EQUATORIAL COOPERATION FOR SPS 2000 RECTENNAS

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Introduction

As part of the work currently in progress for the "SPS 2000" solar power satellite pilot-plant system design project, field research is now under way in countries around the equator. The objectives of this fieldwork are to identify potential sites for receiving antennas, and to establish a network of researchers in these countries to collaborate on the design of the system. Although many details of the satellite design have yet to be finalized, this equatorial field research has become necessary since, like any energy system, the requirements of the intended users are an essential input to the system design. In addition, it is not possible to evaluate the overall costs and benefits of the project without detailed plans for the ground systems and their utilization. At present plans for rectennas in each country are at an early stage, but as work progresses the role of the equatorial countries in the project is expected to grow.

SPS 2000 concept

The initial objective of the planners of the SPS 2000 system was to design a realistic SPS that could be built and operated in the near future (1). Satellites today typically have solar arrays of the order of 10 KW output; terrestrial electricity generation systems have outputs of 100s of MW. 10 MW was chosen as being large enough to be of interest to electric utility companies, but small enough to be realistic. To generate 10 MW nearly 10 hectares of thin-film sola-cells will be used.

As an experimental system it is necessary to limit the overall cost, and so it was decided to place the satellite in low Earth orbit at 1100 km altitude, which is relatively free of orbital debris. Not being in stationary orbit, the satellite can deliver power to receiving antennas ("rectennas") on Earth only intermittently. However, by using an orbit above the equator power can be delivered to the same rectennas on every orbit.

In order to provide a continuous power supply to users, an energy storage system will be needed at each rectenna, which will deliver some 100 KW to the local community. By chance, many people living near the equator have no access to electricity, and even 100 KW would be sufficient to provide an initial supply to some hundreds of homes.

In order to minimize the use of expensive space technology the satellite will be passively stable, using gravity-gradient stabilisation, and there will be no rotating joint between the solar arrays and the transmitting antenna. Instead the solar arrays will be supported on 2 sides of a saddle roof more than 300 meters square (although this doubles the solar array area).

The microwave power intensity in the beam will be no more than 10 W/sqm in the center of the beam, which is within the internationally accepted standard for microwaves leaking from microwave ovens, which use the same frequency as SPS 2000 of 2.45 GHz. Because of the low intensity in the beam, the rectenna area will need to be of the order of 1 square kilometer. However, since the rectenna surface will be similar to wire mesh, sunlight will pass through it, and the land beneath it can be used for agriculture.

The current objective for the ground system is to plan rectennas in as many equatorial countries as possible, in order to achieve the maximum utilization of the power generated. This will also maximize the range of experience of utilizing microwave energy from space - in terms of different countries, climates, and means of utilization. In addition, since the cost of each rectenna will be much less than the cost of building and launching the satellite, this will not add greatly to the total cost of the system. The need for rectennas in equatorial countries makes SPS 2000 an interesting project involving international cooperation between Japan and a range of countries at differing stages of economic development (2, 3, 4, 5). The current status of the project is summarized in the SPS 2000 Home Page (6), in a number of papers (1, 7, 8, 9), and in the project newsletters (10, 11).

Siting Constraints

There are a number of constraints on the selection of rectenna sites.

a) West-east separation

The microwave beam from the satellite can be steered over a range of +/- 30 degrees west-east. Consequently, if the maximum output is required at each rectenna, neighbouring rectennas should be separated by 1200 km or more (though this may not be appropriate at all sites). Since much of the equator lies in the sea, there is a practical limit of perhaps 10 rectennas in total.

b) Equatorial region

Orbiting above the equator, the satellite can transmit to rectennas only within a few degrees of the equator. Consequently only equatorial countries are candidates for rectenna sites.

c) Sufficient demand

There must be a community near the rectenna for whom a supply of some 100 KW of electricity would be useful. In places where there is currently no supply, this should be sufficient for some hundreds of homes. Depending on local needs it may suffice for thousands of homes (3, 12).

d) Land use plan

In cases where the land beneath the rectenna is not waste-land, there is a need for the utilization of this land to be planned in parallel with plans for the rectenna and power distribution system.

e) Multi-national

In order to maximise the value of the project for SPS research it is desirable to site rectennas in as many different countries and climatic regions as possible.

f) Popular support is essential at several levels. As the first SPS ever to be built and operated, the popular reaction to SPS 2000 may be of critical importance in creating a supportive popular view of this new energy source.

i) Local support is necessary from those living in the vicinity of the rectenna, who will receive power supplies from it.

ii) National political support is necessary for each equatorial country to participate in this international project, and for their utilization of this new energy source.

iii) Equatorial countries' support, both collective and mutual, will be helpful since the project will involve many of the countries around the equator. The newsletter "Equatorial Times" has been started in order to facilitate the growth of cooperative ties between the countries involved (11).

iv) International support is necessary for such matters as electro-magnetic frequency allocation, which is governed by the International Telecommunications Union (ITU). For example, in case of problems of electro-magnetic interference, the solution should be sought through the ITU.

Research Partners

Four equatorial countries have been visited to date, Tanzania, Papua New Guinea, Brazil and Indonesia. In each country contacts have been made with a range of government departments; agreement has been given in principal to the siting of a rectenna; potential rectenna sites have been visited; agreement has been reached to carry out further studies together: and international links between researchers will be extended as resources permit.

