

Solar Power Satellites and Microwave Wireless Power Transmission Technology

Ms. S.G. Satavekar

*ENTC Department , Shivaji University, Kolhapur, Maharashtra - 416114, India.
E-mail: snehal_satavekar@yahoo.co.in*

Abstract

Solar Power Satellites (SPS) converts solar energy in to micro waves and sends that microwaves in to a beam to a receiving antenna on the Earth for conversion to ordinary Electricity. SPS is a clean, large-scale, stable electric power source. For SPS Wireless power transmission is essential. WPT contains microwave beam, which can be directed to any desired location on Earth surface. This beam collects Solar Energy and converts it into Electrical Energy. This concept is more advantageous than conventional methods. The SPS will be a central attraction of space and energy technology in coming decades. 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.

Keywords: Solar Power Satellites; Microwaves;

1. Introduction

The new millennium has introduced increased pressure for finding new renewable energy sources. The exponential increase in population has led to the global crisis such as global warming, environmental pollution and change and rapid decrease of fossil reservoirs. Also the demand of electric power increases at a much higher pace than other energy demands as the world is industrialized and computerized. Under these circumstances, research has been carried out to look in to the possibility of building a power station in space to transmit electricity to Earth by way of radio waves-the Solar Power Satellites. Solar Power Satellites (SPS) converts solar energy in to micro waves and sends that microwaves in to a beam to a receiving antenna on the Earth for conversion to ordinary Electricity. SPS is a clean, large-scale, stable electric power

source. Solar Power Satellites is known by a variety of other names such as Satellite Power System, Space Power Station, Space Power System, Solar Power Station, Space Solar Power Station etc. [1]. One of the key Technologies needed to enable the future feasibility of SPS is that of Microwave Wireless Power Transmission.

WPT is based on the energy transfer capacity of microwave beam I e, energy can be transmitted by a well focused microwave beam. Advances in Phased array antennas and rectennas have provided the building blocks for a realizable WPT system [2]

1.1 Why SPS

Increasing global energy demand is likely to continue for many decades. Renewable energy is a compelling approach – both philosophically and in engineering terms. However, many renewable energy sources are limited in their ability to affordably provide the base load power required for global industrial development and prosperity, because of inherent land and water requirements. The burning of fossil fuels resulted in an abrupt decrease in their availability. It also led to the green house effect and many other environmental problems. Nuclear power seems to be an answer for global warming, but concerns about terrorist attacks on Earth bound nuclear power plants have intensified environmentalist opposition to nuclear power. Earth based solar panels receives only a part of the solar energy. So it is desirable to place the solar panel in the space itself, where, the solar energy is collected and converted in to electricity which is then converted to a highly directed microwave beam for transmission. This microwave beam, which can be directed to any desired location on Earth surface, can be collected and then converted back to electricity. This concept is more advantageous than conventional methods. Also the microwave energy, chosen for transmission, can pass unimpeded through clouds and precipitations.

1.2 SPS –The Background

The concept of a large SPS that would be placed in geostationary orbit was invented by Peter Glaser in 1968 [1]. The SPS concept was examined extensively during the late 1970s by the U.S Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA). The DOE-NASA put forward the SPS Reference System Concept in 1979 [2]. 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. But, as a result of the huge price tag, lack of evolutionary concept and the subsiding energy crisis in 1980-1981, all U.S SPS efforts were terminated with a view to re-assess the concept after about ten years. During this time international interest in SPS emerged which led to WPT experiments in Japan.

1.3 SPS-A General Idea

Solar Power Satellites would be located in the geosynchronous orbit. The difference between existing satellites and SPS is that an SPS would generate more power-much more power than it requires for its own operation. 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 a large array of devices known as rectifying antenna or rectennas.

Each SPS would have been massive; measuring 10.5 km long and 5.3km wide or with an average area of 56 sq. 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 1 km in diameter and the Receiving antenna on the Earth's surface would have been about 10 km in diameter [5].In order to obtain a sufficiently concentrated beam; a great deal of power must be collected and fed into a large transmitter array. The power would be beamed to the Earth in the form of microwave at a frequency of 2.45 GHz. Microwaves have other features such as larger band width, smaller antenna size, sharp radiated beams and they propagate along straight lines. Microwave frequency in the range of 2-3 GHz are consider edoptimal for the transmission of power from SPS to the ground rectennas site [7].

The amount of power available to the consumers from one SPS is 5GW. The peak intensity of microwave beam would be 23 m W/cm². SPS has all the advantage of ground solar, it generates power during cloudy weather and at night. In other words SPS receiver operates just like a solar array. It receives power from space and converts it into electricity. This reduces the size and complexity of satellite [8].

