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Study of the Solar Power Satellite in NASDA

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Introduction

Energy is essential for daily life, industry and transportation. Demands for the energy are increasing every year. Increasing uses of the fossil fuel (wood, coal, oil and gas) will shorten their future availability. No one can say that we can use the fossil energy forever. Uses of the fossil energy create forest / environmental destruction and global climate change. Uses of fossil energy create CO^2 and will create the greenhouse effect that will produce years-long effects for everyone.

The space solar power satellite (SSPS or SPS) that will transmit energy from space to the Earth has a potential to become an alternative energy sources even though there are many technical and other hurdles to realize it. Dr. P. E. Graser first introduced a concept of the solar power satellite in 1968. Since then, many concepts of the solar power satellites were studied. NASA and DoE (Department of Energy) of U.S.A. conducted feasibility study of the proposed SPS in 1970's. This study was summarized as the so-called 1979 NASA/DoE reference model (see Fig.1). The proposed SPS has the solar array of 5km by 10km wide and a microwave antenna of 1km diameter. The on-ground rectifying antennas (Rectenna) of 10km by 13km in oval axis will produce 5GW of electrical power on ground. This is the baseline or starting point of the study of SSPS that are conducted later. Recent studies of SSPS are to find better solution to realize SSPS. Studies of SSPS in Japan started in 1980's. This paper introduces recent SSPS study activities in Japan.

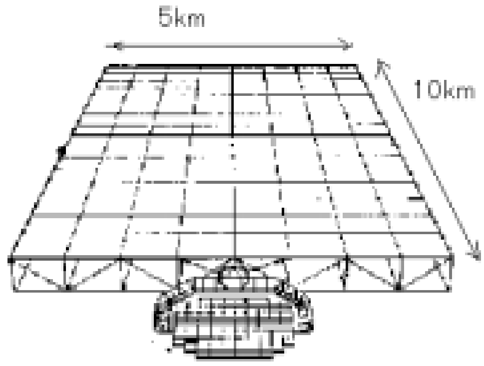

Fig.1 1979 NASA/DoE Reference System

2. Basic idea of SSPS

Basic idea of SSPS is to collect the solar energy in orbit and send it to ground by microwave, laser beam or some other way. In case of sending the energy by microwave, the solar energy must be converted to electrical energy and then converted further to the microwave (see Fig.2).

The on-ground rectifying antenna will receive this microwave beam and convert it into the electrical energy. Major hurdle in this power transmission is how to improve efficiency of converting the solar energy to the electrical energy. Many type of solar cells and other type of energy conversion system are being developed or proposed. Typical energy conversion ratio from the solar energy to the electrical energy is 10% to 30%. Since other conversion ratio such as from the electricity to the microwave, from the microwave to the electricity are much higher than this conversion ratio, the conversion ratio from the solar energy to the electrical energy will mainly decide the size of the space segment (satellite)

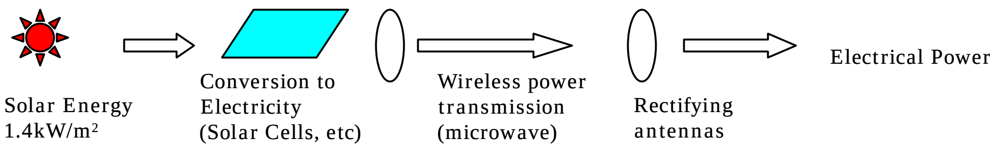

Fig.2 Transmission of the solar energy to the ground

Another promising energy transmission method is to use laser beam. The laser beam will be produced from the solar energy using solid-state laser devices. This laser beam will be collected on ground and will be used to produce electrical energy of other type of energy sources such as hydrogen. Technical challenge of this method is to how to produce laser beam from the solar energy, and how to convert the laser beam to other form of storable or transmittable energy forms.

3. Major SSPS concepts

3.1 NASA/DoE Reference Model

Fig.1 shows 1979 NASA/DOE reference model. The solar energy is converted to the electricity using solar cells / photovoltaic cells. The generated electricity is sent to the microwave antenna. To build this satellite, it was estimated that 500 astronauts must work on this satellite. Mass of the satellite would be 50,000ton. Therefore very advanced space transportation system for cargo transfer and astronauts transfer are required. Another critical problem in design of the satellite was existence of the rotary joint between the solar array panel and the microwave power transmission antenna. Since the solar cells surface must turn to the Sun while the microwave antenna must turn to the Earth, the solar cells and the microwave antenna must be connected by slip rings. However passage of large energy through this rotary joint will produce critical problem in realizing the reliability, since the rotary joint is so critical to send the collected energy to the ground. Therefore, concepts produced later than this are trying to avoid such single failure point.

