KIET IJCE KIET International Journal of Communications & Electronics
Volume. No. 6, Issue No. 1, Jan-June 2018, ISSN: 2320 – 8996

Space based solar power-a review

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Abstract

In the recent decades, there has been a huge energy demand due to the exponential increase of the human population and consequently, the depletion of non-renewable energy sources. This creates the need to explore alternate routes for renewable energy resources. The solar energy was the best alternative of the conventional energy system in last few decades, but because of intermittent energy and huge land area requirement it is the need of the hour to look for an alternate solar energy system. Space-based solar power (SBSP) is a step towards this technology to overcome the limitation of intermittent supply as solar energy is always available in the space. SBSP is the concept of collecting solar power in outer space and distributing it to Earth. Potential advantages of collecting solar energy in space include a higher collection rate and a longer collection period due to the lack of a diffusing atmosphere, and the possibility of placing a solar collector in an orbiting location where there is no night.

INTRODUCTION

Energy generation to meet the demand is a very big issue, and almost 10-15% of the total economic expenditures in the world are used for meeting this supply and demand [1]. The total resources which can be used for energy generation in the world can be broadly categorized into fossil fuels, renewable sources and nuclear resources. The fossil fuels and nuclear sources comes under the category of non-renewable sources further[2]out of these three sources of energy, fossil fuels are the conventional sources which are used to meet the major portion of the energy requirements in the world but they are depleting with time and also have adverse consequences such as global warming. Nuclear sources are also harmful for the living beings. This lead to shift towards renewable sources which is the best promising alternative of energy generation as compared with the above two categories of energy sources. The renewable energy source includes solar energy, wind energy, and hydel energy. Out of these solar energy was used and researched in last few decades, but because of its intermittent supply, it is not a very efficient energy generation system. So, the researchers thought to overcome this limitation by generating the energy directly in space where the availability of sunlight is always there using satellite and then transmit it to the earth. SBSP is an effort related to this initiative. Although the proposed system is in research state and not in use anywhere till now, but the researchers are targeting to achieve it till the end of 2025. In the present system which converts solar energy in to electrical energy, a considerable fraction of incoming solar energy (55–60%) is lost on its way through the Earth's atmosphere by the effects of reflection and absorption. But in Space-based solar power, the system convert sunlight to microwaves outside the atmosphere, avoiding these losses and the downtime due to the Earth's rotation, but at great cost due to the expense of launching material into orbit. SBSP is considered a form of sustainable or green energy, renewable energy, and is occasionally considered among climate engineering proposals. It is attractive to those seeking large-scale solutions to anthropogenic climate change or fossil fuel depletion (such as peak oil).

History

In 1941, science fiction writer Isaac Asimov published the science fiction short story "Reason", in which a space station transmits energy collected from the Sun to various planets using microwave beams. The SBSP concept, originally known as satellite solar-power system (SSPS), was first described in November 1968[6]. In 1973 Peter Glaser was granted U.S.

patent number 3,781,647 for his method of transmitting power over long distances (e.g. from an SPS to Earth's surface) using microwaves from a very large antenna (up to one square kilometer) on the satellite to a much larger one, now known as a rectenna, on the ground[7]. Glaser then was a vice president at Arthur D. Little, Inc. NASA signed a contract with ADL to lead four other companies in a broader study in 1974. They found that, while the concept had several major problems – chiefly the expense of puttingthe required materials in orbit and the lack of experience on projects of this scale in space – it showed enough promise to merit further investigation and research[8]. Between 1978 and 1986, the Congress authorized the Department of Energy (DoE) and NASA to jointly investigate the concept. They organized the Satellite Power System Concept Development and Evaluation Program[9][10]. The project was not continued with the change in administrations after the 1980 US Federal elections. In 1997 NASA conducted its "Fresh Look" study to examine the modern state of SBSP feasibility. In assessing "What has changed" since the DOE study, NASA asserted that the "US National Space Policy now calls for NASA to make significant investments in technology (not a particular vehicle) to drive the costs of ETO [Earth to Orbit] transportation down dramatically. This is, of course, an absolute requirement of space solar power"[30]. On Nov 2, 2012, China proposed space collaboration with India that mentioned SBSP is a Space-based Solar Power initiative so that both India and China can work for long term association with proper funding along with other willing space faring nations to bring space solar power to earth[32].

Space Solar Power Exploratory Research and Technology program

In 1999, NASA's Space Solar Power Exploratory Research and Technology program (SERT) was initiated for the following purposes:

- Perform design studies of selected flight demonstration concepts.
- Evaluate studies of the general feasibility, design, and requirements.
- Create conceptual designs of subsystems that make use of advanced SSP technologies to benefit future space or terrestrial applications.
- Formulate a preliminary plan of action for the U.S. (working with international partners) to undertake an aggressive technology initiative.
- Construct technology development and demonstration roadmaps for critical Space Solar Power (SSP) elements.

