ISSN 2229-5518

Generation and Transmission of Electrical Power through Solar Power Satellite (SPS)

Mr. Gaurav **Tanwar,** Asstt**. Prof. Mohd.** Ilyas**, Mr. Raj Kumar Singh**

Abstract— In this paper a new technique is discussed to generate and transmit electrical power using solar power. The solar energy can be converted into electrical energy by using solar cells. Solar energy is available in large amount continuously in free space which can be utilized by solar power satellite (SPS) to convert it into electrical form. This electrical power can be transmitted to the earth using microwave technology which can be received by using rectifying antenna placed on the ground. Rectenna must have a diameter of about 2-3 Km range.

Index Terms—Solar power satellite (SPS), Ractenna, Transmitted, Microwave technology.

INTRODUCTION

Solar power satellite (SPS) attracts attention as clean energy which does not take out CO_2 and can solve an environmental problem and the energy problem of drain of a fossil fuel. In outer space there is an **uninterrupted** availability of huge amount of solar energy in the form of light and heat. So the use of satellites primarily aimed at collecting the solar energy and beam it back to the earth is being considered. Efficiency is much higher than the solar power placed on the ground as a base power supply which can be supplied for 24 hours. As a consequence of an ever-increasing world-wide energy demand and of a need for a clean energy source, the solar power satellite (SPS) concept has been explored by scientists and engineers. In a typical SPS system, solar energy is collected in space by a satellite in a geostationary orbit. The solar energy is converted to direct current by solar cells, and the direct current is in turn used to power microwave generators in the gigahertz frequency (microwave) range. The generators feed a highly directive satellite-borne antenna, which beams the energy to the Earth. On the ground, a rectifying antenna (rectenna) converts the microwave energy from the satellite into direct current, which, after suitable processing, is fed to the terrestrial power grid. Two critical aspects that have motivated research into SPS systems are the lack of attenuation of the solar flux by the Earth's atmosphere, and the twenty-four-hour availability of the energy, except around midnight during the equinox periods.

Mr.Gaurav Tanwar is doing M.Tech from Al-Falah School of Engineering and Tech, M.D University, Rohtak, Haryana in power systems branch (e-mail: gaurav.tanwar@gmail.com)

Asstt. Prof. Mohd. Ilyas is working with Al-Falah School of Engineering and Tech, M.D University Rohtak, Haryana with the Electrical & Electronics department

Mr. Raj Kumar Singh is doing M.Tech from Al-Falah School of Engineering and Tech, M.D University Rohtak, Haryana in power systems branch. (e-mail: raj.jadon03@gmail.com)

DESIGNING PARAMETERS

A solar power satellite is a very large-area satellite in an appropriate orbit, which would function as an electric power plant in space. The satellite would consist of **three** main parts: a solar-energy collector to convert solar energy into dc electric power, a dc-to- microwave converter and a large antenna array to beam the microwave power to the ground. For the production of 1 GW of dc power, the solar collector would need to have an area of 10 km^2, and would consist of either photovoltaic cells or solar thermal turbines. The dc-to-microwave converter could be realized using either a microwave-tube system or a semiconductor system, or a combination of both. For transmitting the power to the ground, frequency bands around 5.8 GHz or 2.45 GHz have been proposed, which are within the microwave radio windows of the atmosphere. Concerning the power transmission efficiency of the WPT, there are some good optical approaches in Russia [2] [3].

In addition to the SPS orbiter, a ground-based power-receiving site has to be constructed, consisting of a device to receive and rectify the microwave power beam, i.e. to convert it back to dc electric power. This device is called a rectenna (rectifying antenna). The dimensions of the rectenna site on the ground depend on the microwave frequency and the size of the transmitting antenna. A model system, operating at 2.45 GHz, would use a rectenna site with a diameter of 4 km and a satellite-based transmitting antenna with a diameter of 2 km. The peak microwave power-flux density at the rectenna site would then be 300 W/m^2; if a Gaussian power profile of the transmitted beam is assumed. The beam-intensity pattern would be nonuniform, with a higher intensity in the centre of the rectenna and a lower intensity at its periphery. For human safety requirements, the maximum-allowable microwave power level has been set to 10 W/m^2 in most countries, and the SPS power-flux density would be constructed to satisfy this requirement at the periphery of the rectenna. After suitable power conditioning, the electric output of the rectenna would be delivered to the power network. More details about the SPS concept can be found in [1].

