Wireless Power Transmission Via Solar Power Satellite

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ABSTRACT—In this paper, we present the concept of Solar Power Satellites -The solar cells in the satellite will convert sunlight to electricity, which will changed to radio frequency energy, then beamed to a receiver site on earth and reconverted to electricity by using transmitting and receiving antenna with the technology of wireless power transmission (i.e., transmitting power as microwaves in order to reduce the transmission and distribution losses). This concept is also known as Microwave Power Transmission. The advantages, disadvantages, biological impacts and applications of WPT are also presented.

Index Terms—Grid, Microwaves, Microwave generator, Nikola Tesla, Rectenna, Solar Power Satellites (SPS), Transmitting antenna, Wireless Power transmission (WPT).

1 INTRODUCTION

The Solar Power Satellite energy system is to place giant satellites, covered with vast arrays of solar cells, in geosynchronous orbit 22,300 miles above the Earth's equator. Each satellite will be illuminated by sunlight 24 hours a day for most of the year. Because of the 23" tilt of the axis, the satellites pass either above or below the Earth's shadow. It is only during the equinox period in the spring and fall that they will pass through the shadow. They will be shadowed for less than 1% of the time during the year. The solar cells will convert sunlight to electricity, which will then be changed to radio-frequency energy by a transmitting antenna on the satellite and beamed to a receiver site on Earth. It will be reconverted to electricity by the receiving antenna, and the power would then be routed into our normal electric distribution network for use here on the Earth. One of the major issue in power system is the losses occurs during the transmission and Distribution of electrical power. As the Demand increases day by day, the power generation increases and the power loss is also increased. The percentage of loss of power during transmission and distribution is approximated as 26%. The main reason for power loss during transmission and distribution is the resistance of wires used for grid. The efficiency of power transmission can be improved to certain level by using high strength composite over head conductors and underground cables that use high temperature super conductor. But, the transmission is still inefficient. According to the World Resources Institute (WRI), India's electricity grid has the highest transmission and distribution losses in the world – a whopping 27%. Numbers published by various Indian government agencies. Put that number at 30%, 40% and greater than 40%. This is attributed to technical losses (grid's inefficiencies) and theft. Any problem can be solved by state–of-the-art technology. The above discussed problem can be solved by choose an alternative option for power transmission which could provide much higher Efficiency, low transmission cost and avoid power theft. Microwave Power Transmission is one of the promisingTechnologies and may be the righteous alternative for efficient power transmission.

2 SEGMENTS OF SPS

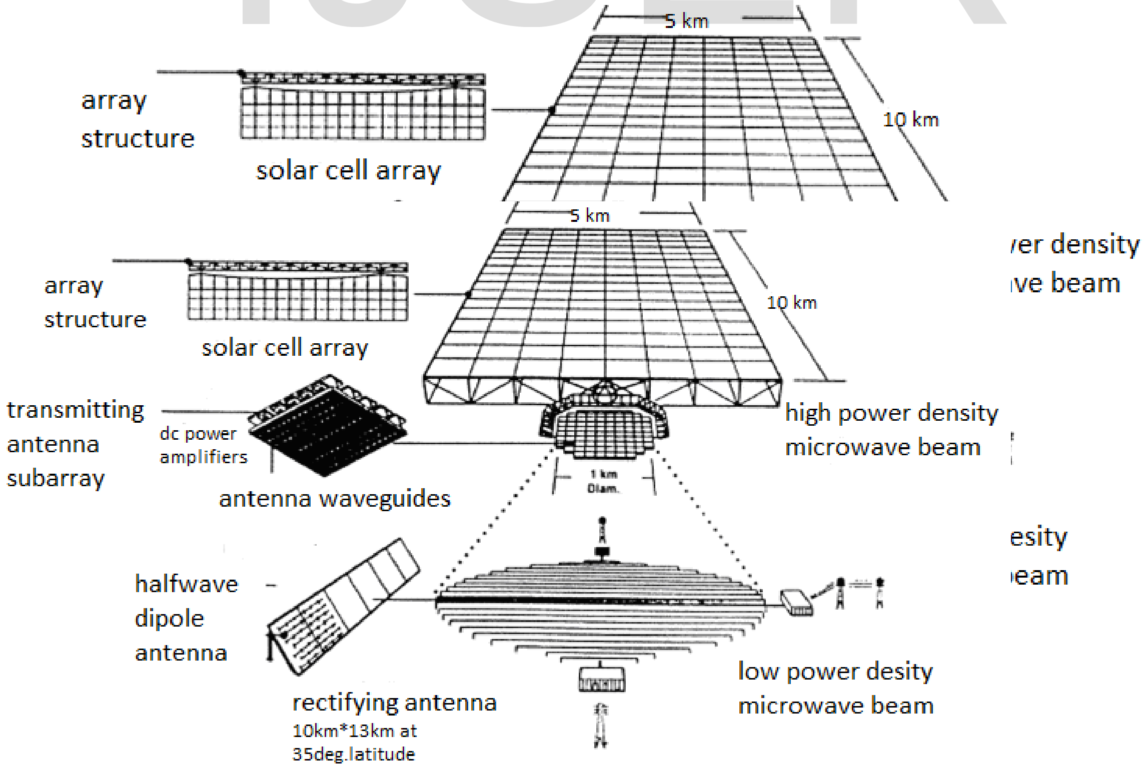
The SPS is a gigantic satellite designed as an electric power plant orbiting in the Geostationary Earth Orbit (GEO). It consists of mainly three segments; solar energy collector to convert the solar energy into DC (direct current) electricity, DC-to-microwave converter, and large antenna array to beam down the microwave power to the ground. The first solar collector can be either photovoltaic cells or solar thermal turbine. The second DC-to-microwave converter of the SPS can be either microwave tube system and/or semiconductor system. It may be their combination. The third segment is a gigantic antenna array. An amplitude taper on the transmitting antenna is adopted in order to increase the beam collection efficiency and to decrease sidelobe level in almost all SPS design. A typical amplitude taper is called 10 dB Gaussian in which the power density in the center of the transmitting antenna is ten times larger than that on the edge of the transmitting antenna. Power will be transmitted over a 1-1/4 mile range to a receiving antenna (rectenna) and then fed into a commercial utility power grid. Table 1 shows some typical parameters of the transmitting antenna of the SPS The rectenna array, with a typical radius of approximately 2 km, is an important element of the radio technology for which high efficiency is essential. The efficiency depends on the input power, and the input-power flux density is not constant over the entire rectenna site for the SPS system.