SERT went about developing a solar power satellite (SPS) concept for a future Gigawatt space power system, to provide electrical power by converting the Sun's energy and beaming it to Earth's surface, and provided a conceptual development path that would utilize current technologies. SERT proposed

an inflatable photovoltaic gossamer structure with concentrator lenses or solar heat engines to convert sunlight into electricity. The program looked both at systems in sun-synchronous orbit and geosynchronous orbit. Some of SERT's conclusions:

A. The increasing global energy demand is likely to continue for many decades resulting in new power plants of all sizes being built.

B. The environmental impact of those plants and their impact on world energy supplies and geopolitical relationships can be problematic.

X. Renewable energy is a compelling approach, both philosophically and in engineering terms.

Δ. Many renewable energy sources are limited in their ability to affordably provide the base load power required for global industrial development and prosperity, because of inherent land and water requirements.

E. Based on their Concept Definition Study, space solar power concepts may be ready to reenter the discussion.

Φ. Solar power satellites should no longer be envisioned as requiring unimaginably large initial investments in fixed infrastructure before the emplacement of productive power plants can begin.

Γ. Space solar power systems appear to possess many significant environmental advantages when compared to alternative approaches.

H. The economic viability of space solar power systems depends on many factors and the successful development of various new technologies (not least of which is the availability of much lower cost access to space than has been available); however, the same can be said of many other advanced power technologies options.

Δ. Space solar power may well emerge as a serious candidate among the options for meeting the energy demands of the 21st century. Space Solar Power Satellite Technology Development at the Glenn Research Center—An Overview. James E. Dudenhoefer and Patrick J. George, NASA Glenn Research Center, Cleveland, Ohio.

E. Launch costs in the range of $100–$200 per kilogram of payload to low Earth orbit are needed if
SPS are to be economically viable[11].

Japan Aerospace Exploration Agency

The May 2014 IEEE Spectrum magazine carried a lengthy article "It's Always Sunny in Space" by Dr. Susumu Sasaki[33]. The article stated, "It's been the subject of many previous studies and the stuff of sci-fi for decades, but space-based solar power could at last become a reality—and within 25 years, according to a proposal from researchers at the Tokyo-based Japan Aerospace Exploration Agency (JAXA)."

JAXA announced on 12 March 2015 that they wirelessly beamed 1.8 kilowatts 50 meters to a small receiver by converting electricity to microwaves and then back to electricity. This is the standard plan for this type of power.[34][35] On 12 March 2015 Mitsubishi Heavy Industries demonstrated transmission of 10 kilowatts (kW) of power to a receiver unit located at a distance of 500 meters (m) away[36].

Design

Space-based solar power essentially consists of three elements[2]:

II Collecting solar energy in space with reflectors or inflatable mirrors onto solar cells

JJ Wireless power transmission to Earth via microwave or laser

KK Receiving power on Earth via a rectenna, a microwave antenna

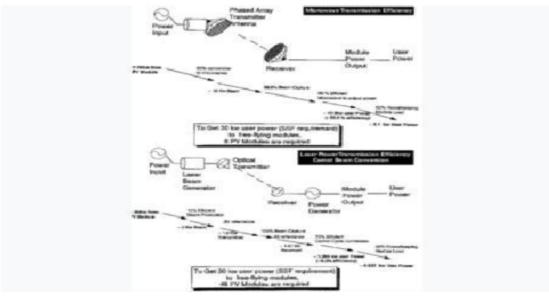
The space-based portion of collecting solar energy will not need to support itself against gravity (other than relatively weak tidal stresses). It needs no protection from terrestrial wind or weather, but will have to cope with space hazards such as micrometeors and solar flares. Two basic methods of conversion have been studied: photovoltaic (PV) and solar dynamic (SD). Most analyses of SBSP have focused on photovoltaic conversion using solar cells that directly convert sunlight into electricity. Solar dynamic technology uses mirrors to concentrate light on a boiler which is not suitable to use in the space. The orbital location also matters a lot for placing a satellite in the
space. According to the researchers, the SBSP satellite should be place in the geostationary orbit. The main advantage of locating a space power station in geostationary orbit is that the antenna geometry stays constant, and so

keeping the antennas lined up is simpler. Another advantage is that nearly continuous power transmission is immediately available as soon as the first space power station is placed in orbit; other space-based power stations have much longer start-up times before they are producing nearly continuous power.