Typical parameters of the transmitting antenna of the **SPS** [4]

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

Model	Old JAXA Model	JAXA1 Model	JAXA2 Model	NASA /DOE Model
Frequency (GHz)	5.80	5.80	5.80	2.45
Diameter of transmitting antenna	2.60 kmφ	1.00 kmφ	1.93 kmφ	1.00 kmφ
Amplitude taper	10 dB Gaussian	10 dB Gaussian	10 Db Gaussian	10 dB Gaussian
Output power	1.3 GW	1.3 GW	1.3 GW	1.3 GW
Max. power density at center	63 mW/ cm^2	420 mW/cm^2	114 mW/cm^2	2.2 W/ cm2
Min. power density	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/ antenna (No. of elements)	0.95 W (3.54 billion)	6.1W (540 million)	1.7 W (1,950 million)	185 W (97 million)
Rectenna Diameter	2.0 kmφ	3.4 Kmφ	2.45 kmφ	1 kmφ
Max. Power Density	180 mW/cm^2	26 mW/cm^2	100 mW/cm^2	23 mW/cm^2
Collection Efficiency	96.5 %	86 %	87 %	89 %

HISTORICAL VIEW

The first concept of an SPS system was proposed by P. Glaser in 1968 [5], after a series of experiments on microwave power transmission [6, 7]. Following this article, the United States conducted an extensive feasibility study in 1978-1980. The feasibility study was a joint effort of NASA (National Aeronautics and Space Administration) and the Department of Energy. A reference model was proposed in 1979, known as the NASA/DoE reference model [8]. An SPS system using mirrors for sunlight concentration on the solar cells, the Integrated Symmetrical Concentrator, was also proposed. It uses 24 or 36 plane mirrors of 500 m diameter for a concentration factor of two or four [9].

Japanese scientists and engineers started their SPS research in the early 1980s. They conducted a series of microwave power-transmission experiments, such as the world's first rocket experiment with powerful microwave transmission in the ionosphere [10], experiments on the ground, computer simulations, theoretical investigations, and system studies for a demonstration experiment. After a conceptual study phase, two Japanese organizations have recently proposed their own models. JAXA (Japan Aerospace Exploration Agency) proposed an SPS 5.8 GHz/1 GW model, which is different from the NASA/DoE model.

Coherent Set of Numerical Values

Assuming that an SPS unit will generate 1 GW effective power on the ground, the characteristic efficiencies are summarized in Table 1. The figures are given for a 2.45- GHz unit; corresponding values for a 5.8-GHz unit are not fundamentally different. Therefore, in order to generate 1 GW at the ground, one needs to collect about 14 GW in space. Since the solar radiation power flux is equal to 1.37 kW/m^2, one needs a solar-panel area of approximately 10 km^2. The transmitted RF power is $14 \times 0.13 \times 0.78 \approx 1.44$ GW. Taking into account the RF collection efficiency of 87%, the RF power received at the ground level is $P = 1.25$ GW. The efficiency of the microwave power transmission (dc-microwave-dc) is the product of the efficiencies given in lines 2-4 of Table 1, i.e. 54%. (Actually, 54.18% was demonstrated and certified in a NASA laboratory test).

