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FEASIBILITY STUDY OF MULTI-BUS TETHERED-SPS

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ABSTRACT

Tethered-Solar Power Satellite (Tethered-SPS) consists of power generation/transmission panels suspended by tether wires. The most important feature of the Tethered-SPS is that it is constructed by perfectly equivalent power generation/transmission units. Each unit panel, 100 m x 95 m, is suspended by four 5 km-tether wires deployed from a bus unit. The weight and output power of the unit SPS are 42.5 MT and 2.1 MW, respectively. The engineering studies have been conducted to design the power generation/transmission panel and to show how to deploy the panel. In addition to the engineering research, two major environmental issues, the effect of hyper-velocity impact of the debris or meteoroids and the interaction of the solar cell array with the ambient plasma, have been studied. The engineering studies have shown that the power generation/transmission panel is technically feasible using the near-term technologies. The environmental studies have shown preliminary guidelines to design the power generation/transmission panel.

1. INTRODUCTION

The SPS concept was first proposed by Peter Glaser in 1968, followed by NASA/DOE studies in the 1970's. Since the early investigations, various types of SPS have been proposed in Japan, the United States, and Europe. The most difficult point in the system configuration of the SPS is to direct the large solar panel to the sun while the transmitting antenna, another large structure, is pointed to the rectenna on the ground. This requires a movable or rotating mechanism in the system configuration, such as a rotary joint or rotating mirrors. However, there are no practical technologies for the rotary joint mechanism without a serious power loss. The rotating mirrors require complicated configuration and almost infeasible technologies for the attitude control and stabilization of the rotating large thin-film structure. Furthermore, the movable system has a fatal problem to be damaged by a single point failure which could lead to a total loss of the SPS function.

In order to avoid the difficulties associated with the sun-pointing SPS, ISAS SPS research group has investigated earth-pointing SPS; SPS-2000 in 1990's [1] and recently Tethered-SPS [2-4]. The Tethered-SPS, consisting of a power generation/transmission panel suspended by tether wires, has been studied for 5 years under coordination with USEF (Institute for Unmanned Space Experiment Free Flyer) and researchers from Kyoto University, Hokkaido University, Kanazawa University, Shizuoka University, Tokyo Metropolitan University, and

NICT (The National Institute of Information and Communications Technology). Since this system does not track the sun, the total power efficiency is 36 % lower than that for the sun-pointing type SPS even when the solar cells are attached to both sides of the panel. However, the simple, technically feasible, and practical configuration resolves almost all the technical problems in the past SPS models. Figure 1 shows a unit of Tethered-SPS, in which a power generation/transmission panel of 100 m x 95 m is suspended by four 2~10 km tether wires extended from a bus system. The weight is about 42.5 MT. The unit has a power transmission capability of 2.1 MW. The units are connected to form a larger SPS as shown in Fig.2, depending on user requirements. 1 GW-class SPS can be constructed by 25 x 25 unit assembly.

This simple and flexible configuration has many advantages, as summarized below;

(1) Since the attitude is stabilized automatically by the gravity gradient force, no active attitude control is required.

(2) There is no moving structure, that makes the system highly robust and stable. Especially one-point failure mode peculiar to the rotary mechanism is excluded.

(3) The system is composed of equivalent units, that enables the phased construction and leads to easy integration and maintenance.

(4) The unit consists of equivalent power generation/transmission modules, that enables low cost mass production.

(5) There is no wired signal/power interface between the modules, that leads to easy deployment of the unit panel.

(6) Active thermal control is not required because of uniform distribution of the transmitting power.

(7) A scale model of the unit of the Tethered-SPS can be used for the demonstration experiment on the ground and in orbit in the near future, that assures an evolutional scenario for the SPS development from the initial demonstration to the commercial SPS.

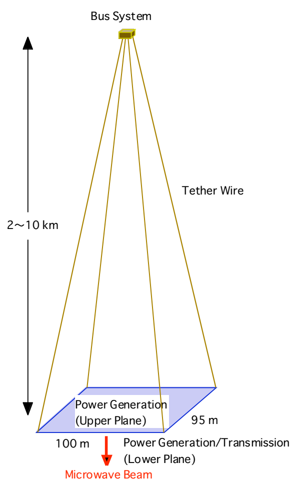


Fig.1 A unit of Tethered-SPS.

2. CONSTRUCTION SCENARIO

The over all construction scenario is illustrated in Fig.3. Each unit cargo (10mx5mx3.8m, 42.5MT) is transported from the ground to the low earth orbit by reusable launch vehicles (RLV). The cargo is transferred to the orbit transfer vehicle (OTV) in the low earth orbit around 500 km and transported to the geo-stationary orbit. Delta-V required for the transportation is 4,500 m/s. To minimize the degradation of the solar cells by the trapped energetic particles in the radiation belt, the cargo will be contained in a radiation shield vessel. If we use a 200 MT OTV equipped with an electric propulsion of 80 N thrust, the cargo is transferred to the geo-stationary orbit in 3-4 months. The unit of Tethered-SPS is deployed

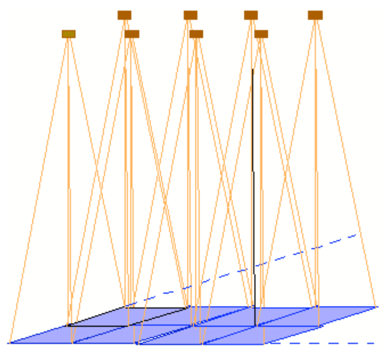


Fig.2 Integration of Tethered-SPS units by connecting panels.

