Solar Power Satellites & Microwave Power Transmission Technology

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Abstract: ***The search for a new, safe and stable renewable energy source led to idea of building a power station in space which transmits electricity to earth. The concept was invented by Glaser in 1968. Research is going on in this field and NASA is planning to implement one in near future. SPS converts solar energy into microwaves and transmit it to a receiving antenna on earth for conversion to electric power. The key technology needed to enable the future feasibility of SPS is Microwave Power Transmission. It would be a massive structure. Estimated cost is about $74 billion and would take several years for its construction. Suggestions are made to employ extra-terrestrials resources for its construction. This paper throws some light on solar power satellites and the application of microwave power transmission in order to meet the energy demands sustainably.***

Keywords: SPS (Solar Power Satellite), MPT (Microwave Power Transmission), LEO (Low earth Orbit), URSI (International Union of Radio Science), WPT (Wireless Power Transmission)

1. INTRODUCTION

The exponential increase in population has led to the global crisis. Also the demand of electric power increases at a much higher pace. Thus research has been carried out to look into the possibility of building a power station in space to transmit electricity to earth by way of radio waves- the Solar Power Satellites. One of the key technologies needed to enable the future feasibility of SPS is that Microwave Wireless Power Transmission. WPT is based on the energy transfer capacity of microwave beam. Radio waves can benefit the welfare of humanity through other purposes than communications. Microwave power transmission (MPT) is one of the new technological frontiers. Solar power satellites (SPS) will provide a clean and limitless energy resource from space through this technique. This article answers the fundamental question of why we need to develop the SPS from a viewpoint of critical global issues for mankind. A summary of recent research committee activities on SPS and a road map of future SPS research plans in Japan conclude the article. Nicola Tesla first conceived of the idea of radio power transmission about a century ago [1], [2]. From the beginning of the 20th century on, however, radio has been used mainly for transmitting intelligence and information, and very few attempts have been made to transmit electric power over radio, though Yagi and Uda [3] predicted a technical feasibility of power transmission on radio waves, foreseeing the era of microwave availability. The post-war history of research on radio power transmission is well documented by Brown [4], who was a pioneer of practical MPT. It was Brown who first succeeded in demonstrating a microwave-powered helicopter in 1964, using 2.45 GHz in the frequency range of 2.4-2.5 GHz reserved for the industrial, scientific, and medical (ISM) applications of radio waves [5]. A microwave-to-dc power-conversion device, called a "rectenna," was also invented by Brown [6]-[8].In the early 1990s, the idea of using Earth's largest satellite as a platform for collecting solar energy was proposed as a Lunar Solar Power option [9,10]. NASA began the Solar Power Concept Definition Study [11] in 1998 to evaluate feasibility of the SPS concept. Satellite and system architectures based on laser wireless power transmission were also considered later on. The receiving antennas for laser systems are compact. However,beam safety is an issue [13]. Proposals have been made to effectively combine the benefits of laser and microwave transmission systems[12]. Inflatable structures have been demonstrated in space [14] paving a way for concepts of less bulky satellite structures.

2. WHY SOLAR POWER SATELLITE?

Increasing global energy demand is likely to continue for many decades. Renewable energy is compelling approach both philosophically and in engineering terms. However many renewable energy sources are limited in their ability.

Burning of fossil fuels resulted in an abrupt decrease in their and also green house effect and other environmental problems. Switching on to the natural fission reactor, the sun, yields energy with no waste products. Earth based solar panels receives only a part of this energy. So it is desirable to place the solar panels in the space itself. This concept is more advantageous than conventional methods. Also the microwave energy, chosen for transmission, can pass unimpeded through clouds and precipitations.

2.1 SPS Background

In 1968, the concept of a large SPS that would be placed in geostationary orbit was invented by Peter Glaser. The SPS concept was examined extensively during the late 1970s by the US Department of Energy (DOE) and the National Aeronautics and Space Administration. The central feature of this concept was the creation of a large scale power infrastructure in space, consisting of about 60 SPS, delivering a total of about 300GW. In 1980-1981, all U.S SPS efforts were terminated with a view to re-asses the concept after about ten years. During 1995-96, NASA conducted a re-examination of the technologies, Fresh look study. During 1998, NASA conducted the SSP Concept Definition Study which was a focused one year effort that tested the results of the previous Fresh Look Study. In 2000, NASA conducted the SERT Program (SSP Exploratory and Research Technology Program) which further defined new system concepts. In 2011, IAA"First International Assessment of Space Solar Power".