2. 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. 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.

The microwave power output of the magnetron is channeled into an array of parabolic reflector antennas for transmission to the receiving end antennas. To compensate for the large loss in free space propagation and boost at the receiving end the signal strength as well as the conversion Efficiency, the antennas are connected in arrays. 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-Increasing directivity of the antenna array.Using dc to ac inverters with higher conversion efficiency .Using schottky diode with higher ratings.

2.1 Microwave Power Transmission In SPS

The microwave transmission system have had three aspects [5]:

1. The conversion of direct power from the photovoltaic cells, to microwave power on the satellites on geosynchronous orbit above the Earth.
2. The formation and control of microwave beam aimed precisely at fixed locations on the Earth's surface.

3. The collection of the microwave energy and its conversion into electrical energy at the earth's surface.

The key microwave components in a WPT system are the transmitter, beam control and the receiving antenna called rectennas. At the transmitting antenna, microwave power tubes such as magnetrons and klystrons are used as RF power sources. Rectenna is a component unique to WPT systems. The following section describes each of these components in detail.

2.2 Transmitter

The key requirement of a transmitter is its ability to convert dc power to RF power efficiently and radiate the power to a controlled manner with low loss. The transmitter's efficiency drives the end-to-end efficiency as well as thermal management system [2]. The main components of a transmitter include dc-to-RF converter and transmitting antenna. Power distribution at the transmitting antenna $= (1 - r^2)$, where r is the radius of antenna [7]. There are mainly three dc-to-RF power converters: magnetrons, klystrons and solid state amplifiers.

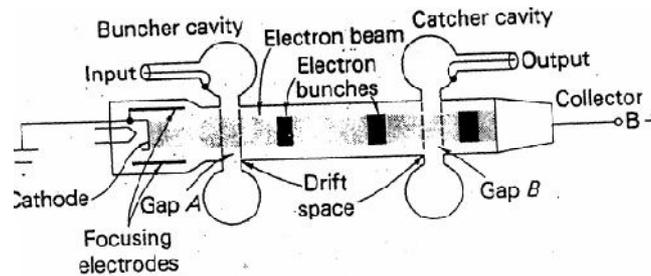


Fig. 2: Klystron amplifier schematic diagram.

Klystron

Fig. 2 shows the schematic diagram of a klystron amplifier [15]. Here a high velocity electron beam is formed, focused and sent down a glass tube to a collector electrode which is at high positive potential with respect to the cathode. As the electron beam having constant velocity approaches gap A, they are velocity modulated by the RF voltage existing across this gap. Thus as the beam progresses further down the drift tube, bunching of electrons takes place. This variation in current enables the klystron to have significant gain. Thus the catcher cavity is excited into oscillations at its resonant frequency and a large output is obtained.

Fig. 3 shows a klystron transmitter [2]. The tube body and solenoid operate at 300°C and the collector operates at 500°C. The overall efficiency is 83%. The microwave power density at the transmitting array will be 1 kW/m² for a typical 1 GW SPS with a transmitting antenna aperture of 1 km diameter. If we use 2.45 GHz for MPT, the number of antenna elements per square meter is on the order of 100.

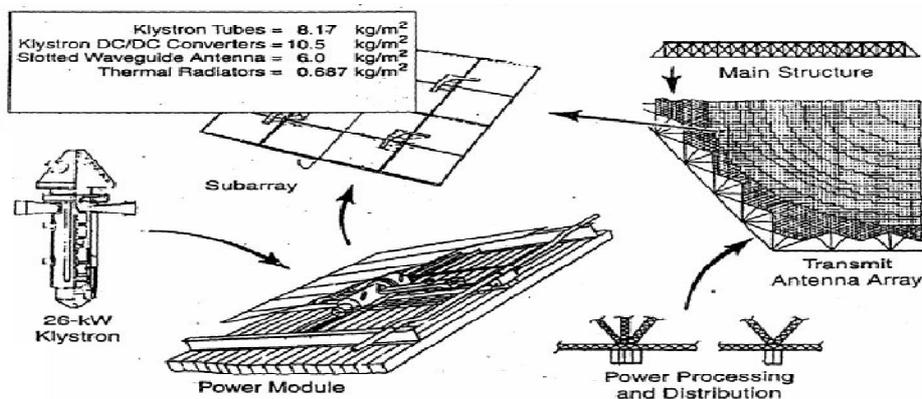


Fig. 3: Klystron Transmitter.