In addition, in each equatorial country partners have been found who will take responsibility for research collaboration during the current preliminary phase. These partners are as follows:

1) University of Dar es Salaam, Faculty of Engineering in Dar es Salaam, Tanzania;
2) UNITECH, Department of Electrical and Communication Engineering in Lae, Papua New Guinea;
3) Brazilian Space Agency (AEB), in Brasilia, Brazil; and

4) Satya Wacana Christian University, Faculty of Engineering, Department of Electronics in Salatiga, Indonesia.

Until it is decided that the project will go ahead, the amount of effort that can be given to preparatory rectenna design work is necessarily limited. However, unless this work is timely, it will not be possible to assess the overall value of the SPS 2000 system. Topics requiring study at this preliminary stage include such matters as deciding the voltage at which power would be handled within the rectenna; designing the rectenna support structure; designing the user network to distribute some 100-200 KW to hundreds of homes; and estimation of the costs of the system. Some of this work can be carried out as student projects. An important parameter for the design of each rectenna system is the amount of energy that will be received at the rectenna during each satellite pass; this is currently being studied in Japan (12). Current plans for future field research visits include Ecuador, Maldives, Malaysia and Kiribati.

Potential Costs and Benefits

The SPS 2000 satellite is being designed to have costs substantially lower than other satellites. The target for the capital cost of the satellite is to be comparable to that of photovoltaic power plants on Earth, or roughly ¥10 billion (US$100 million). At present the estimated cost is some 2 or 3 times this. Provided that the overall system is expected to achieve its objectives, this may be tolerable for a first pilot plant.

The single major cost of the SPS 2000 project is expected to be the cost of launching the satellite into Earth orbit in separate modules which will deploy automatically. Using high-priced expendable launchers, this would be many times the cost of the satellite itself. However, if low launch costs can be achieved, for example by using Proton launchers from Alcantara, or one of the reusable launch vehicles currently being planned in the USA and Japan, the cost of the SPS 2000 project should be some ¥ tens of billions (US$ hundreds of millions). This would be similar to the cost of a number of other experimental satellites that have been developed in the past, or a few % of the annual expenditure by governments in the advanced countries on energy research or space research. As such it should be considered as a candidate for funding.

Balancing the cost of the SPS 2000 project would be the wide range of benefits, both local and global, which it would provide. First, it would have the benefit of demonstrating and testing SPS as an energy source for Earth, in a framework of international collaboration between advanced and developing countries - which would continue as progressively more advanced systems are built and put into operation. Although the concept of SPS was put forward as long ago as the 1960s, even before Apollo 11, it has never been demonstrated. As a result SPS is still commonly overlooked in discussions of the energy problem facing humans in coming decades. Demonstrating its feasibility will change this fundamentally, making it a real candidate for further consideration.

SPS 2000 would have benefits for the engineers who design both satellite and ground stations, in the form of the data that will be amassed through carrying out the launch, assembly and operation of the SPS 2000 satellite, and the planning, construction and operation of the rectenna systems.

It would have benefits for the local communities around the equator, comprising several thousand people in total, who will be supplied by SPS 2000, and who are among the more than 1 billion people around the world who still do not have access to electricity. Some of the advantages of SPS as a future energy source for developing countries have been described elsewhere (13), and SPS 2000 and its successors would demonstrate these. Due to their low land and labour costs, rectennas in developing countries will be low-cost, giving them an advantage in bidding for future supplies of microwave energy from space (8).

SPS 2000 would have benefits also for the world electricity supply industry, in the form of a 10 MW SPS pilot plant enabling them to perform a wide range of experiments on this new energy system (15). Although the power supply available to consumers will be of the order of 100 kw, the power delivery to the rectenna will be some 10 MW, which is large enough to be of interest as a genuine power station. To date, although electricity companies have contributed to research on wireless power transmission, the space industry have still not provided a realistic image of a future SPS system on which electricity companies can base plans. SPS 2000 will fill this gap, and will enable electricity companies to include SPS as an option in their future plans.

Summary

In the 1970s the "first generation" of SPS studies clarified a number of issues concerning the potential of SPS to become a major new energy source for Earth, including technical, environmental and legal issues. However, those studies failed to generate sufficient momentum for the research to continue, or for a solar power satellite system to be realized.

It is hoped that the very different and characteristic international approach of the present SPS 2000 project, embodying a unique partnership between Japan and the equatorial countries, will succeed in creating the momentum of international public support that is needed in order to build the first SPS "pilot plant" to demonstrate the feasibility of this new energy source. Once started successfully, the demand for microwave power from space delivered to terrestrial receivers will grow, creating a growing commercial market for the output of successive generations of solar power satellites, particularly in developing countries (8).

Limitless and environmentally benign, orbiting satellites carrying large areas of solar panels have the potential to provide a substantial part of the energy that humans will need in coming decades as economic growth continues around the world. But this will not be possible until power delivery from space to Earth has been proven to be feasible by building and operating a pilot-plant. Provided that the detailed project design gives confidence that it will achieve its objectives, SPS 2000 would seem attractive as a path-breaking project which combines the energy and space sectors in a unique international partnership.

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