2.2 SPS A General Idea

Solar Power Satellites would be located in the geosynchronous orbit. The solar energy collected by an SPS would be converted into electricity, then into microwaves. The microwaves would be beamed to the Earth's surface, where they would be received and converted back into electricity by rectenna. Each SPS would have been massive; measuring 10.5 km long and 5.3 km wide or with an average area of 56sq.km. The surface of each satellite would have been covered with 400 million solar cells. The transmitting antenna on the satellite would have been about 1km in diameter and the receiving antenna on the Earth's surface would have been about 10 km in diameter. The SPS would weigh more than 50,000 tons. The reason that the SPS must be so large has to do with the physics of power beaming. The smaller the transmitted array, the larger the angle of divergence of the transmitted beam.

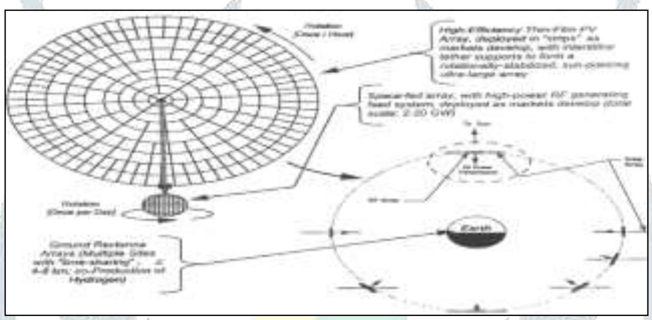

Figure 1: Configuration of SPS in space

2.3 Other Important Aspects

Another important feature of the SPS is its continuous operation i.e 24 hours a day, 365 days a year basis. Only for total of 22 in a year would the SPS would be eclipsed for a period of time to a maximum of 72 min. The power would be beamed to the Earth in the form of microwaves at a frequency of 2.45 GHz. Microwave frequency in the range of 2-3 GHz are considered optimal for the transmission of power from SPS to the ground rectenna site. The amount of power available to the consumers from one SPS is 5 GW. The peak intensity of microwave beam would be 23mW/cm². SPS receiver operates just like a solar array.

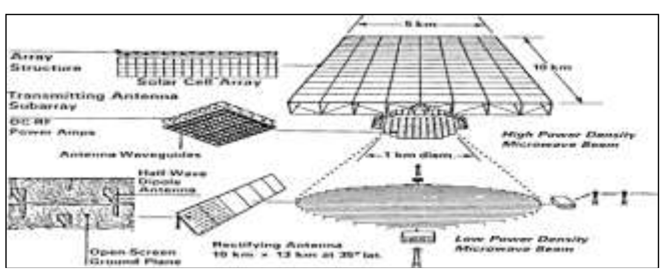

Figure 2: A Typical Configuration of SPS

3. Wireless Power Transmission

Transmission or distribution of 50 or 60 Hz electrical energy from the generation point to the consumer end without any physical wire has yet to mature as a familiar and viable technology. However, the reported works on terrestrial WPT have not revealed the design method and technical information. Main thrust of WPT has been on the concept of space-to-ground (extraterrestrial) transmission of energy using microwave beam. The 50 Hz ac power tapped from the grid lines is stepped down to a suitable voltage level for rectification into dc. This is supplied to an oscillator fed magnetron. Inside the magnetron electrons are emitted. As they pass by the resonating cavities of the magnetron, a continuous pulsating magnetic field i.e., electromagnetic radiation in microwave frequency range is generated. The frequency of the radiation is adjusted by varying the inductance or capacitance of the resonating cavities.

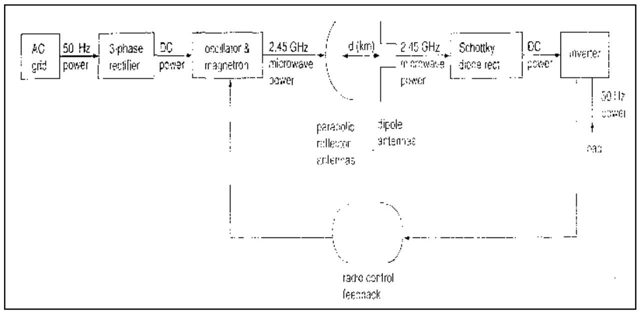

Figure 3: WPT system annexed to a grid

The microwave power output of the magnetron is channeled into an array of parabolic reflector antennas for transmission to the receiving end antennas. A series parallel assembly of schottky diodes, having a low standing power rating but good RF characteristics is used at the receiving end to rectify the received microwave power back into dc. Inverter is used to invert the dc power into ac. A simple radio control feedback system operating in FM band provides an appropriate control signal to the magnetron for adjusting its output level with fluctuation in the consumers demand at the receiving side. The overall efficiency of the WPT system can be improved by: (1) Increasing directivity of the antenna array. (2) Using dc to ac inverters with higher conversion efficiency. (3) Using schottky diode with higher ratings.

