THE SATELLITE SOLAR POWER STATION

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ABSTRACT

The feasibility of power production on Earth by means of a satellite solar power station is discussed. The status of technology to achieve solar energy conversion, microwave generation, transmission and rectification and transportation to synchronous orbit is reviewed, and costs for the system and components are presented.

INTRODUCTION

The concept of a satellite solar power station (SSPS) was first presented as an alternative method for the production of energy five years ago.[1] Since then, the energy crisis experienced in the technologically advanced countries has intensified because of the increasing use of energy and the demands for a clean environment. Thus, it is appropriate to evaluate the present status of the SSPS and to ascertain progress made toward the realization of its potential.

An assessment of the feasibility of the SSPS concept has shown that it is worthy of consideration as an alternative method of energy production. Its development can be realized by building on scientific realities, an existing industrial capacity for mass production, and demonstrated technological achievements.

PRINCIPLES OF A SATELLITE SOLAR POWER STATION

Figure 1 shows the concept and Figure 2 the design principles for an SSPS. Two symetrically arranged solar collectors are used to convert solar energy directly to electricity by the photovoltaic process, while the satellite is maintained in synchronous orbit around the Earth. The electricity is then fed to microwave generators incorporated in a transmitting antenna located between the two solar collectors. The antenna accurately directs the microwave beam to a receiving antenna on Earth where the microwave energy is efficiently and safely converted back to electricity. The solar collector is pointed toward the sun to within ±1 degree while the antenna maintains a pointing accuracy of ±1 minute. Electronic phase shifting provides beam control to 1 arc-second at the receiving antenna. There are no moving parts, except for joints which allow the antenna to rotate with respect to the solar collector to maintain the required attitude.

An SSPS can be designed to generate electrical power on Earth at specific levels ranging from about 2,000 to 15,000 megawatts. Over this range of power output, the orbiting portion of the SSPS exhibits the best power-to-weight characteristics. Reaction control systems will be required for attitude control purposes to overcome orbit-disturbing influences such as the gravitational effects of the sun and the moon, solar pressure, and the eccentricity of the Earth. A space transportation system based on a reusable space shuttle and an ion engine-propelled space tug will be required to place the SSPS into synchronous orbit at orbital locations of 123° West and 57° East. The microwave beam permits all-weather transmission so that full use can be made of the nearly 24 hours of available solar energy. Power can be delivered to most desired geographic locations with the receiving antenna placed on land or on platforms over water near major load centers.

