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Space Based Solar Power Wireless Transmission

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***Abstract*— The aim of this paper is to analyze advanced solar dynamic space power systems for electrical space power generation and reduction the losses in transmission of energy. Space -based solar power (SBSP) is a system for the collection of solar power in space, to meet the ever increasing demand for energy on Earth. SBSP differs from the usual method of solar power collection in the Earth. At the earth based solar power collection, array of panels are placed in the ground facing the sun, which collects sun's energy during the day-time alone. In SBSP huge solar panels are fitted in the large satellite which collects the entire solar energy present in orbit and beams it down to Earth.. A major interest in SBSP stems from the fact that solar collection panels can consistently be exposed to a high amount of solar radiation. Also this paper analyze the advance methods for reducing the size of antenna at the satellite.**

***Index Terms*— Space-based solar power (SBSP), solar power satellite (SPS), Rectifying Antenna (Rectanna)**

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.

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).

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. [2]

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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 (Rectanna).

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. Procedure for Paper Submission

II. SPACE BASED-SOLAR POWER (SBSP)

Space-based solar power (SBSP) is the concept of collecting solar power in space (using an "SPS", that is, a "solar-power satellite" or a "satellite power system") for use on Earth. SBSP would differ from current solar collection methods in that the means used to collect energy would reside on an orbiting satellite instead of on Earth's surface. Some projected benefits of such a system are a higher collection rate and a longer collection period due to the lack of a diffusing atmosphere and nighttime in space.

Part of the solar energy is lost on its way through the atmosphere by the effects of reflection and absorption. Space-based solar power systems convert sunlight to microwaves outside the atmosphere, avoiding these losses, and the downtime (and cosine losses, for fixed flat-plate collectors) due to the Earth's rotation.

Besides the cost of implementing such a system, SBSP also introduces several new hurdles, primarily the problem of transmitting energy from orbit to Earth's surface for use. Since wires extending from Earth's surface to an orbiting satellite are neither practical nor feasible with current technology, SBSP designs generally include the use of some manner of wireless power transmission. The collecting satellite would convert solar energy into electrical energy onboard, powering a microwave transmitter or laser emitter, and focus its beam toward a collector (Rectanna) on Earth's surface. Radiation and micrometeoroid damage could also become concerns for SBSP.

The solar energy available in space is literally billions of times greater than we use today. The lifetime of the sun is an estimated 4-5 billion years, making space solar power a truly long-term energy solution. As Earth receives only one part in 2.3 billion of the Sun's output, space solar power is by far the largest potential energy source available, dwarfing all others combined. Solar energy is routinely used on nearly all spacecraft today. This technology on a larger scale, combined with already demonstrated wireless power transmission, can supply nearly all the electrical needs of our planet.

Another need is to move away from fossil fuels for our transportation system. While electricity powers few vehicles today, hybrids will soon evolve into plug-in hybrids which can use electric energy from the grid. As batteries, super-capacitors, and fuel cells improve, the gasoline engine will gradually play a smaller and smaller role in transportation — but only if we can generate the enormous quantities of electrical energy we need. It doesn't help to remove fossil fuels from vehicles if you just turn around and use fossil fuels again to generate the electricity to power those vehicles. Space solar power can provide the needed clean power for any future electric transportation system.

III. SOLAR POWER SATELLITE (SPS) WORKING

The initial sizing for the solar power satellite (SPS) was optimized to a 1-km transmitting antenna producing 5 GW of DC power from a receiving antenna (rectenna) approximately 10 km in diameter. There are advantages to a lower power output and a smaller rectenna. Commercial utility companies prefer to integrate lower power levels into their grids. Rectennas smaller than

The 10-km diameter in the reference configuration would make more rectenna sites available.

The purpose of this paper is to investigate the tradeoffs of smaller SPS systems. The end result is a comparison between the costs of smaller systems and those of the 5 GW, 10 km diameter rectenna reference system. The microwave system is reoptimized for each antenna/rectenna configuration. Both the 2.45 GHz reference frequency and a higher (5.8 GHz) frequency are used in the candidate systems. In compliance with the NASA's publication policy, the original units of measure have been converted to the equivalent value in the Systsme Inter- national d'Unit& (SI). As an aid to the reader, the SI units are written first and the original units are written parenthetically thereafter.

A. Solar 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 Method. 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. . 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.

B. 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 and 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 effect 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.

IV. TRANSMISSIONH

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, the wavelength and the Rayleigh criterion or diffraction limit, used in standard radio frequency antenna design, which also applies to lasers.

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.

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.due to their several key advantages over conventional wire and metallic antennas, microstrip antennas have been used for many applications, such as Direct Broadcasting Satellite (DBS) Systems, mobile communications, Global Positioning System (GPS) and various radar systems [1–7]. Their advantages include low profile, light weight, low cost, ease of fabrication and integration with RF devices, etc. They can also be made conformal to mounting structures. However, when they are applied in the frequency range below 2GHz, the sizes of conventional rectangular microstrip patches seem to be too large, which makes it difficult for them to be installed on televisions, notebook computers or other hand-held terminals, etc. Several techniques have thus been proposed to reduce the sizes of conventional half-wavelength microstrip patch antennas. In [8], using high dielectric constant material has been proposed; however, this will lead to high cost and high loss due to the use of high dielectric constant material. Also, poor efficiency due to surface wave excitation is another drawback of this method. Another technique for reducing the size of a micro strip antenna is to terminate one of the radiating edges with a short circuit[4].

V. GROUND SEGMENT-RECEPTION

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%.

VI. ADVANTAGE AND DISADVANTAGE OF SBPS

A. 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.

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.

VII. 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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