Table 1 Typical parameters of the transmitting antenna of the SPS

Model	Old JAXA Model	JAXA1 model	JAXA2 model	NASA/DOE MODEL
Frequency	5.8 GHz	5.8 GHz	5.8 GHz	2.45 GHz
Diameter of Transmitting antenna	2.6 kmϕ	1 kmϕ	1.93 kmϕ	1 kmϕ
Amplitude taper	10 dB Gaussian	10 dB Gaussian	10 dB Gaussian	10 Db Gaussian
Output power (beamed to earth)	1.3 GW	1.3 GW	1.3 GW	6.72 GW
Maximum power Density at center	63 mW/ cm^2	420 mW/cm^2	114 mW/cm^2	2.2 W/ cm^2
Minimum power Density at center	6.3 mW/ cm^2	42 mW/ cm^2	11.4 mW/cm^2	0.22 W/ cm^2
Antenna spacing	0.75 λ	0.75 λ	0.75 λ	0.75 λ
Power per one antenna (Number of elements)	Max. 0.95 W (3.54 billion)	Max. 6.1W (540 million)	Max. 1.7 W (1,950 million)	Max. 185 W (97 million)
Rectenna diameter	2.0 kmϕ	3.4 kmϕ	2.45 kmϕ	1 kmϕ
Maximum power Density	180 mW/cm^2	26 Mw/cm^2	100 mW/cm^2	23 mW/cm^2
Efficiency	96.5 %	86 %	87 %	89 %

JAXA : Japan Aerospace Exploration Agency, NASA : National Aeronautics and Space Administration, DOE : U.S. Department Of Energy.

3 WIRELESS POWER TRANSMISSION



Nicola Tesla he is who invented radio and shown us he is indeed the 'Father of Wireless'. Nicola Tesla is the one who first conceived the idea Wireless Power Transmission and demonstrated "the transmission of electrical energy without wires" that depends upon Electrical conductivity as early as 1891.

COMPONENTS OF WPT SYSTEM

The Primary components of Wireless Power Transmission are Microwave Generator, Transmitting antenna and Receiving antenna (Rectenna). The components are described in this chapter.

Microwave Generator

The microwave transmitting devices are classified as Microwave Vacuum Tubes (magnetron, klystron, Travelling Wave Tube (WT), and Microwave Power Module (MPM)) and Semiconductor Microwave transmitters (GaAs MESFET, GaN pHEMT, SiC MESFET, AlGaN/GaN HFET, and InGaAS). Magnetron is widely used for experimentation of WPT. The microwave transmission often uses 2.45GHz or 5.8GHz of ISM band. The other choices of frequencies are 8.5 GHz 10 GHz *and 35 GHz . The highest efficiency over 90% is achieved at 2.45 GHz among all the frequencies .*

Transmitting Antenna

The slotted wave guide antenna, microstrip patch antenna, and parabolic dish antenna are the most popular type of transmitting antenna. The slotted waveguide antenna is ideal for powertransmission because of its high aperture efficiency (> 95%) and high power handling capability.