Wireless power transmission was proposed early on as a means to transfer energy from collection to the Earth's surface, using either microwave or laser radiation at a variety of frequencies.The wireless power transmission via Microwave is based on the conclusion of demonstration done by William C. Brown demonstrated in 1964, during Walter Cronkite's CBS

News program, a microwave-powered model helicopter that received all the power it needed for flight from a microwave beam. Between 1969 and 1975, Bill Brown was technical director of a JPLRaytheon program that beamed 30 kW of power over a distance of 1 mile (1.6 km) at 84% efficiency[43].

Microwave power transmission of tens of kilowatts has been well proven by existing tests at Goldstone in California (1975)[43][44][45]and Grand Bassin on Reunion Island (1997)[46].



Comparison of laser and microwave power transmission. NASA diagram

More recently, microwave power transmission has been demonstrated, in conjunction with solar energy capture, between a mountain top in Maui and the island of Hawaii (92 miles away), by a team under John C. Mankins[47][48]. Technological challenges in terms of array layout, single radiationelement design, and overall efficiency, as well as the associated theoretical limits are presently a subject of research, as it is demonstrated by the Special Session on "Analysis of Electromagnetic Wireless Systems for Solar Power Transmission" to be held in the 2010 IEEE Symposium on Antennas and Propagation[49]. In 2013, a useful overview was published, covering technologies and issues associated with microwave power transmission from space to ground. It includes an introduction to SPS, current research and future prospects[50]. Moreover, a review of current methodologies and technologies for the design of antenna arrays for microwave power transmission appeared in the Proceedings of the IEEE [51]

Laser power beaming can also be used for the transmission of electricity generated from the space to the earth. It was envisioned by some at NASA as a stepping stone to further industrialization of space. In the 1980s, researchers at NASA worked on the potential use of lasers for space-to-space power beaming, focusing primarily on the development of a solar-powered laser. In 1989 it was suggested that power could also be usefully beamed by laser from Earth to space. In 1991 the SELENE project (Space Laser Energy) had begun, which included the study of laser power beaming for supplying power to a lunar base. The SELENE program was a two-year research effort, but the cost of taking the concept to operational status was too high, and the official project ended in 1993 before reaching a space-based demonstration[52].

In 1988 the use of an Earth-based laser to power an electric thruster for space propulsion was proposed by Grant Logan, with technical details worked out in 1989. He proposed using diamond solar cells operating at 600 degrees to convert ultraviolet laser light.

The designing receiver for receiveing the electricity generated in the space on the earth is one of the major hurdle in this project. Such receivers are called Rectennas on the earth. The Earth-based rectenna would likely consist of many short dipole antennas connected via diodes. Microwave broadcasts from the satellite would be received in the dipoles with about 85% efficiency[54]. With a conventional microwave antenna, the reception efficiency is better, but its cost and complexity are also considerably greater. Rectennas would likely be several kilometers across.

Launching costs

One problem for the SBSP concept is the cost of space launches and the amount of material that would need to be launched.

Much of the material launched need not be delivered to its eventual orbit immediately, which raises the possibility that high efficiency (but slower) engines could move SPS material from LEO to GEO at an acceptable cost. Examples include ion thrusters or nuclear propulsion. Power beaming from geostationary orbit by microwaves carries the difficulty that the required 'optical aperture' sizes are very large. For example, the 1978 NASA SPS study required a 1-km diameter transmitting antenna, and a 10 km diameter receiving rectenna, for a microwave beam at 2.45 GHz. These sizes can be somewhat decreased by using shorter wavelengths, although they have increased atmospheric absorption and even potential beam blockage by rain or water droplets. Because of the thinned array curse, it is not possible to make a narrower beam by combining the beams of several smaller satellites. The large size of the transmitting and receiving antennas means that the minimum practical power level for an SPS will necessarily be high; small SPS systems will be possible, but uneconomic. To give an idea of the scale of the problem, assuming a solar panel mass of 20 kg per kilowatt (without considering the mass of the supporting structure, antenna, or any significant mass reduction of any focusing mirrors) a 4 GW power station would weigh about 80,000 metric tons[58], all of which would, in current circumstances, be launched from the Earth. Very lightweight designs could likely achieve 1 kg/kW[59], meaning 4,000 metric tons for the solar panels for the same 4 GW capacity station. This would be the equivalent of between 40 and 150 heavy-lift launch vehicle (HLLV) launches to send the material to low earth orbit, where it would likely be converted into subassembly solar arrays, which then could use high-efficiency ion-engine style rockets to (slowly) reach GEO (Geostationary orbit). With an estimated serial launch cost for shuttle-based HLLVs of $500 million to $800 million, and launch costs for alternative HLLVs at $78 million, total launch costs would range between $11 billion (low cost HLLV, low weight panels) and $320 billion ('expensive' HLLV, heavier panels. To these costs must be added the environmental impact of heavy space launch missions, if such costs are to be used in comparison to earth-based energy production. For comparison, the direct cost of a new coal[60]or nuclear power plant ranges from $3 billion to $6 billion per GW (not including the full cost to the environment from CO2 emissions or storage of spent nuclear fuel, respectively); another example is the Apollo missions to the Moon cost a grand total of $24 billion (1970s dollars), taking inflation into account, would cost $140 billion today, more expensive than the construction of the International Space Station.