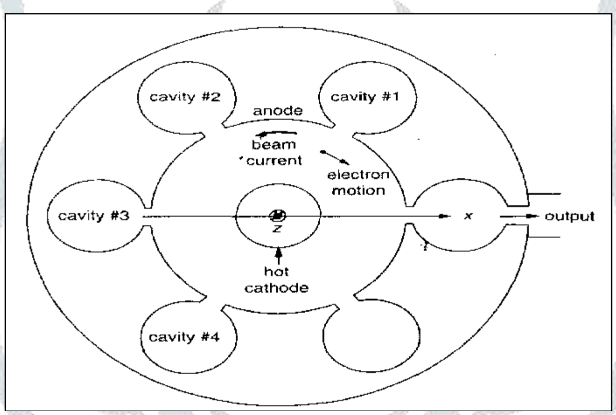

Figure 4: Re-entrant electron beam in a six-cavity magnetron

3.1 Microwaves Environmental Issues

Because of their large size, SPS would appear as a very bright star in the relatively dark night sky. SPS in GEO would show more light than Venus at its brightest. Thus, the SPS would be quite visible and might be objectionable. SPS posses many environmental questions such as microwave exposure, optical pollution that could hinder astronomers , the health and safety of space workers in a heavy-radiation (ionizing) environment , the potential disturbance of the ionosphere etc. On the earth, each rectenna for a full-power SPS would be about 10 km in diameter. The classic rectenna design would be transparent in sunlight, permitting growth and maintenance of vegetation under the rectenna. However, the issues related to microwaves continue to be the most pressing environmental issues. Based on well developed antenna theory, the environmental levels of microwave power beam drop down to $0.1\mu W/cm^2$. Serious discussions and education are required before most of mankind accepts this technology with global dimensions Microwaves, however is not a 'pollutant' but more aptly, a man made extension of the naturally generated electromagnetic spectrum that provides heat and light for our sustenance.

4. PREVALENCE OF SPS

The idea collecting solar energy in space and returning it to earth using microwave beam has many attractions. The full solar irradiation would be available at all times except when the sun is eclipsed by the earth. Thus about five times energy could be collected, compared with the best terrestrial sites. The power could be directed to any point on the earth's surface. The zero gravity and high vacuum condition in space would allow much lighter, low maintenance structures and collectors. The power density would be uninterrupted by darkness, clouds, or precipitation, which are the problems encountered with earth based solar arrays. The realization of the SPS concept holds great promises for solving energy crisis. No moving parts, No fuel required, No waste product.

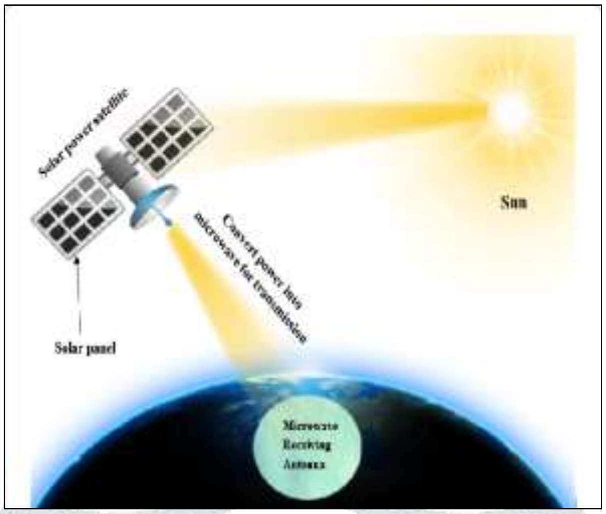

Figure 5: Conversion of SPS to MPT

5. Other recommendations

The SPS will be a central attraction of space and energy technology in coming decades. However, large scale retro directive power transmission has not yet been proven and needs further development. Another important area of technological development will be the reduction of the size and weight of individual elements in the space section of SPS. Large-scale transportation and robotics for the construction of large-scale structures in space include the other major fields of technologies requiring further developments. Technical hurdles will be removed in the coming one or two decades. Finally, we look forward to universal acceptance of the premise the electromagnetic energy is a tool to improve the quality of life for mankind. It is not a pollutant but more aptly, a man made extension of the naturally generated electromagnetic spectrum that provides heat and light for our sustenance. From this view point, the SPS is merely a down frequency converter from the visible spectrum to microwaves. SPS researchers in Japan are interested in designing and launching an experimental power satellite with a scale of 10-100 kW in low Earth orbit (LEO) to prove technical feasibility In this article we have mainly discussed only MPT. Other key technologies to be considered include large-scale transportation and robotics for the construction of large-scale structures in space. Technical hurdles will be removed in the coming one or two decades. The difficult issue of radio regulation is to be overcome with a long-term philosophy of radio usage in this century. To this end, a special working group was formed in 2002 within the International Union of Radio Science (URSI) to have a serious discussion on this matter, including communication engineers, SPS engineers, radio astronomers, and bio radio scientists. This working group and the Scientific Committee on Telecommunications within URSI will make an effort to contact the International Telecommunications Union, which is a regulatory organization of radio spectrum.

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