Rectenna

The rectenna is a passive element consists of antenna, rectifying circuit with a low pass filter between the antenna and rectifying diode. The antenna used in rectenna may be dipole, Yagi – Uda, microstrip or parabolic dish antenna. The patch dipole antenna achieved the highest efficiency among the all. Schottky barrier diodes (GaAs-W, Si, and GaAs) are usually used in the rectifying circuit due to the faster reverse recovery time and much lower forward voltage drop and good RF characteristics.

OPERATION

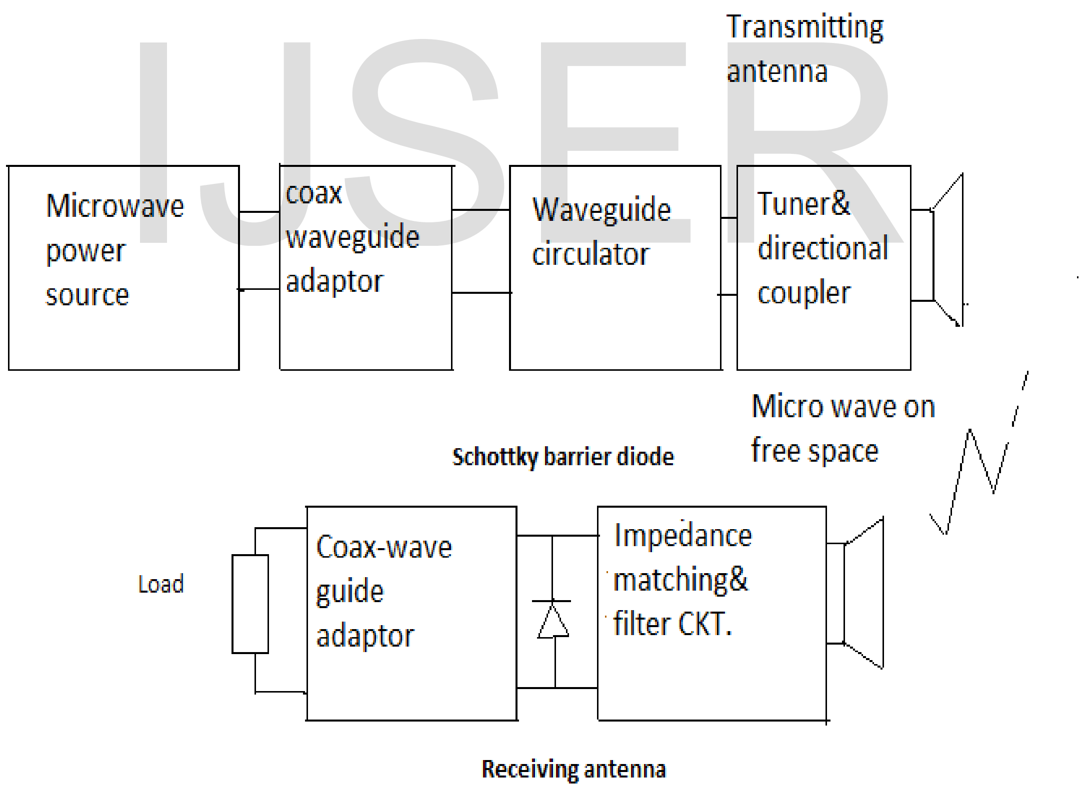
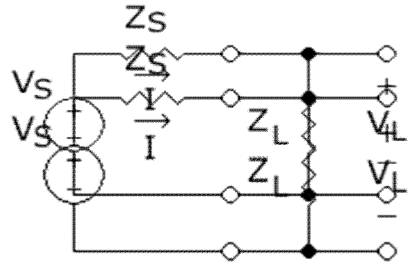


Fig.2 Functional Block Diagram of Wireless Power Transmission System

In the transmission side , the microwave power source generates microwave power and the output power is controlled by electronic control circuits.The waveguide 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 impedence between the transmitting antenna and the microwave source .The transmitting antenna radiates the power uniformly through free space to the rectenna impedance matching is the practice of designing the input impedance electrical load output impedance to maximize the power transferor minimize reflections from the load. In the case of a complex source impedance Z_S and load impedance Z_L, maximum power transfer is obtained when*

$$Z_S = Z_L^* \quad (1)$$



Source and load circuit impedance

*where * indicates the complex conjugate.* Filters *are frequently used to achieve impedance matching in telecommunications and radio engineering.The power received at the coax wave guide adaptor is transmitted to the load.*

