Solar Power Satellites and Electrical Charge / Discharge

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Abstract

The Solar Power Satellite (SPS) and the Space Solar Power System (SSPS) have been studied for years as future alternative energy sources when fossil fuel becomes scarce. An SPS collects solar energy in orbit and transmits the energy to various destinations. An SSPS is a total system that includes an SPS and ground facilities to utilize power from the SPS.
JAXA is presently conducting system-level studies of a microwave-based SSPS (M-SSPS) and laser-based SSPS (L-SSPS). The M-SSPS is comprised of solar energy collection mirrors, power generators (PV arrays), and power transmitters (amplifiers and antennas). The size of the primary mirror will be 7km^2, and the total mass will be 10 thousand tons to receive 1 gigawatt of electrical power on Earth. The other major SSPS concept is a laser-based system SSPS (L-SSPS), which uses a laser to transmit power. The M-SSPS requires the use of high voltage to transmit electrical power from the power generator (PV arrays) to the power transmitter to reduce the mass of cables and electrical loss at the cables. The power transmission tube (e.g., a magnetron) also must use high voltage. These high voltage devices may generate electrical charge and discharge. This is one of many technical challenges to be overcome before an SSPS is realized.

1. INTRODUCTION

The Solar Power Satellite (SPS) and Space Solar Power System (SSPS) have been studied for years as future alternative energy sources when fossil fuel becomes scarce. There are many SPS and SSPS concepts. SPS collects solar energy in space and transmits the collected energy to the ground.
Two types of energy transmission are presently being studied, a microwave-based energy transmission system (M-SSPS) and a laser-based energy transmission system (L-SSPS). Illuminating the nighttime region or near-polar region using a large mirror satellite that directs sunlight toward those areas has also been studied. However, a mirror satellite in a low Earth orbit will pass over the area quickly. Sending reflected solar light from a higher orbit is also problematic since solar light is not ideally parallel and therefore it is difficult to focus on a specific area from a great distance.

2. CONCEPTS OF AN SSPS

2.1 Microwave-based SSPS (M-SSPS)

Microwave-based SSPSs have been studied by many researchers for years, and therefore there are many concepts for an M-SSPS.

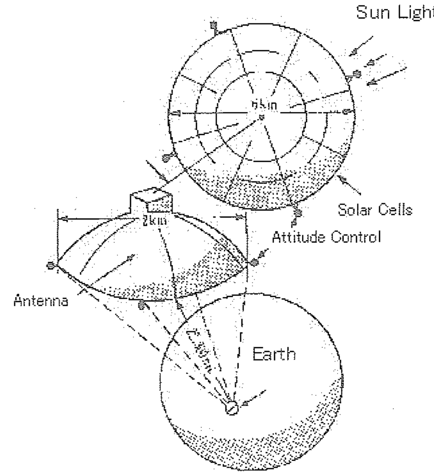

Fig.1 Peter Glaser's SPS concept

Figure 1 illustrates the first SPS concept, proposed by Dr. Peter Graser in 1968. The oil crisis that occurred in the mid-1970s prompted studies of SSPSs. NASA and the Department of Energy (DOE) conducted a feasibility study and proposed the reference system in Fig. 2. It consists of a Sun-looking PV array panel and an Earth- looking microwave antenna.

The PV arrays in these systems must be directed toward the Sun, and the power transmission antenna must be directed toward Earth. Therefore, rotary joints are necessary between the PV array panel and the microwave antenna. The rotary joints are a reliability concern, since a large volume of electrical power must pass through the slip rings at the rotary joints. The mass of cables between each PV cell and the microwave antenna is also immense. Novel concepts that do not include rotary joints have been proposed to satisfy these concerns.

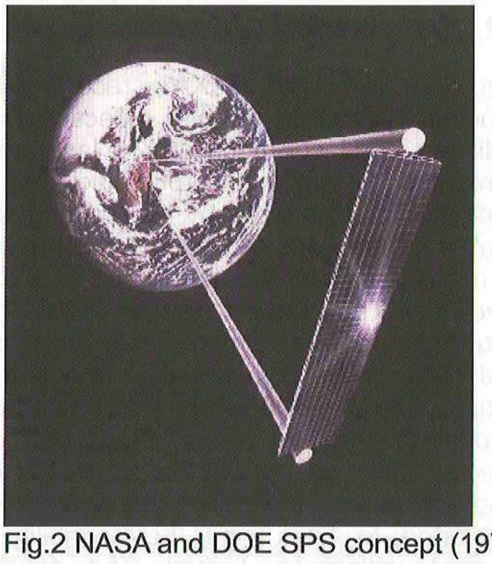
Fig.2 NASA and DOE SPS concept (1979)

Figure 3 depicts the SPS2000, which was proposed in the early 1990s by Japanese researchers at the Institute of Space and Astronautical Science (ISAS). SPS2000 is an experimental SPS to be placed in a low Earth orbit. Its microwave antenna and PV arrays are mounted on a rigid triangular prism. The microwave antenna must be directed toward Earth, while the PV arrays are not necessarily directed toward Earth. Therefore, the power generation / transmission efficiency is unsatisfactory. Several new concepts have been proposed within the last decade to overcome these weaknesses. The new SPS concepts use solar energy collection mirrors, energy converters (PV arrays), and power transmitters.

