Use of Geosynchronous Satellites for Production and Wireless Transfer of Solar Power

Akhil Nair
Student,Electronics & Telecommunication
K C College of Engineering
Thane, India
akhilnair1730@yahoo.com

***A*bstract— This study examines the use of Geosynchronous satellites for collecting sunlight, harnessing it to produce solar power and transmitting the generated power back to Earth using Wireless power transmission(WPT), safely and reliably. The advantage of placing solar cells in space is the 24 hour availability of sunlight. Also the urgency of finding an alternative energy source due to the depleting energy resources on earth calls for Space Based Solar Power. Here we study the concept of Solar Power Satellites(SPS), investigate the feasibility of implementation, the overall architecture & the underlying components. The results highlight the effectiveness of this system as an environment friendly, low-loss and large-scale method of energy transfer.**

***Keywords*— Solar Power Satellites(SPS), Microwave Power transmission (MPT), Tesla, Wireless PowerTransfer(WPT), Rectenna.**

I. Introduction

A recent survey conducted on consumption of the existing oil reserves on earth revealed shocking facts that if we keep consuming oil at the current rate ,the oil wells might dry up within the next 65 years. This definitely calls for an alternative source of energy for future generations. The advent of solar cells gave an impetus to harnessing the Solar power as a renewable energy resource. But the drawback of solar cells on earth is non-availability of sunlight at night. Another disadvantage of solar panels on earth is the obstruction of sunrays due to the clouds. The solution to these difficulties in producing solar power on Earth is the use of Solar Power Satellites(SPS).The SPS are illuminated by the Sun for 99% of the time in a year except for a short duration during equinox. Also the microwave power can pass through the clouds and other barriers and thus is an unobstructed source of energy.

The following Sections will built upon the concepts of Solar Power Satellite(SPS), Wireless Power Transmission(WPT) and Advantages & Disadvantages of SPS.

II. SOLAR POWER SATELLITE CONCEPT

The idea of 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 Earth's 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[1]. The concept of a large SPS that would be placed in geostationary Earth orbit (GEO) to collect sunlight, use it to generate an electromagnetic beam, and transmit the energy to the Earth was invented in 1968 by Dr.Peter Glaser of Arthur D. Little. In the United States, a major study of the SPS concept was conducted during1976-1980 by the Department of Energy (DOE) with the support of NASA[2].

III. WIRELESS POWER TRANSMISSION

In 1893, Nikola Tesla demonstrated the illumination of vacuum bulbs without using wires for power transmission at the World Columbian Exposition in Chicago[3]. William C. Brown, the pioneer in wireless power transmission technology, had designed, developed a unit and demonstrated to show how power can be transferred through free space by microwaves. In 1961, Brown published the first paper proposing microwave energy for power transmission, and in 1964 he demonstrated a microwave-powered model helicopter that received all the power needed for flight from a microwave beam at 2.45 GHz [4] from the range of 2.4GHz – 2.5 GHz frequency band which is reserved for Industrial, Scientific, and Medical (ISM) applications. Typical WPT is a point-to-point power transmission. For the WPT, we had better concentrate power to receiver. It was proved that the power transmission efficiency can approach close to 100%.[5]

A. *Wireless Power Transmission System*

The main components of Wireless Power Transmission are Microwave Generator, Transmitting antenna and Receiving antenna (Rectenna). These essential components are described in detail further

1) Microwave Generator: The Microwave generator takes the DC power generated by the solar cells and converts it to radiated RF output. It consists of a DC-RF conversion oscillator, which is typically low-power and followed by a gain stage and finally a power amplifier (PA)[6]. Typically the microwave generating devices are classified as microwave tubes (e.g klystron,,magnetron, TWT etc) or semiconductor MW devices. But generally a Phase and Amplitude Controlled Magnetron is preferred. The microwave transmission often uses 2.45GHz or 5.8GHz of ISM band. The other choices of frequencies are 8.5 GHz [7], 10 GHz [8] and 35 GHz[9] . The highest efficiency over 90% is achieved at 2.45 GHz among all the frequencies [9].

TABLE 1. 2.45-GHz RF TUBE COMPARISON

Parameter	**2.4GHz RF Tube Comparision**	
	***Klystron*[10]**	***Magnetron*[11]**
Amplifier output power	50 w	4.39KW
Overall efficiency	74%	87.5% 81.7%
Carrier-to-noise ratio	120 dB @ 10 kHz 135 dB @ 1 MHz 140 dB @ 20 MHz 160 dB @100MHz	110 dB @ 10kHz 137 dB @ 1MHz 160 d @20MHz 196 dB 50MHz
Lifetime	25 years	50 years

The comparison figures in the above table show why Magnetron is preferred for Microwave Generation.

2) Transmitting Antenna: The antenna elements might be dipoles[12], slot antennas, or any other type of antenna, even parabolic antennas[13]. We need higher efficient generator/amplifier for the MPT system than that for the wireless communication system. For highly efficient beam collection on rectenna array, we need higher stabilized and accurate phase and amplitude of microwave when we use phased array system for the MPT[14].