Quantity	Efficiency
Solar-power-to-dc-power efficiency	13%
dc-power-to-RF-power efficiency	78%
RF collection efficiency	87%
RF-power-to-dc-power (rectenna)	80%
Total efficiency	7%

Economic Issues

There are four main factors that determine the power- production costs of an SPS system: photovoltaic module efficiency and costs, mass-specific power production (W/ kg) of the solar modules and the transmission system, microwave power-transmission efficiency, and launch costs. The target is an efficiency of about 50% for the total microwave power transmission dc-microwave-dc conversion, and a specific power output of 1 kW/kg for the whole microwave power-transmission system. The published SPS cost estimates are based on a launch cost of USD150/kg [1]. All these assumptions lead to an estimated energy-generation cost of approximately USD0.1-0.2 per kWh for an SPS system.

A direct comparison of the output power from a space-based solar power unit with that from a terrestrial photovoltaic array with equal area is not straightforward. On one hand, a simple estimate of the energy output yields an advantage of about a factor 2.5 for the SPS.

For the SPS system,

1.37 kW/m^2 solar power flux in space x 0.07 overall SPS efficiency (Table 1) x 24 h = 2.3 kWh/m^2/day.

For a terrestrial solar-cell array,

5 kWh/m^2/day average solar power flux at a sunny place (Arizona) x 0.17 solar cell efficiency = 0.85 kWh/ m^2/day.

SPS RADIO TECHNOLOGIES

Microwave Power Transmission: In the microwave power-transmission system, radio waves would be used as carriers of energy. The main parameters of the microwave power-transmission system for the SPS system are the frequency, the diameter of the transmitting antenna, the output power (beamed to the Earth), and the maximum power-flux density. Efficiency is very important for the microwave power- transmission system. Assuming the SPS transmitting- antenna-to-rectenna propagation path is optimum, the following efficiencies will be important: dc-to-radio- frequency (RF) conversion, RF-to-dc conversion, and beam- collecting efficiencies. Conversion efficiencies higher than 80% for both RF-dc and dc-RF conversions are necessary to make the cost of the SPS system reasonable. A phased antenna array is planned for the SPS system, in order to obtain high- efficiency beam collection under the condition of fluctuating SPS attitudes. Depending on the frequency of the microwave power transmission, e.g. 2.45 GHz or 5.8 GHz, the number of antenna elements per square meter would need to be of the order of 100 or 400, where the power delivered by a single element would be 10 W or 2.5 W, respectively [1].

Microwave Power Devices: Many possibilities have been proposed for the microwave generators, such as microwave vacuum tubes (klystrons, magnetrons, travelling-wave tube amplifiers), semiconductor transmitters, and combinations of both technologies. These types of generators have been compared with respect to their efficiency, output power, weight, and emitted harmonics [1]. Compared to semiconductor technologies, a microwave tube has higher efficiency, lower cost, and a smaller power-to-weight ratio (kW/kg). From a manufacturing point of view, recent semiconductor technologies could be useful for SPS systems.

Rectennas: The rectenna (located on the Earth) receives the microwave power from the SPS and converts it to dc electricity. The rectenna is composed of an RF antenna, a low-pass filter, and a rectifier. Various rectenna schemes have been proposed, and the maximum conversion efficiencies anticipated so far are 91.4% at 2.45 GHz and 82% at 5.8 GHz.

Control and Calibration: Another important issue concerning the space-based microwave antenna is the necessarily high precision of the control of the beam direction. This is important for two reasons: to maximize the energy transferred to the Earth and to limit radiation in undesired directions, in order to avoid adverse effects on existing telecommunications, passive radio-detection systems, and biological systems. This goal may be achieved with the concept of a retro directive array, in which the rectenna sends a pilot signal to the SPS in order to indicate its position before the power beam is transmitted. This pilot beam is then used to direct the power beam back along exactly the same path as the pilot beam: in the retro directive direction. Emergency procedures should be defined and have to be applied when the beam direction is not contained within the predefined angle of 0.0005°. Technologies to achieve these goals are presently under study.