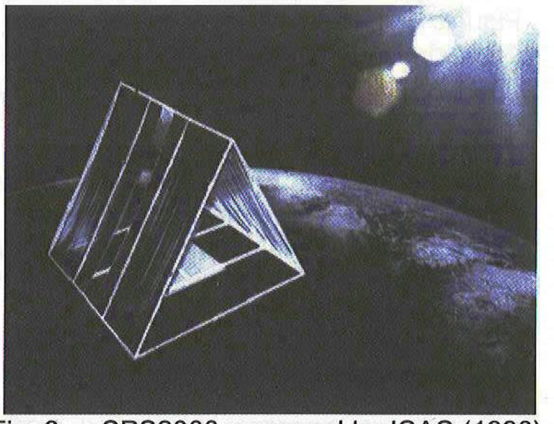
Fig. 3 SPS2000 proposed by ISAS (1990)

Figure 4 presents NASA's SPS concept, the Integrated Solar Concentrator (ISC). A similar concept was proposed by the former NASDA.

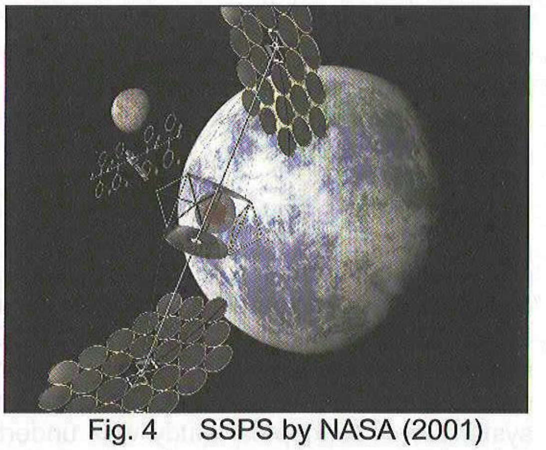
Fig. 4 SSPS by NASA (2001)

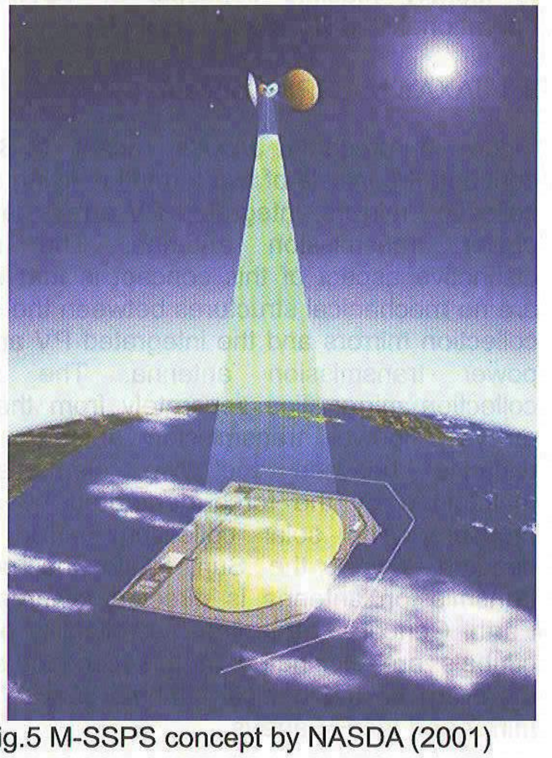
Fig.5 M-SSPS concept by NASDA (2001)

Figure 5 depicts a conceptual model of a 1GW-class M-SSPS consisting of large solar energy collection mirrors, PV arrays, and microwave power transmission antennas. These concepts avoid using rotary joints between the PV arrays and the microwave antenna. However, there are still several areas that require improvement, including the possibility of using gimbals to support the large reflection mirrors.

2.2 Laser-based SSPS (L-SSPS)

Studies of a laser-based SSPS (L-SSPS) are relatively new. Very effective energy conversion from solar energy to the laser is crucial for an L-SSPS with total power transmission efficiency. The laser beam is conventionally generated by electrical power using the PV cells. This makes the total efficiency very low, since the energy conversion ratio of the PV cells is low. Recent technological improvements in direct solar pumping laser oscillation have enhanced the potential for L-SSPSs.

3. JAXA'S SSPS STUDY

JAXA and the former NASDA have conducted SSPS studies for years. The studies include a system-level conceptual study and R&D for individual necessary technologies, such as robotics and wireless power transmission. A system-level conceptual study was undertaken to identify feasible concepts of 1GW-class operational M-SSPSs and L-SSPSs.

3.1 JAXA's M-SSPS Concept

Figure 6 presents JAXA's recent M-SSPS concept. It consists of two formation-flying solar collection mirrors, integrated PV arrays, and a power transmission antenna. The most distinctive aspect of this concept is that there are no mechanical structures between the solar collection mirrors and the integrated PV array / power transmission antenna. The solar collection mirror flies separately from the PV arrays / power transmission antenna. The distance between the two elements is maintained by the force generated by solar pressure. The solar collection mirrors are directed toward the Sun, while the power transmission antenna is directed towards the Earth. Concerns regarding the reliability of the gimbals are eliminated in this concept since there are no mechanical gimbals between the mirror and the PV arrays.

