy can be economically transmitted without wires to any terrestrial distance, so there will be no transmission and distribution loss. The efficiency of the transmission can be as high as 96 or 97 per cent, and there are practically no losses.

B. DEMERITS

Common beliefs fear the effect of microwave radiation. But the studies in this domain repeatedly proves that the microwave radiation level would be never higher than the dose received while opening the microwave oven door, meaning it is slightly higher than the emissions created by cellular telephones [14]. Calculating the circulating reactive power, it was found that the frequency is very small and such frequency is very biologically compatible.

IX . ECONOMIC ASPECTS

In terms of economic theory many countries will be benefited by this wireless power transmission method.By keeping a receiver module at any point or inside any devices.The receiver can receive power without the use of any cords.The capital cost of the practical implementation of wireless power transmission seems to be very high.But the maintanence cost of the WPT is very low when compared to the conventional power transmission system.

X . CONCLUSION

The transmission of power without wires is not a theory or a mere possibility, it is now a reality. The electrical energy can be economically transmitted without wires to any terrestrial distance. Dr.N.Tesla is the pioneer of this invention.Wireless power transmission of electrical power can be considered as a large scope in electrical engineering for future prospects of power generation and transfer. The various methods and aspects regarding wireless transmission of electrical power are discussed. The evolution of the technology from the time of Tesla has been overviewed.

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