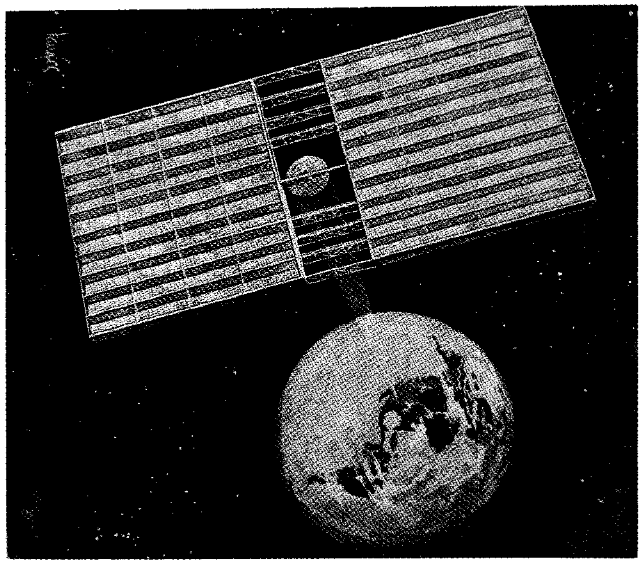

FIGURE 1
CONCEPT FOR A SATELLITE SOLAR POWER STATION

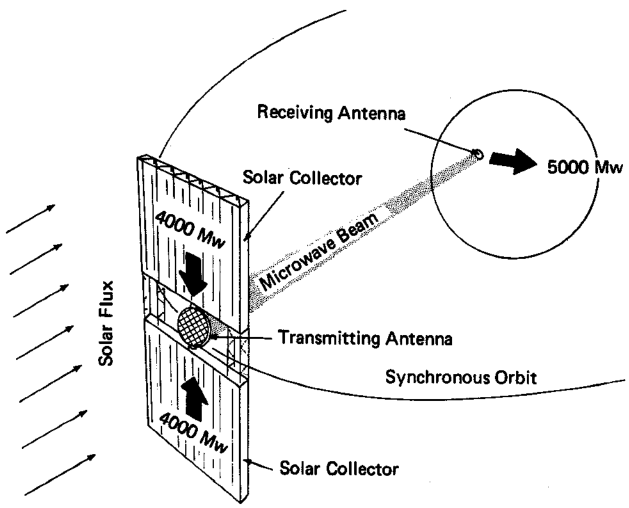

FIGURE 2
PRINCIPLES OF A SATELLITE SOLAR POWER STATION

SOLAR ENERGY CONVERSION

Single-crystal, silicon solar cells can be used for photovoltaic conversion of solar energy into electricity.[2] Such cells have already reached efficiencies of 16% for use in communication satellites and efficiencies of 20% appear to be achievable. A solar cell array can be produced from 50-micron thick silicon solar cells assembled in a blanket between thin plastic films with electrical interconnection between individual cells obtained by vacuum-depositing metal alloy contact materials. Solar energy-concentrating mirrors are arranged to form troughs, with the solar cells forming the bottom part of the trough. Thus, a smaller area of solar cells is required to achieve the same electrical power output leading to substantial weight and cost reductions.

Major cost reductions for the silicon solar cells can be projected, based on the continuous production of ribbons of single-crystal silicon. With improved assembly techniques and mass production, the solar collector costs for the SSPS are projected to be about $310 per kilowatt.

Solar radiation damage will cause a logarithmic decay of solar cell effectiveness. Improvements in radiation-resistant solar cells indicate that a 30-year minimum operation lifetime for the SSPS can be achieved. After this period, normal operational effectiveness can be restored by adding a small area of new solar cells. Thus, there is no absolute time limit on effective SSPS operation. In synchronous orbit, the solar collector will be subjected to the impact of micrometeoroids leading to an estimated 1% loss of solar cells during a 30-year period.

MICROWAVE POWER GENERATION, TRANSMISSION, AND RECTIFICATION

Considerable experience has been accumulated in high-power microwave generation, transmission, and rectification.[3] The microwave generator design is based on the principle of a cross-field device. The cathode and anode of the microwave generator are designed to reject waste heat to space with extended surface radiators. The output of an individual microwave generator can range from 2-5 kilowatts; the weight will be a fraction of a pound per kilowatt. A series of microwave generators are combined in a subarray which forms part of the transmitting antenna. Each subarray is provided with an automatic phasing system so that the individual antenna-radiating elements will be in phase. These subarrays are assembled in a slotted-waveguide, phased-array transmitting antenna about 1 kilometer in diameter to obtain a microwave beam of the desired power density distribution. A master phase control actuated by a pilot signal beamed from the center of the area occupied by the receiving antenna regulates the phase of the microwave transmitted by each subarray. This phase control approach assures that the beam cannot be directed either accidentally or deliberately toward any other location but the receiving antenna. This inherent fail-safe feature of the microwave transmission system is backed by switching devices which can open-circuit the solar cell arrays to interrupt the power supply to the microwave generators. The cost of the microwave portion of the system in the satellite is projected to be about $130 per kilowatt.