3.2 Recent NASA's concepts

Study of SSPS in U.S.A. was suspended for more than 10 years after the 1979 NASA/DoE reference model was introduced.

In 19** NASA conducted the Fresh Look Study. In 19** NASA conducted SERT program.

Through these studies, various new SSPS concepts were examined. Several new alternative concepts were derived from these studies. Fig.* is the so-called the Sun-Tower. Fig.* is the so-called the "Sun Tower". Each solar collector and power generator are connected each other by a tether. At the end of the tether, microwave antenna is connected. This system will be launched into a low Earth orbit. If 12 of this type of satellites are launched into the equatorial orbit, each on-ground station that is located near the equator can receive power continuously. However, if this type of satellite is placed in the equatorial orbit, each power collector will be shadowed by other solar collectors / power generators.

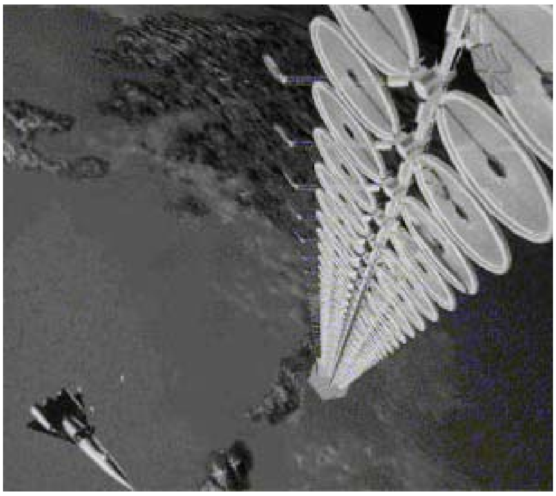

Fig.3 Sun tower SPS

Fig.4 is the so-called "Integrated Symmetric Concentrator. Solar energy is collected by the two large mirrors and is provide to the integrated power generator. The integrated power generators and the rectena are mounted on the Earth looking antenna module. In this configuration, the electrical power does not have to be transferred via any type of the rotary joints.

Another recent NASA's SSPS concept is the Abacus reflector that is shown in Fig.5. A point that characterizes this concept is existence of a rotating microwave beam reflection mirror. The microwave reflection mirror will control direction of the microwave beam, while the solar cells surface turn to the Sun.

Fig.4 Integrated Symmetric Concentrator

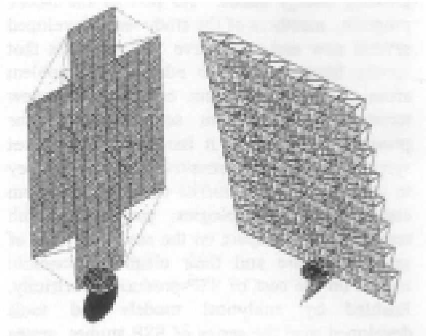

Fig.5 Abacus Reflector

3. Study of SSPS in Japan

Study of SSPS in Japan started in 1980's. Wireless power transmission experiments were conducted in space using rockets (see Fig.6; MINIX / Microwave Ionosphere Nonlinear Interaction eXperiment.).

Fig.6 MINIX experiment (1983)

A group of researchers at ISAS (Institute of Space and Astronautical Science) conducted feasibility study of an experimental solar power satellite named SPS2000 in 1990's. SPS2000 is a straw man mission to clarify the problem areas and for educational purpose. It will be built in low earth equatorial orbit to reduce mission const. 10MW electricity will be received on ground stations located near equatorial nations that are mostly developing countries. Fig.7 shows artist image of the SPS2000.