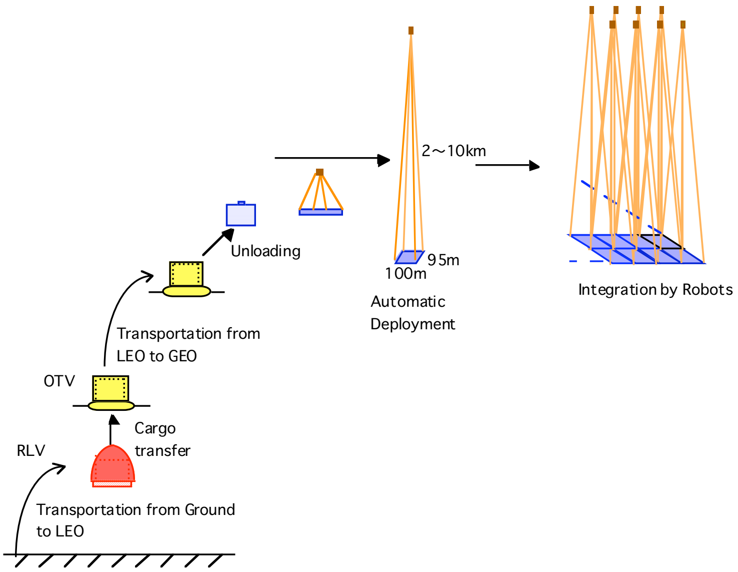


Fig.3 Transportation and construction scenario of Tethered-SPS.

automatically in the geo-stationary orbit. After the performance test of the unit is completed, it is integrated to the sub-panel SPS by connecting the panels and bus systems. Once the sub-panel SPS consisting of 25 units of Tethered-SPS is constructed, it is integrated to the SPS main body by connecting the panels to each other. A combination of a sheet magnet and a steel plate together with a guide mechanism is considered for the connecting and latching mechanism. Docking assistant robots which are manipulated from the ground control center will be used for the integration. The SPS function of the main body can be verified intermittently during the construction phase from the low power to the full power. After completion of construction, any unit in trouble can be unconnected and removed from the main SPS for maintenance, and a new unit can be installed for the wrong one.

3. ENGINEERING STUDIES

3.1 Design of Power Generation and Transmission Module

The power generation/transmission unit consists of 3800 equivalent power modules. In each power module, the electric power generated by the solar cells is converted to

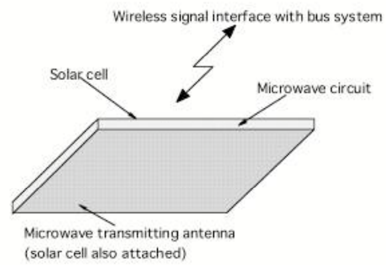


Fig.4 Configuration of Power generation/ transmission module.

the microwave power and no power line interface is required between the modules. Figure 4 shows the configuration of the power module. The power module has thin film solar cells both on the upper and lower planes. The microwave transmitting antennas are on the lower plane. The module contains a power processor, microwave circuits, and their controller. Figure 5 illustrates the block diagram of the module. Each module transmits a microwave power of 555 W constant (power storage type). The weight of the module is 10.6 kg. A laboratory test model, shown in Fig.6, was fabricated and tested to study the configuration of the power generation/transmission module, which consists of solar array panel, a battery, a microwave oscillator, an amplifier and 4 antennas. It transmits 1 W microwave

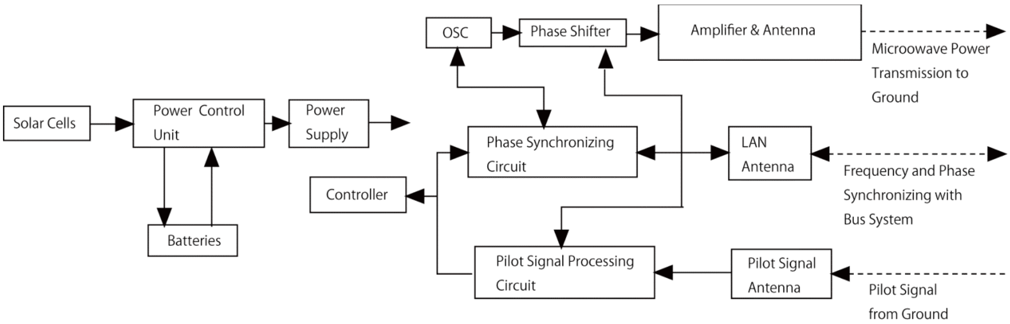


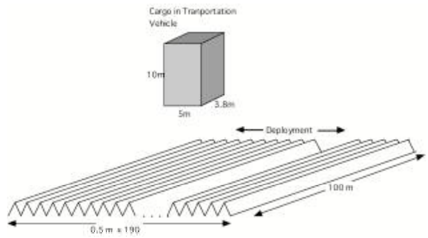
Fig.5 Power generation/transmission module.