Microwave Power Transmission Effects on Human Health

Above the centre of the rectenna, the SPS power-flux density will be considerably higher than the currently permissible safety levels for human beings. The ICNIRP (International Commission on Non-Ionizing Radiation Protection) and Japan both apply limits of 50 W/m^2 and 10 W/m^2 for 2.45 GHz and 5.8 GHz, respectively. Established safety limits for microwave exposure are exceeded in an area around and above the rectenna during normal operation of the SPS access would need to be carefully controlled to ensure that environmental safety and health standards are maintained. It should be noted that there are currently insufficient data on specific microwave power-transmission effects on human health, and that standards for this particular application are not sufficiently developed. Taking into consideration the importance of this field, more studies are urgently needed regarding human health and its bioeffects

CONCLUSION

The increasing global energy demand is likely to continue for many decades. New power plants of all sizes will be built. Fossils fuels will run off in another 3-4 decades. However energy independence is something only Space based solar power can deliver. Space based solar power (SBSP) concept is attractive because it is much more advantageous than ground based solar power. 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. Based on current research space based solar power should no longer be envisioned as requiring unimaginably large initial investments. Moreover, space solar power systems appear to possess many significant environmental advantages when compared to alternative approaches to meeting increasing terrestrial demands for energy including necessity of considerably less land area than terrestrial based solar power systems. Though the success of space solar power depends on successful development of key technology, it is certain the result will be worth the effort. Space solar power can completely solve our energy problems long term. The sooner we start and the harder we work, the shorter "long term" will be.

REFERENCES

1) H. MATSUMOTO AND K. HASHIMOTO (EDS.), REPORT OF THE URSI INTER COMMISSION WORKING GROUP ON SPS, URSI, 2006.

2) VAGANOV, R. B., "MAXIMUM POWER TRANSMISSION BETWEEN TWO APERTURES WITH THE HELP OF A WAVE BEAM", JOURNAL OF COMMUNICATIONS TECHNOLOGY AND ELECTRONICS, VOL.42, NO.4, 1997, PP.430-435.

3) GARMASH, V.N., KATSENELENBAUM B.Z., S.S.SHAPOSHNIKOV, S.S., V. N. TIOULPAKOV, AND R. B.VAGANOV, "SOME POSSIBLE METHODS OF THE DIFFRACTION EXPANSION DECREASE", PROC.OF SPS'97, 1997. PP.87-92.

4) SUPPORTING DOCUMENT FOR THE URSI WHITE PAPER ON SOLAR POWER SATELLITE SYSTEMS, 2006

5) P. GLASER, "POWER FROM THE SUN: ITS FUTURE," SCIENCE, 162, 22 NOVEMBER 1968.

6) W. C. BROWN, "SATELLITE POWER STATIONS: A NEW SOURCE OF ENERGY," IEEE SPECTRUM, 10, 3, 1973, PP. 38-47.

7) W. C. BROWN, "THE HISTORY OF POWER TRANSMISSION BY RADIO WAVES," IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, MTT-32, 1984, PP. 1230-1242.

8) US DEPARTMENT OF ENERGY AND NASA, "SATELLITE POWER SYSTEM, CONCEPT DEVELOPMENT AND EVALUATION PROGRAM, REFERENCE SYSTEM REPORT," OCTOBER 1978 (PUBLISHED IANUARY 1979).

9) H. FEINGOLD, ET AL., "EVALUATION OF COMPARISON OF SPACE SOLAR POWER CONCEPTS," IAC-02-R.1.08, IAF, 2002

10) H. MATSUMOTO, N. KAYA, I. KIMURA, S. MIYATAKE, M. NAGATOMO, AND T. OBAYASHI, "MINIX PROJECT TOWARD THE SOLAR POWER SATELLITE - ROCKET EXPERIMENT OF MICROWAVE ENERGY TRANSMISSION AND ASSOCIATED NONLINEAR PLASMA PHYSICS IN THE IONOSPHERE," ISAS SPACE ENERGY SYMPOSIUM, 1982, PP. 69-76.