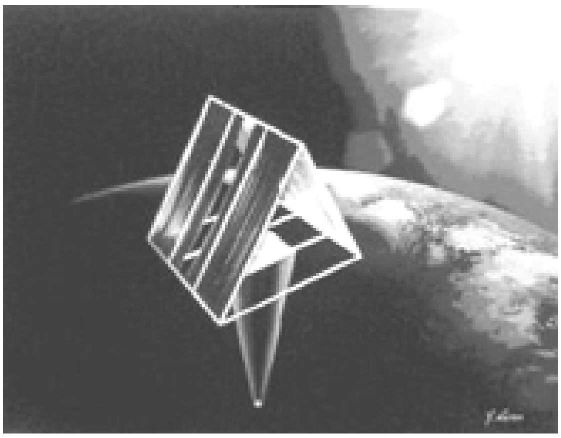

Fig.7 SPS2000 (ISAS)

Ministry on International Trade and Industries (now Ministry of Economy, Trade and Industry) is responsible for country's energy supplies. It conducted feasibility study of SPS in early 1990's and late 1990's. Fig.8 shows MITI's concept of the satellite like 1GW class SPS at GEO that was proposed by MITI in 1992. Fig.9 is another concept of SPS proposed in late 1990's by MIT. Unfortunately, specific R&D activities to realize these concepts are not yet undertaken.

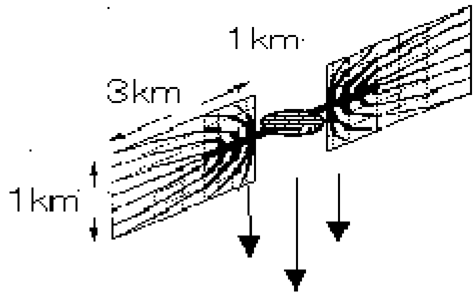

Fig.8 MITI/NEDO's concept of SSPS (satellite type)

Fig.9 MITI's concept of SPS (flat plate type)

3.1 Study of SSPS in NASDA

NASDA started study of the SSPS in 1990's as the next logical step of space activities and payloads of future space transportation system. In this study, the goal was set to realize the 1 GW class operational solar power satellite in the Geo-stationary Earth Orbit in 20 to 30 years. 1GW is an output of a popular atomic power plant. There are several concepts of the 1GW class SSPS. Fig.10 is an example of the concepts. Solar lights are collected by mirrors at the integrated power generator / transmitter. Since there is not a rotational joint that must pass electricity of other material and most of the equipment are existing at the power generator / transmitter, it is easy to build such system by robots.

