IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
ISSN: 2278-2834, ISBN: 2278-8735, PP: 59-64
www.iosrjournals.org

Solar Power Satellite

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ABSTRACT— *The concept of placing enormous solar power satellite (SPS) systems in space represents one of a handful of new technological options that might provide large-scale, environmentally clean base load power into terrestrial markets. In the United States, 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). More recently, the subject of space solar power (SSP) was re-examined by NASA from 1995-1997 in the "Fresh Look Study" and during 1998 in an SSP "Concept Definition Study." As a result of these efforts, in 1999-2000, NASA undertook the SSP Exploratory Research and Technology (SERT) program, which pursued preliminary strategic technology research and development to enable large, multimegawatt SSP systems and wireless power transmission (WPT) for government missions and commercial markets (in space and terrestrial). During 2001-2002, NASA has been pursuing an SSP Concept and Technology Maturation (SCTM) [1] program follow-up to the SERT, with special emphasis on identifying new, high-leverage technologies that might advance the feasibility of future SSP systems.*

I. INTRODUCTION

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. In geosynchronous orbit, i.e. 36,000 km (22,369 miles), a Solar Power Satellite (SPS) would be able to face the sun over 99% of the time. No need for costly storage devices for when the sun is not in view. Only a few days at spring and fall equinox would the satellite be in shadow. Unused heat is radiated back into the space. Power can be beamed to the location where it is needed, need not have to invest in as large as a grid.

Electrical power accounts for much of the energy consumed. On the one hand, the major loss of power occurs during transmission, from generating stations to the end users. The resistance of the wire in the electrical grid distribution system causes a loss of 26% to 30% of the energy generated. Therefore, the loss implies that our present system of electrical transmission is 70% to 74% efficient. On the other hand, the generation is done primarily based on fossil fuels, which will not last long (say by 2050).

In 1968, Dr. Peter Glaser introduced the concept of a large solar power satellite system of square miles of solar collectors in high geosynchronous orbit (GEO is an orbit 36,000 KM above the equator), for collection and conversion of sun's energy into an electromagnetic microwave beam to transmit usable energy to large receiving antennas (rectennas) on earth for distribution on the national electric power grid.

The concept of the Solar Power Satellite (SPS) is very simple. It is a gigantic satellite designed as an electric power plant orbiting the earth which uses wireless power transmission of space based solar power.

Space-based solar power essentially consists of three functional units:

A. A Solar energy collector to convert the solar energy into DC (Direct current) electricity.
B. A DC to Microwave converter.
C. Large antenna array to beam the Microwave power to the ground.
D. A means of receiving power on earth, for example via microwave antennas (Rectenna).

The space-based portion will be in a freefall, vacuum environment and will not need to support itself against gravity other than relatively weak tidal stresses.

The major advantages of SBSP are those they are pollution free, 100% replacement for fossil fuels in the near future, elimination of transmission lines, overhead lines and cables as the power can be beamed directly to a particular spot all over the world. No air or water pollution is created during generation.

II. SOLAR POWER SATELLITE (SPS) SYSTEM

2.1Solar Energy Conversion - Solar Photons to DC

Two basic methods of converting sunlight to electricity
have been studied: photovoltaic (PV) conversion, and solar dynamic (SD) conversion. Most analyses of solar power satellites have focused on photovoltaic conversion (commonly known as "solar cells"). Photovoltaic

conversion uses semiconductor cells (*e.g.*, silicon or gallium arsenide) to directly convert photons into electrical power via a quantum mechanical mechanism.