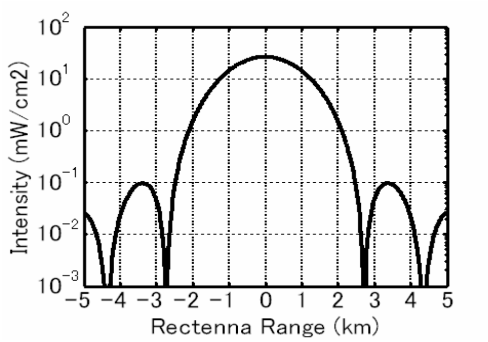
4 CASE STUDIES

The SPS space segment consists of solar cells, RF circuits and antennas, a sensor for the pilot signal, and a control unit for beamforming and retrodirectivity, and circuit power supply. A 1 GW SPS power plant has the following typical dimensions. The area of a solar cell panel is approximately 10 km2 (2km x 5km) for production of 2GW DC power with the solar cell conversion efficiency of 15%. The transmitting antenna array will typically be 1km in diameter. The aperture distribution of the transmitting antenna is determined such as uniform profile or Gaussian profile based on the required beam collecting efficiency. Assuming an antenna element spacing of 0.75 =3.8cm at 5.8GHz, a radiator weight density of 2.69g/cc, and 160 antenna elements, one could get 9.6 kg/ m2 with this design approach.

Ground Segment

A typical rectenna site is 4 km in diameter for a transmitting antenna diameter of 1km operating at 5.8 GHz. Under these conditions, 93% of the transmitted power is collected. The peak microwave power density at the rectenna site is 27 mW/cm2 if a Gaussian power profile is assumed for the transmitter. The beam intensity pattern has a non-uniform distribution with a higher intensity in the center of the rectenna and a lower intensity at its periphery as shown in Fig. 2. The safety requirement for the microwave power density for humans is set to 1mW/cm2 in most countries, which is satisfied at the periphery.

Fig. 3 Typical power density at a rectenna site (1km TX antenna with 10dB Gaussian power distribution)



5 ADVANTAGES

Wireless Power Transmission system would completely eliminates the existing high-tension power transmission line cables, towers and sub stations between the generating station and consumers and facilitates the interconnection of electrical generation plants on a global scale. It has more freedom of choice of both receiver and transmitters. Even mobile transmitters and receivers can be chosen for the WPT system. The cost of transmission and distribution become less and the cost of electrical energy for the consumer also would be reduced. The power could be transmitted to the places where the wired transmission is not possible. Loss of transmission is negligible level in the Wireless Power Transmission; therefore, the efficiency of this method is very much higher than the wired transmission. Power is available at the rectenna as long as the WPT is operating. The power failure due to short circuit and fault on cables would never exist in the transmission and power theft would be not possible at all. The development of Solar Power Satellites gain the benefits of abundant, low-cost, nonpolluting energy. The great advantage of placing the solar cells in space instead of on the ground is that the energy is available 24 hours a day, and the total solar energy available to the satellite is between four and five times more than is available anywhere on Earth and 15 times more than the average location.

6 DISADVANTAGES

The Capital Cost for practical implementation of WPT seems to be very high and the other disadvantage of the concept is interference of microwave with present communication systems. Heat reduction is most important problem in space. All lost power converts to heat. We need special heat reduction system in space. If we use high efficient microwave transmitters, we can reduce weight of heat reduction system. We should aim *for over 80 % efficiency for the microwave transmitter, which must include all loss in phase shifters, isolators, antennas, power circuits.*

7 APPLICATIONS

The SPS is expected to realize around 2030. Before the realization of the SPS, we can consider the other application of the WPT. In resent years, mobile devices advance quickly and require decreasing power consumption. It means that we can use the diffused weak microwave power as a power source of the mobile devices with low power consumption such as RF-ID. The RF-ID is a radio IC-tug with wireless power transmission and wireless information. This is a new WPT application like broadcasting.

8 BIOLOGICAL IMPACTS

*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 c*reated by cellular telephones *Cellular telephones operate with power densities at or below the ANSI/IEEE exposure standards . Thus public exposure to WPT fields would also be below existing safety guidelines. However Tests have also shown that the energy density in the radio-frequency beam can be limited to safe levels for all life forms.*

9 CONCLUSION

The concept of Microwave Power transmission (MPT) andWireless Power Transmission system is presented. The technological developments in Wireless Power Transmission (WPT), the advantages, disadvantages, biological impacts and applications of WPT are also discussed. This concept offers greater possibilities for transmitting power with negligible losses and ease of transmission. Furthermore, it appears almost certain that there will be a shift towards renewable sources and that solar will be a major contributor. *It is asserted that if the energy system of the world is to work for all its people and be adequately robust, there should be several options to develop in the pursuit of and expanded supply. While the option of Space Solar Power may seem futuristic at present,* it is technologically feasible and, given appropriate conditions, can become economically viable.

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