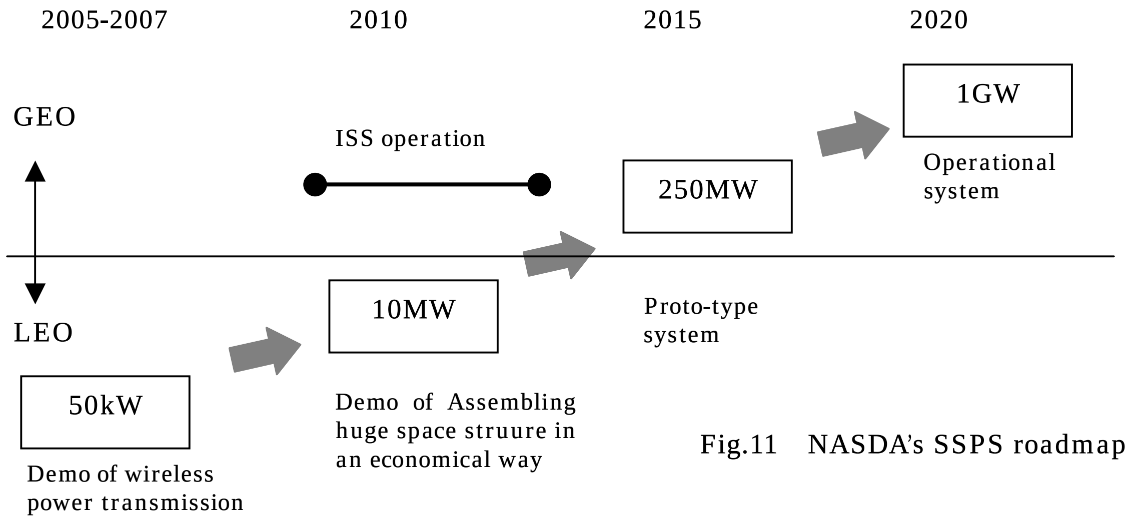

Fig.11 NASDA's SSPS roadmap

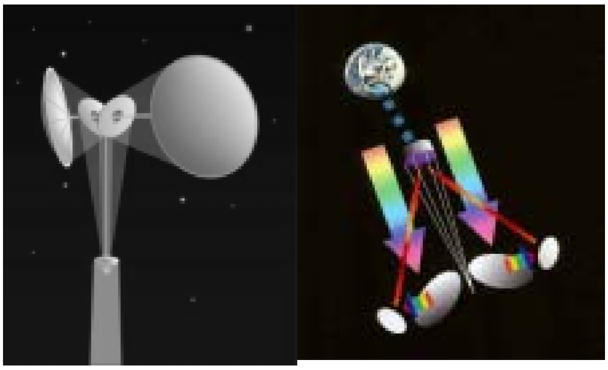

Fig.10 Example of NASDA's SSPS concept

However, still there should be a lot of technical challenges to realize the operational solar power satellite, a road map to realize the operational solar power satellite in 20 years were proposed. The roadmap that is shown in Fig.10 proposes a stepwise development of the solar power satellite. The first step is the demonstration of the wireless power transmission (WPT) and evaluation of environmental effects that may be caused by the wireless power transmission. A satellite with solar paddles and a large phased array microwave power transmission antenna will be build for this mission.

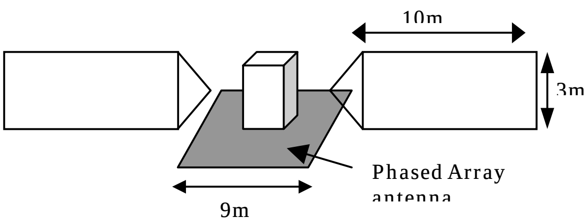

Fig.12 WPT test satellite (NASDA)

The second step of the roadmap is development and verification of technologies to build a huge space structure in an economical way. 10MW class experimental solar power satellite that might be a scale model of the operational solar power satellite will be built using robots in a low Earth orbit. Economical building of the SSPS is essential in realizing the operational SSPS.

The third step is building a 250MW class prototype solar power satellite will be build in the Geo-stationary Earth Orbit. Economical and Efficient space transportation system must be developed to realize this system.

3.2 Development of Technologies

R&D of several SSPS related technologies are underway now. Fig.13 is a breadboard of the integrated power generator / transmitter.

Fig.13 Breadboard model of the integrated power generator / transmitter

The solar cells illuminated by simulated solar lights (lumps) generate electricity. The phased array antenna generates the microwave beam whose direction is controllable. The rectifying antennas generate DC power and provided to LED lights those are co-located with the rectifying antenna.

Fig.14 is a laboratory model of the SSPS structures and three-legs walking robot that can walk on the SSPS structure. Preparations of experiments are underway now and the results will be reported later. We are now also preparing a concept of the second step in-orbit technology demonstrations whose mission is to demonstrate assembling huge space structure in an economical way.

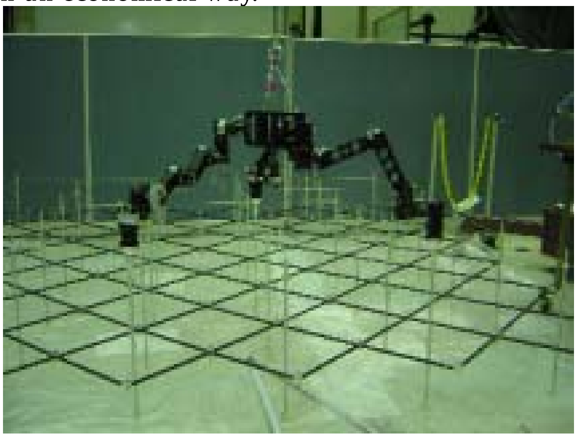

Fig.14 simulated SSPS structure and walking robot

4. Conclusions

This paper introduced activities of SSPS studies being conducted in US and Japan. Various concepts of SSPS were being proposed. However actual R&D activities to realize or at least clarify various problems are not being conducted widely. NASDA is now studying SSPS concepts and its precursors. A concept of the experimental satellite to demonstrate the wireless power transmission is proposed. Concept of experiments on or near the international space station to verify technologies to assemble a huge space structure in an economical way is also underway. A robot test bed to verify robotic assemble of space structure is also being conducted. Results of these activities will be reported soon.

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