2.3 Rectenna

Brown was the pioneer in developing the first 2.45GHz rectenna [2]. Rectenna is the microwave to dc converting device and is mainly composed of a receiving antenna and a rectifying circuit. Fig .4 shows the schematic of rectenna circuit [2]. It consists of a receiving antenna, an input low pass filter, a rectifying circuit and an output smoothing filter. The input filter is needed to suppress radiation of high harmonics that are generated by the non linear characteristics of rectifying circuit. Because it is a highly non linear circuit, harmonic power levels must be suppressed.

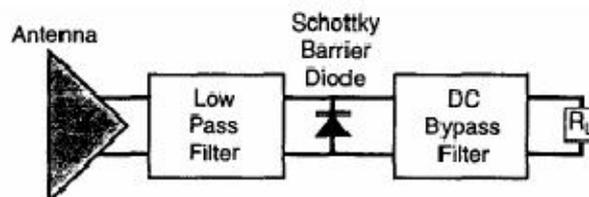


Fig. 4: Schematic of rectenna circuit.

For rectifying Schottky barrier diodes utilizing silicon and gallium arsenide are employed. Diode selection is dependent on the input power levels. The breakdown voltage limits the power handling capacity and is directly related to series resistance and junction capacitance through the intrinsic properties of diode junction and material .For efficient rectification the diode cut off frequency should be approximately ten times the operating frequency.

Diode cut off frequency is given by $f=1/[2RsCj]$, where f is the cut off frequency, Rs is the diode series resistance, Cj is the zero-bias junction capacitance.

2.5 Recently Developed MPT Systems

The Kyoto University developed a system called Space Power Radio Transmission System (SPORTS) [1]. The SPORTS is composed of solar panels, a microwave

transmitter subsystem, a near field scanner, a microwave receiver. The solar panels provide 8.4 kW dc power to the microwave transmitter subsystem composed of an active phased array. It is developed to simulate the whole power conversion process for the SPS, including solar cells, transmitting antennas and rectenna system. Another MPT system recently developed by a team of Kyoto University, NASDA and industrial companies of Japan, is an integrated unit called the Solar Power Radio Integrated Transmitter (SPRITZ), developed in 2000 [1]. This unit is composed of a solar cell panel, microwave generators, transmitting array antennas and a receiving array in one package.

3. Construction of SPS from Non Terrestrial Materials: Feasibility and Economics

SPS, as mentioned before is massive and because of their size they should have been constructed in space [5]. The aluminum and silicon can be refined to produce solar arrays [12]. Among them are the shallow gravity wells of the Moon and asteroids; the presence of an abundance of glass, metals and oxygen in the Apollo lunar samples; the low cost transport of those materials to a higher earth orbit by means of a solar-powered electric motor; the availability of continuous solar energy for transport, processing and living [12] One major new development for transportation is required: the mass driver [12]. The mass driver is a long and narrow machine which converts electrical energy into kinetic energy by accelerating 0.001 to 10 kg slugs to higher velocities. The mass driver conversion efficiency from electrical to kinetic energy is close to 100 percent.

3.1 Microwaves-Environmental Issues

The price of implementing a SPS includes the acceptance of microwave beams as the link of that energy between space and earth. Because of their large size, SPS would appear as a very bright star in the relatively dark night sky. SPS poses 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. The atmospheric studies indicate that these problems are not significant, at least for the chosen microwave frequency [13].

On the earth, each rectenna for a full-power SPS would be about 10 km in diameter. This significant area possesses classical environmental issues. These could be overcome by sitting rectenna in environmentally insensitive locations, such as in the desert, over water etc. However, the issues related to microwaves continue to be the most pressing environmental issues. On comparing with the use of radar, microwave ovens, police radars, cellular phones and wireless base stations, laser pointers etc. public exposures from SPS would be similar or even less. Based on well developed antenna theory, the environmental levels of microwave power beam drop down to 0.1 W/cm^2 [12].

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 substance.

4. Advantages and Disadvantages

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 [14]. 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 [14]. 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.

The concept of generating electricity from solar energy in the space itself has its inherent disadvantages also. Some of the major disadvantages are:

The main drawback of solar energy transfer from orbit is the storage of electricity during off peak demand hours [15]. The frequency of beamed radiation is planned to be at 2.45 GHz and this frequency is used by communication satellites also. The entire structure is massive. High cost and require much time for construction. Radiation hazards associated with the system. Risks involved with malfunction. High power microwave source and high gain antenna can be used to deliver an intense burst of energy to a target and thus used as a weapon [15].

5. Conclusion and Future Scope

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. 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.

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