Fig.6 Laboratory test model of the power generation/transmission module. left: solar array. right: microwave circuits and antenna.

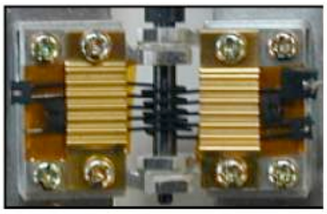
power at 2.45 GHz, which can be used as an educational demonstrator for publicity together with a rectenna.

3.2 Panel Deployment

Since all modules are controlled by the wireless LAN system, there is no wired signal interface between the power modules. The 3,800 structural panels consisting of 10 power modules each are folded in a block cargo when it is transported in the transportation vehicle from the ground to the orbit. Figure 7(a) illustrates how to deploy the cargo to the flat panel. Since there need a huge number of actuators to deploy the module panels, the deployment mechanism must be simple and light-weight. The SMA (Shape Memory Alloy) plate or coil that can be activated by heat is one of the potential candidates for the expedient actuator (Fig.7(b)). A deployment experiment using the SMA coils has been conducted for the 4x8 miniature panels (23cm x 11cm each) as shown in Fig.7(c). It has been demonstrated that a combination of the SMA actuators and magnets works quite well for the panel deployment and latch.



(a) panel deployment



(b) SMA actuator

(c) demonstration experiment

Fig.7 Demonstration of deployment of 4x8 miniature panels using SMA coils.

4. ENVIRONMENTAL STUDIES

There are two major environmental issues associated with the SPS; impact of space debris or meteoroids onto the SPS structure and plasma interaction with solar cell array.

4.1 Hyper-velocity Impact

The impact damage by space debris or meteoroids has been studied by colliding a high-speed projectile to the thin-film structure simulating thin film solar cell. The impact experiment was conducted by a rail-gun accelerator at ISAS. The experimental results have shown that the damage of the thin film structure was typically 10 times larger than the size of projectile at 4-7 km/s. It was also found that the plasma generated at the impact propagated forward in a spherical shape, but propagated along the film sheet in the rear side, as shown in Fig.8. These results are used in designing the configuration of solar cells and sub-array antenna units to minimize the loss of SPS function.

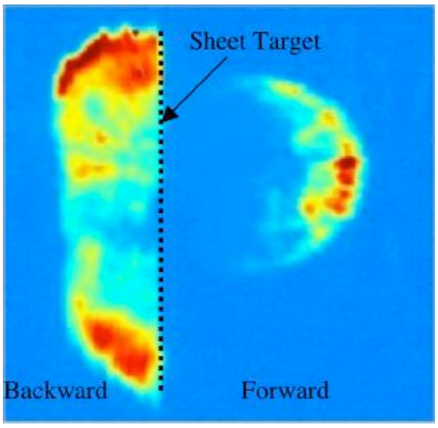


Fig.8 Propagation of impact plasma (right: forward propagation in spherical shape, left: propagation in rear side along the sheet target).

4.2 Solar Array Plasma Interaction

Current-voltage characteristics of array electrodes on dielectric material have been studied in laboratory plasma [5]. This configuration simulates the interaction between the inter-connectors of the solar array and the space plasma. It has been found that the charging effect and secondary electrons of the dielectric material play an important role in collection of the electrode current. In the array configuration, the current of each electrode was generally suppressed as compared with that of single electrode, but a rapid enhancement of the electrode current was observed when spacing of the electrodes was less than a critical value as shown in Fig.9. These results show an existence of the upper limit of the array voltage that depends on the array configuration and the dielectric material.

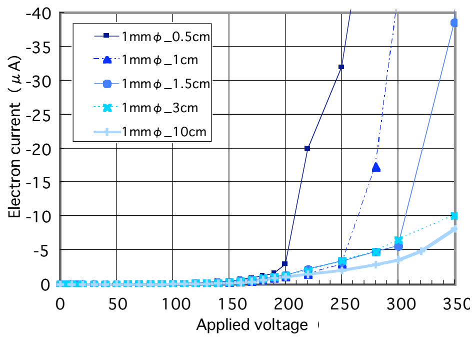


Fig.9 Dependence of current-voltage characteristics on electrode spacing (0.5cm-10cm). The size of the electrode is 1mm diameter. Enhancement in electron current is observed when the spacing of the electrode is equal to or less than 1.5 cm.

5. CONCLUSION

The Tethered-SPS are studied in the engineering and environmental aspects. The construction scenario has been generated based on the future but plausible technologies. The power generation/ transmission panel was designed and tested partly to demonstrate the electrical performance. The method to deploy the panel in two dimensions was tested using the miniature panels with SMA actuators. These engineering studies have increased the technical readiness for the Tethered SPS. The results obtained in the laboratory experiments on the hyper-velocity impact and solar array plasma interaction will be used to establish the design guidelines for the power generation/transmission panel.

References

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