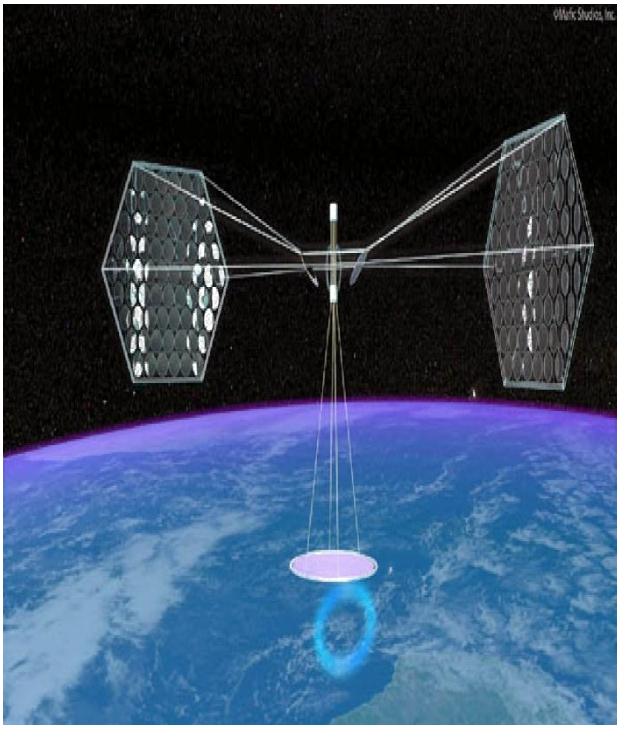

Figure 1 shows a design of Solar Power Satellite (SPS)

Photovoltaic cells are not perfect in practice, as material purity and processing issues during production affect performance; each has been progressively improved for some decades. Some new, thin-film approaches are less efficient (about 20% vs. 35% for best in class in each case), but are much less expensive and generally lighter. In an SPS implementation, photovoltaic cells will likely be rather different from the glass-pane protected solar cell panels familiar to many from current terrestrial use, since they will be optimized for weight, and will be designed to be tolerant to the space radiation environment (it turns out fortuitously, that thin film silicon solar panels are highly insensitive to ionizing radiation), but will not need to be encapsulated against corrosion by the elements. They do not require the structural support required for terrestrial use, where the considerable gravity and wind loading imposes structural requirements on terrestrial implementations.

2.2 Converting DC to Microwave Power

To convert the DC power to microwave for the transmission through antenna towards the earth's receiving antenna, microwave oscillators like Klystrons, Magnetrons can be used. In transmission, an alternating current is created in the elements by applying a voltage at the antenna terminals, causing the elements to radiate an electromagnetic field. [3]

The DC power must be converted to microwave power at the transmitting end of the system by using microwave oven magnetron. The heat of microwave oven is the high voltage system. The nucleus of high voltage system is the magnetron tube. The magnetron is diode type electron tube, which uses the interaction of magnetic and electric field in the complex cavity to produce oscillation of very high peak power. It employs radial electric field, axial magnetic field, anode structure and a cylindrical cathode.

The cylindrical cathode is surrounded by an anode with cavities and thus a radial electric field will exist. The magnetic field due to two permanent magnets which are added above end below the tube structure is axial. The upper magnet is North Pole and lower magnet is South Pole. The electron moving through the space tends to build up a magnetic field around itself. The magnetic field on right side is weakened because the self-induced magnetic field has the effect of subtracting from the permanent magnetic field. So the electron trajectory bends in that direction resulting in a circular motion of travel to anode. This process begins with a low voltage being applied to the cathode, which causes it to heat up. The temperature rise causes the emission of more electrons. This cloud of electrons would be repelled away from the negatively charged cathode. The distance and velocity of their travel would increase with the intensity of applied voltage. Momentum is provided by negative 4000 V DC. This is produced by means of voltage doubler circuit. The electrons blast off from cathode like tiny rocket.

As the electrons move towards their objective, they encounter the powerful magnetic. The effect of permanent magnet tends to deflect the electrons away from the anode. Due to the combined affect of electric and magnetic field on the electron trajectory they revive to a path at almost right angle to their previous direction resulting in an expanding circular orbit around the cathode, which eventually reaches the anode. The whirling cloud of electrons forms a rotating pattern. Due to the interaction of this rotating space chare wheel with the configuration of the surface of anode, an alternating current of very high frequency is produced in the resonant cavities of the anode. The output is taken from one of these cavities through waveguide. The low cost and readily available magnetron is used in ground.

The same principle would be used but a special magnetron would be developed for space use. Because of the pulsed operation of these magnetrons they generate much spurious noise. A solar power satellite operating with 10 GW of radiated power would radiate a total power of one microwatt in a 400 Hz channel width.

2.3 Transmitting Antennae

Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. Power beaming using microwaves has been proposed for the transmission of energy from orbiting solar power satellites to Earth and the beaming of power to spacecraft leaving orbit has been considered. [4][5]
The size of the components may be dictated by the distance from transmitter to receiver distance , the wavelength and the Rayliegh Criterion or diffraction limit, used in standard radio frequency antenna design, which also applies to lasers. In addition to the Rayleigh criterion Airy's diffraction limit is also frequently used to determine an approximate spot size at an arbitrary distance from the aperture.

