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PROBLEMS AND CONCEPTS OF THE DEVELOPMENT OF SOLAR POWER SATELLITES

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Abstract

Solar radiation is a renewable and ecologically pure source of energy. The amount of solar power is huge but the use of that power for the production of electricity involves great difficulties, the major ones being the low density of solar radiation on the Earth's surface and the impermanent nature of that radiation (clouded skies, nighttime). A certain way to overcome those obstacles are the already developed energy accumulators and the combined solar-thermal energy systems, as well as the devices concentrating solar power and increasing its density. Unfortunately, these solutions are not widely applicable and are not competitive to conventional electric power stations. However, giving up ground-based solar electric power stations and placing them in a geosynchronous or low equatorial orbit would produce essentially different results.

1. Introduction

In 1968, P. E. Glaser [1], Head of the Technoscientific Department of the firm Arthur D. Little Inc. (USA) proposed a project for the development of a solar power satellite (SPS) on a synchronous orbit. The solar power satellite transforms solar radiation into electricity with the help of semiconductor photocells and sends the energy to the Earth as microwaves [2].

The SPS in Glaser's project has a number of merits: registration of the increased density of the solar radiation stream, dispersion of the thermal background in space (ruling out any danger of heat "pollution" of the Earth), lack of contact with the Earth's biosphere.

2. Current relevance

Currently, mankind uses annually about 10 billion tons of fuel and this figure is constantly rising – primarily in the developing countries which seek to provide to their citizens living conditions on a par with those in the highly developed nations [3]. In the USA, the daily per capita use of electric power is 10 kWh [4]. The consumption level in the developing nations is tens of times less while these countries account for 2/3 of the global population. If the tendency to close this gap continues, the total consumption of energy will grow several-fold and by the year 2020 it will reach 34 billion tons of fuel [5]. The steep rise of power generation is very dangerous: it could cause thermal "pollution" of the Earth and irreversible climate changes. Mankind's need of energy grows with the growth of technology. At present, fossil fuels provide the bulk of power: oil, natural gas and coal. But their deposits underneath the Earth's crust are not limitless. Given the current rate of explotation, they are bound to dry up in a few hundred years's time. Besides that, these fossils are needed by the chemical industries. Fossils can partially be replaced by nuclear fuel. The deposits of uranium are not limitless, either, while those of deuterium in the oceans are huge. In spite of that, no profitable controlled thermonuclear reactors have been developed so far. The use of all fuels enumerated on Table 1 [6], except for the solar and geothermal power station, pollutes the environment and harms Nature.

Table 1

Balance sheet of the output of electric energy in the world

Type	Per cent
Thermal electric power stations (coal, oil, natural gas)	63
Hydroelectric stations	19
Nuclear power station	17
Geothermal electric station	0,5
Solar, wind electric stations	0,1

The solution of the global ecological and power problems through pure energy is a serious and difficult task. One of the topical modern opportunities is the development of a project for building a system of solar power satellites. These discussions arise from the growing needs of ecologically pure power at the expense of the traditional power sources, which endanger the ecological balance.

3. SPS orbits

Powell [7] proposes launching of a platform with photocell panels onto a geosyncronous or solar-synchronous orbit, 35,800 km away from the Earth. At an angle of 23.5° between the orbit and the ecliptic, the panels will be illuminated by the Sun, which is the prime advantage of the SPS [8, 9]. A key problem is the location of the SPSs and their consumers. Glaser's original idea [1] was to launch geosyncronous equatorial orbit (GEO) actively controlled SPSs, containing solar panels and equipped with relay antennae; these would constantly face the Sun, sending directed microwave rays to ground-based reception stations (Fig.1)

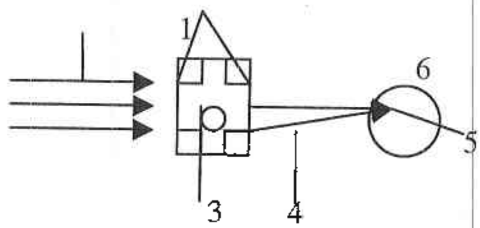

Fig. 1. 1 – solar radiation; 2 – photovoltaic cells; 3 – transmitting antenna; 4 – microwave beam; 5 – receiving station; 6 - Earth