The diameter of the receiving antenna on the Earth would be about 7 kilometers for Gaussian distribution in the beam within which 90% of the transmitted energy would be intercepted. The use of such a large receiving antenna area would reduce the microwave power flux density on Earth to a value substantially less than the continuous microwave exposure standard accepted in the United States. Within several kilometers beyond the receiving antenna, the microwave density levels drop to less than 1 microwatt per square centimeter.[4]

Half-wave dipoles distributed throughout the receiving antenna capture the microwave power and deliver it to solid-state microwave rectifiers. Schottky barrier diodes have already been demonstrated to have an 80% microwave rectification efficiency at up to 5 watts of output. With improved circuits and diodes, a rectification efficiency of about 90% will be achievable which will result in a substantially lower heat release to the environment compared to any other energy-production method yet developed. For a 5000-megawatts power output on the ground, the receiving antenna costs, including the required support structure, are projected to be about $100 per kilowatt.

At about 3.3 GHz, radio frequency interference can be limited so that an appropriate internationally agreed-upon frequency could be assigned to an SSPS. The ionospheric attenuation of the microwaves will be less than 0.1% at this frequency and at the low power flux densities occurring within the beam. The efficiency of transmission through the atmosphere in temperate latitudes, including some rain (2 millimeters per hour) is approximately 98% and decreases to 94% during heavy rains (33 millimeters per hour). Including microwave attenuation, the overall efficiency of microwave transmission from DC in the SSPS to DC on the ground is projected to be about 70%.

SSPS SYSTEMS CONSIDERATION

Although the SSPS is orders of magnitude larger than any spacecraft yet designed, its overall design is based on known principles of technology. The large size of the SSPS will necessitate new structural and control system design approaches to satisfy orientation requirements. Approaches already identified indicate that adequate structural response can be built into the SSPS to achieve the desired flight control.

A two-stage space transportation system will be required to place the SSPS in synchronous orbit: a low-cost stage capable of carrying a high volume of payload to low Earth orbit and a high-performance stage using ion propulsion capable of delivering partially assembled elements to synchronous orbit for final assembly and deployment.[5] A transportation system for an SSPS capable of generating 5000 megawatts on Earth will have to place in synchronous orbit a payload of about 25 million pounds and propellant supplies, for station-keeping purposes, of about 30,000 pounds per year. The transportation and assembly costs for the SSPS are projected to be about $500 per kilowatt.

The time required for one operational SSPS to pay back the energy expended during the construction phases, including raw materials, manufacturing processes, component assembly, space transportation and ground support facilities, will be less than one year. Workable versions of each component for the SSPS exist today, or can be built, although some entail considerable development. The cost of the major components, such as solar cells, microwave generators, and rectifiers, can be drastically reduced by mass production. Allowing for these potential cost reductions, and based on the present design approaches, the capital costs for a prototype SSPS designed to generate 5000 megawatts on Earth are projected to be about $1300 per kilowatt, including contingencies. Design improvements leading to further weight reductions indicate that the capital costs for an advanced SSPS could be reduced to about $800 per kilowatt.

Based on the identification of the steps required to develop the various technologies, a development program could be phased so that the prototype SSPS could be demonstrated in the early 1990's, with a commercial SSPS system in operation by 2000. In parallel with the development of the required technology, environmental impacts, economic constraints, and social and political consequences have to be assessed, so that the overall desirability of an SSPS can be compared with other energy-production methods and the development of this option for meeting future energy demands can also be placed in proper context.

CONCLUSIONS

It is obvious that the Satellite Solar Power Station not only represents a major challenge to technology but also an unparalleled opportunity to apply space technology for the benefit of mankind. No fundamental breakthroughs are required to achieve the objectives identified with the SSPS but rather major advances and improvements over existing technology. The questions that need to be answered are not only whether the required technology can be developed – because the answer most likely will be yes – but rather whether the development of an SSPS to meet future energy demands is an option that should be pursued. In the face of uncertainties associated with other approaches for generating power with minimal environmental impact, the efforts to explore this option, which is projected to be cost competitive with other energy production methods, should fit within the framework of an integrated energy development program.

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