The Rayleigh criterion dictates that any radio wave microwave or laser beam will spread and become weaker and diffuse over distance; the larger the transmitter antenna or laser aperture compared to the wavelength of radiation, the tighter the beam and the less it will spread as a function of distance (and vice versa). Smaller antennae also suffer from excessive losses due to side lobes. However, the concept of laser aperture considerably differs from an antenna. Typically, a laser aperture much larger than the wavelength induces multi-mode radiation and mostly collimators are used before emitted radiation couples into a fiber or into space.

Ultimately, beam width is physically determined by diffraction due to the dish size in relation to the wavelength of the electromagnetic radiation used to make the beam. Microwave power beaming can be more efficient than lasers, and is less prone to atmospheric attenuation caused by dust or water vapor losing atmosphere to vaporize the water in contact.

Then the power levels are calculated by combining the above parametrers together and adding in gain losses to antenna an due characteristics d the transperecy of the the medium through which the radiation passes. That process is known as calculating a link budget ,
However, the above mathematics does not account for atmospheric absorption which can be A severe damping effect on propagating energy in addition to causing severe fading and loss of Quos.

III. TRANSMISSION

As the electro-magnetic induction and electro-magnetic radiation has disadvantages we are going for implementation of electrical conduction and resonant frequency methods. Of this, the resonant induction method is the most implement able due to the reasons given later. In the distant future this method could allow for elimination of many existing high tension power transmission lines and facilitate the inter connection of electric generation plants in a global scale.

The microwave source consists of microwave oven magnetron with electronics to control the output power. The output microwave power ranges from 50w to 200w at 2.45GHz. A coaxial cable connects the output of the microwave source to a coax-to-wave adaptor. This adapter is connected to a tuning waveguide ferrite circulator is connected to a tuning waveguide section to match the wave guide impedance to the antenna input impedance.

The slotted wave guide antenna consists of 8 waveguide sections with 8 slots on each section. These 64 slots radiate the power uniformly through free space to the rectifying antenna (rectenna). The slotted waveguide antenna is ideal for power transmission because of its high aperture efficiency (>95%) and high power handling capability.

Microwaves are situated on the electromagnetic spectrum with frequencies ranging from 0.3 to 300 GHz.
The energy transmitted by a microwave is very diffusive in nature, such that the receiving antenna area must be very large when compared to the transmitter. Although the use of microwaves to transmit energy from space down to earth is attractive, most part of the microwaves receives significant interference due to atmosphere. Still

there are certain frequency windows in which these interactions are minimized. The frequency windows in which there is a minimum of atmospheric signal attenuation are in the range of 2.45-5.8GHz, and also 35-38GHz; specifically we might expect losses of 2-6%, and 8-11% respectively for these two microwave signal ranges. As the microwave power is beamed towards a particular point (Point to point) using parabolic antennas (Drum antennas) the free space path loss (FSPL) is not in a considerable amount. [6] [7]

Wireless Power Transmission (using microwaves) is well proven. Experiments in the tens of kilowatts have been performed at Goldstone in California in 1975[8] [9] [10] and more recently (1997) at Grand Bassin on Reunion Island. [11]

These methods achieve distances on the order of a kilometer.

IV. GROUND SEGMENT - RECEPTION

Figure 2 shows a design of Earth Receiving Station (Rectenna)

The SPS system will require a large receiving area with a Rectenna array and the power network connected to the existing power grids on the ground. Although each rectenna element supplies only a few watts, the total received power is in the Gigawatts (GW).

A Rectenna may be used to convert the microwave energy back into electricity. Rectenna conversion efficiencies exceeding 95% have been realized. The word ‘Rectenna’ is formed from ‘rectifying circuit’ and ‘antenna.’ A rectifying antenna called rectenna receives the transmitted power and converts the microwave power to direct current (DC) power. The rectenna is a passive element with a rectifying diode, and is operated without any extra power source. The rectenna has a low-pass filter between the antenna and the rectifying diode to suppress re-radiation of higher harmonics. It also has an output smoothing filter. This demonstration rectenna consists of 6 rows of dipole antennas, where 8 dipoles belong to each row. Each row is connected to a rectifying circuit which consists of low pass filters and a rectifier. The rectifier is a GA-As Schottky barrier diode, that is impedance matched to the dipoles by allow pass filter. The 6 rectifying diodes are connected to the light bulbs for indicating that the power is received. The light bulbs also dissipate the received power.