TABLE 2 TYPICAL PARAMETERS OF THE TRANSMITTING ANTENNA OF THE SPS [15]

Model	JAXA2 Model	NASA/DOE model
Frequency	5.8 GHz	2.45 GHz
Diameter of transmitting antenna(0.75 λ)	1.93 kmφ	1 kmφ
Amplitude taper	10 dB Gaussian	10 dB Gaussian
Output Power (beamed to earth)	1.3 GW	6.72 GW

JAXA : Japan Aerospace Exploration Agency, NASA : National Aeronautics and Space Administration

3) Rectenna: The concept and the name 'rectenna' was conceived by W.C. Brown of Raytheon Company in the early of 1960s [16]. A Rectenna is a Rectifying antenna, a special type of antenna that is used to directly convert microwave energy into DC electricity. Its elements are usually arranged in a multi element phased array with a mesh pattern reflector element to make it directional. Rectennas are being developed as the receiving antennas in proposed microwave power transmission schemes, which transmit electric power to distant locations using microwaves. Rectennas are used in RFID tags; the energy to power the computer chip in the tag is received from the querying radio signal by a small rectenna.One possible future application is a receiving antenna for solar Power satellites. A simple rectenna element consists of a dipole antenna with a Schottky diode placed across the dipole elements. The diode rectifies the AC current induced in the antenna by the microwaves, to produce DC power. Schottky diodes are used because they have the lowest voltage drop and highest speed and therefore waste the least amount of power due to conduction and switching. Large rectennas consist of an array of many such dipole elements[17]. Rectennas are highly efficient at converting microwave energy to electricity. In laboratory environments, efficiencies of over 85% have been observed.

TABLE 3. PERFORMANCE OF PRINTED RECTENNA

Type of Rectenna	**Operating Frequency (GHz)**	**Measured Peak Conversion Efficiency (%)**
Printed Dipole	2.45	85
Circular Patch [18]	2.45	81
Printed dual Rhombic	5.6	78
Square Patch[9]	8.51	56

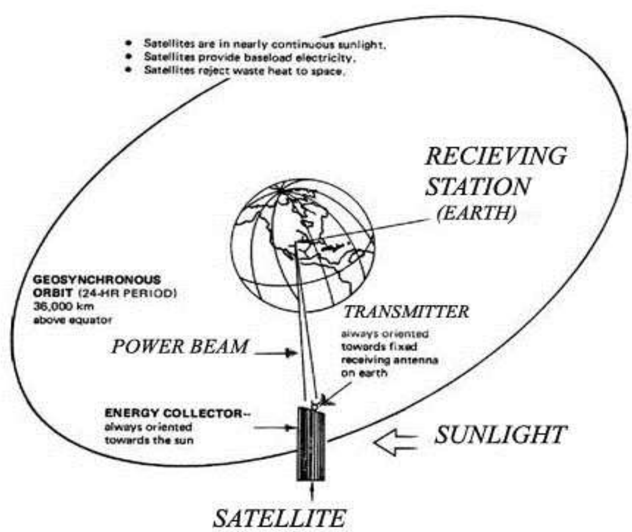

Figure1. Shows how the overall Solar Power Satellite (SPS) system generates and transmits solar power back to Earth

IV. ADVANTAGES AND DISADVANTAGES OF SPS

A. *Advantages*

Unlike oil, gas, ethanol, and coal plants, space solar power does not emit greenhouse gases.Also like nuclear power plants, space solar power will not produce hazardous waste, which needs to be stored and guarded for hundreds of years[20].The following figure also shows that in future the cost of producing electricity using coal will go on increasing.Whereas that using Solar Satellites ,if implemented will keep reducing over the years.

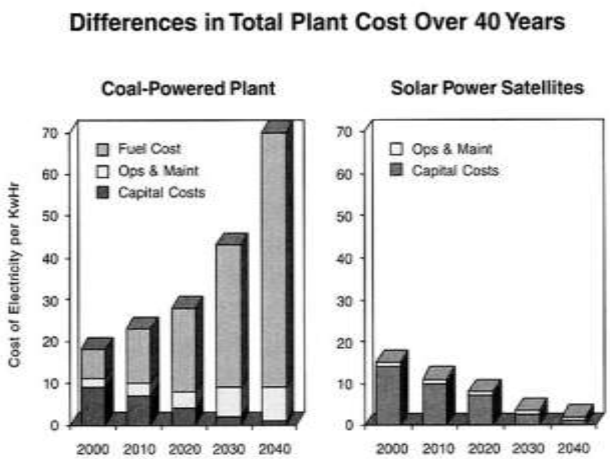

Figure2 Comparison between future estimation of production costs of electricity using Coal vs. Solar Satellites

Another major advantage of solar power is that it is a renewable source of energy. Also the losses in wireless transfer of electricity are much less then transmission lines. The SPS can produce solar power continuously as there is no day-night effect in space. The presence of clouds does not hamper the efficiency of SPS as transmitted microwave power can pass through clouds. As a Geosynchronous satellite is used, the position of the satellite with respect to the Receiving Station on the Earth remains the same.

B. *Disadvantage*

One of the disadvantages of Solar Power Satellites is the high cost of development. Another disadvantage is the interference of microwaves with present communication systems.

C. *Impacts on Environment and Biodiversity*

Wireless power transmission through SPS has no major impacts on Environment or life on Earth. Studies reveal that the microwave radiation used are not higher than that experienced while opening a kitchen microwave oven.The microwave radiations are well within the prescribed safety guidelines. Thus SPS might provide a large scale, clean, green and efficient source of power.

V. CONCLUSION

From the above considerations it can be inferred that SPS can prove to be a promising alternative to fossil fuels .We also came across the fact that the losses in Wireless power transfer are much less compared to the transmission lines. Microwave Power Transmission (MPT) also has no adverse effect on the environment and the biodiversity on the Earth. But the major hurdles in the implementation of Solar Power Satellites is not technology but economical factors. A large scale research is ongoing to overcome the high cost of fabrication and launching of these satellites.

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