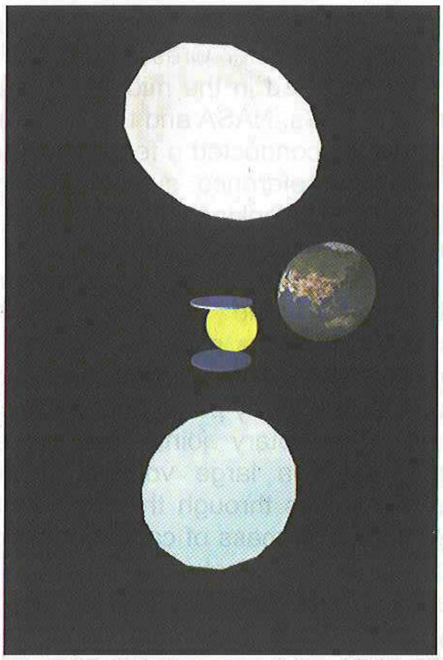

Fig.6 M-SSPS concept by JAXA (2005)

3.2 JAXA's L-SSPS Concept

Figure 7 illustrates JAXA's recent L-SSPS concept. It consists of solar reflection mirrors, radiators, and laser modules. The laser beam is generated by direct solar pumping. The solar energy is concentrated by the solar reflection mirrors to up to one thousand times the energy of natural sunlight and is injected in the laser medium. The laser medium will be a neodymium-doped yttrium aluminum garnet (Nd:YAG) crystal or a similar medium. The shape of the L-SSPS will be determined by the size of the radiator since only a part of the injected solar energy will be converted to the laser beam and the remaining energy will be converted to heat, and the capability of a thermal radiator is limited. The 1GW-class L-SSPS in Fig. 7 will be realized by connecting 100 small L-SSPS satellites.

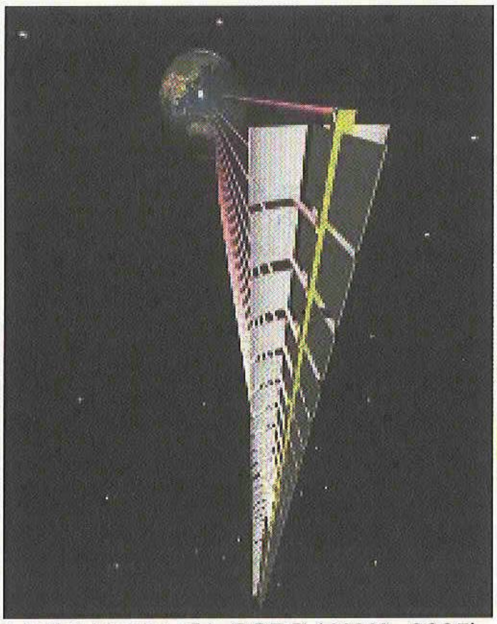

Fig.7 Artist image of L-SSPS (JAXA, 2005)

4. TECHNICAL CHALLENGES FOR REALIZING AN SSPS

SSPSs have been studied for years by many researchers and engineers. However, there are still many technical challenges for realizing an SSPS. Those challenges include the following.

- Developing a low-cost and powerful space transportation system.
- Designing a lightweight SPS.
- Allocating frequency for SSPS energy transmission. (A microwave frequency must be allotted for energy transmission by the SSPS.)
- People's concerns regarding the SSPS, such as environmental effects (e.g., health), must be alleviated.

These technical challenges must be met since the SSPS is a viable alternative energy source of the near future. This paper only addresses the satellite portion of the SSPS.

5. ELECTRICAL CHARGE AND DISCHARGE ON THE SSPS

The electrical charge and discharge on M-SSPSs are important factors. If the PV arrays and the microwave power transmission antenna are separated (such as in Figs. 1, 2, 3, and 4), the electrical energy generated at the PV arrays must be transmitted to the microwave power transmission modules by cables. The total mass of these cables will be significant. An increased cable mass will dominate the total mass of the M-SSPS. Higher voltage (over 1,000 volts) must be used to reduce the cable mass. However, this high voltage will increase the risk of electrical charge and discharge. Another electrical discharge risk exists at the microwave power transmission subsystem. Using a magnetron or other type of tube to generate high-power microwaves requires high voltage to operate the tube, thus increasing the risk of electrical discharge around the tube. An electrical discharge at these subsystems would severely damage the subsystem and the SSPS as well. Extensive research into electrical discharge on an SSPS must be conducted.
Since High voltage equipment will not be used on L-SSPS, electrical charge / discharge will not be so critical like the M-SSPS.

5. CONCLUSIONS

SSPSs have been studied for years by many researchers and engineers. However, there are still many technical challenges to be overcome before realization of an SSPS. Electrical charge / discharge is one of the major technical challenges.

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