The Earth-based receiver antenna (or rectenna) is a critical part of the original SPS concept. It would consist of many short dipole antennas, connected via diodes. Microwaves broadcast from the SPS will be received in the dipoles with about 85% efficiency. With a conventional microwave antenna, the reception efficiency is still better, but the cost and complexity is also considerably greater, almost certainly prohibitively so. Rectenna would be multiple kilometers across. Crops and farm animals may be raised underneath a rectenna, as the thin wires used for support and for the dipoles will only slightly reduce sunlight, or non arable land could be used, so such a rectenna would not be as expensive in terms of land use as might be supposed.

This rectenna has a 25% collection and conversion efficiency, But rectennas have been tested with greater than 90%.

V. HIGHLIGHTS OF SBSP

The SBSP concept is attractive because space has several major advantages over the Earth's surface for the collection of solar power. There is no air in space, so the collecting surfaces would receive much more intense sunlight, unaffected by weather. In geostationary orbit, an SPS would be illuminated over 99% of the time. The SPS would be in Earth's shadow on only a few days at the spring and fall equinoxes; and even then for a maximum of 75 minutes late at night when power demands are at their lowest. This characteristic of SBSP avoids the expense of storage facilities (dams, oil storage tanks, coal dumps) necessary in many Earth-based power generation systems. Additionally, SBSP would have fewer or none of the ecological (or political) consequences of fossil fuel systems.

5.1 Advantages Of Space Solar Power

1) Unlike oil, gas, ethanol, and coal plants, space solar power does not emit greenhouse gases.
2) Unlike bio-ethanol or bio-diesel, space solar power does not compete for increasingly valuable farm land or depend on natural-gas-derived fertilizer. Food can continue to be a major export instead of a fuel provider.
3) Unlike nuclear power plants, space solar power will not produce hazardous waste, which needs to be stored and guarded for hundreds of years.
4) Unlike terrestrial solar and wind power plants, space solar power is available 24 hours a day, 7 days a week, in huge quantities. It works regardless of cloud cover, daylight, or wind speed.
5) Unlike nuclear power plants, space solar power does not provide easy targets for terrorists.
6) Unlike coal and nuclear fuels, space solar power does not require environmentally problematic mining operations.
7) Space solar power will provide true energy independence for the nations that develop it, eliminating a major source of national competition for limited Earth-based energy resources.

B. Disadvantages Of Space Solar Power

1) Maintenance of SPS is expensive and challenging.
2) Geosynchronous orbit is already in heavy use; could be endangered by space debris coming from such a large project.
3) The size of construction for the rectenna is massive.
4) Transportation of all the materials from earth to space and installation is highly challenging.

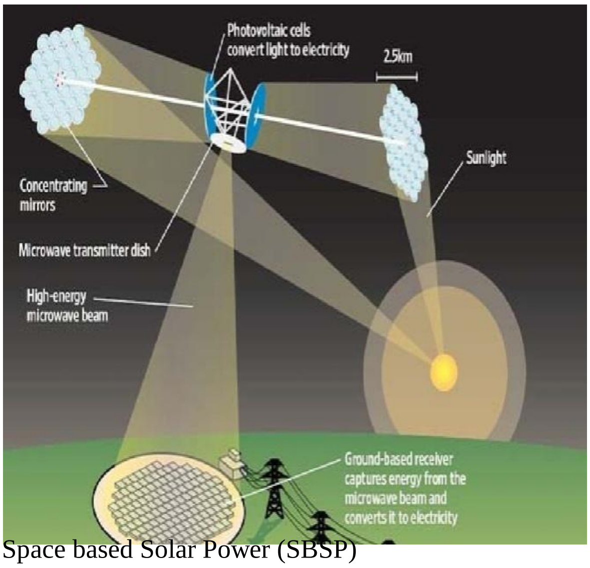

Figure 3 shows a design of Space based Solar Power (SBSP)

VI. 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.

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