Potential and Drawbacks

Potential

The SBSP concept is attractive because space has several major advantages over the Earth's surface for the collection of solar power:

- It is always solar noon in space and full sun.
- Collecting surfaces could receive much more intense sunlight, owing to the lack of obstructions such as atmospheric gasses, clouds, dust and other weather events. Consequently, the intensity in orbit is approximately 144% of the maximum attainable intensity on Earth's surface.
- A satellite could be illuminated over 99% of the time, and be in Earth's shadow a maximum of only 72 minutes per night at the spring and fall equinoxes at local midnight[37]. Orbiting

satellites can be exposed to a consistently high degree of solar radiation, generally for 24 hours per day, whereas earth surface solar panels currently collect power for an average of 29% of the day[38].

A. Power could be relatively quickly redirected directly to areas that need it most. A collecting satellite could possibly direct power on demand to different surface locations based on geographical baseload or peak load power needs. Typical contracts would be for baseload, continuous power, since peaking power is ephemeral.

B. Elimination of plant and wildlife interference.

X. With very large scale implementations, especially at lower altitudes, it potentially can reduce incoming solar radiation reaching earth's surface. This would be desirable for counteracting the effects of global warming.

Drawbacks

The SBSP concept also has a number of problems:

B. The large cost of launching a satellite into space

X. The thinned-array curse preventing efficient transmission of power from space to the Earth's surface

Δ. Inaccessibility: Maintenance of an earth-based solar panel is relatively simple, but construction and maintenance on a solar panel in space would typically be done telerobotically. In addition to cost, astronauts working in GEO (geosynchronous Earth orbit) are exposed to unacceptably high radiation dangers and risk and cost about one thousand times more than the same task done telerobotically.

E. The space environment is hostile; panels suffer about 8 times the degradation they would on Earth (except at orbits that are protected by the magnetosphere)[39].

Φ. Space debris is a major hazard to large objects in space, and all large structures such as SBSP systems have been mentioned as potential sources of orbital debris[40].

Γ. The broadcast frequency of the microwave downlink (if used) would require isolating the SBSP systems away from other satellites. GEO space is already well used and it is considered unlikely the ITU would allow an SPS to be launched[41].

H. The large size and corresponding cost of the receiving station on the ground.

I. Energy losses during several phases of conversion from photons to electrons to photons back to electrons[42].

REFERENCES

[1] Statement of John C. Mankins U.S. House Subcommittee on Space and Aeronautics Committee on Science, Sep 7, 2000

[2] "Satellite Power System (SPS) Resource Requirements (Critical Materials, Energy, and Land). HCP/R-4024-02, October 1978"(PDF).

[3] Satellite Power System (SPS) Financial/Management Scenarios. Prepared by J. Peter Vajk. HCP/R-4024-03, October 1978. 69 pages

[4] Satellite Power System (SPS) Financial/Management Scenarios. Prepared by Herbert E. Kierulff. HCP/R-4024-13, October 1978. 66 pages.

[5] Satellite Power System (SPS) Public Acceptance. HCP/R-4024-04, October 1978. 85 pages.

[6] Satellite Power System (SPS) State and Local Regulations as Applied to Satellite Power System Microwave Receiving Antenna Facilities. HCP/R-4024-05, October 1978. 92 pages.

[7] Satellite Power System (SPS) Student Participation. HCP/R-4024-06, October 1978. 97 pages.

[8] Potential of Laser for SPS Power Transmission. HCP/R-4024-07, October 1978. 112 pages.

[9] Satellite Power System (SPS) International Agreements. Prepared by Carl Q. Christol. HCP-R-4024-08, October 1978. 283 pages.

[10] Satellite Power System (SPS) International Agreements. Prepared by Stephen Grove. HCP/R-4024-12, October 1978. 86 pages.

[11] Satellite Power System (SPS) Centralization/Decentralization. HCP/R-4024-09, October 1978. 67 pages.