A number of authors [10, 11, 12] propose the use of a low-earth-orbit (LEO) instead of GEO. This reduces the difficulty of transporting materials from the ground. In recent years, most intensive consideration [13, 8] was given to LEO and to orbits of the "Molniya" ("Lightning") type, the main problem being to deal with the economic aspect. On the one hand, LEO is a compromise as to the reduction of the difficulties and expenses inherent to GEO, and on the other, the technological and economic risks are easier to predict. The orbit of the "Molniya" type is a Russian satellite system of communication, which uses satellites along strongly eccentric orbits designed to establish radiocommunication between two ground stations [8]. Another widely discussed orbit is the one using a laser system for the transmission of energy (Fig.2). The slight divergence of the ray provides an opportunity to employ mirror relay stations of not big mass of size d. In this case of transmitting power to the ground the relay stations can operate on geosynchronous or high elliptical orbits and in this way it is enough for an SPS to be launched into a low solar-synchronous orbit which will allow to substantially reduce loss during transportation while establishing the station [8].

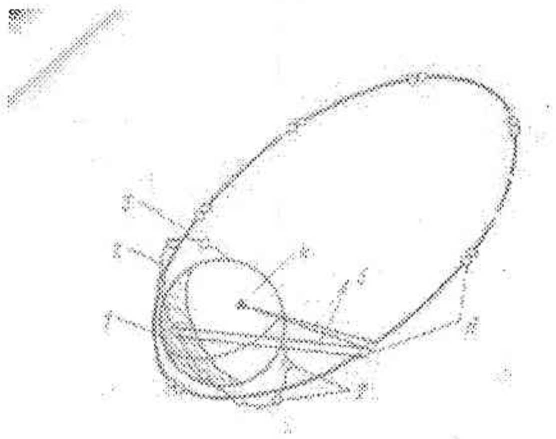

Fig. 2. (Lukuanov). 1 – Earth; 2 – SPS orbit; 3 – high elliptical orbit of the relay station; 4 – consumer; 5 – laser radiation; 6 – relay station; 7 – SPS.

3.1. Relaying reprocessed energy from an SPS

With the help of SPS's, enormous power (up to 10-15 GW or more) can be generated and relayed to any region of the Earth and the space around it.

The concentration of power, obtained from an SPS, and the possibility to transmit power from an SPS to reception stations situated at various places along the way of a rapid reorientation of the ray, allows for a considerable increase of the economic efficiency of the ground-based grid [14].

Types of systems for relaying power:

1. Relaying power through microwave radiation.
2. Relaying power through laser radiation.

1. Transforming solar power on the basis of microwave rays (according to Grilihes)

First version. Solar radiation is directly received by the surface of a converter, which generates electric power; this power is then concentrated using an electric commutation system and is transferred to the generator by a monochrome ray, and from there, via free space, to the transmitting system.

Second version. Transforming solar power into electricity using a generator of radio-frequency emission, which through waveguides is concentrated and is then brought to the receiving system-antenna.

Third version. Contains concentrators of solar radiation which:

i) transform it first into electric power and then into a directed monochrome ray;

ii) transform it directly into radiation within an optic or radio range.

Advantages:

- high efficiency of energy transformation;
- minimal losses in transmitting microwave radiation through the atmosphere.

Shortcomings:

- the great wavelength (10-12 cm) also presupposes great divergence of the ray which requires the establishment of large-area ground receiving stations;
- impossibility of transmitting energy to moving objects such as satellites, orbital transporting devices, etc;
- radio frequency interference is a real problem facing SPSs. It has become clear that SPSs will radiate so much energy that no communication system could operate in the 2.45 GHz sector at a distance of several kilometers from the receiving antenna on the ground [16].

2. Transmitting energy on the basis of powerful lasers

The specific peculiarities of the transformation of solar power into a laser beam have to do with the low density of solar radiation in the outer space, which presupposes the use of concentrators in the power emitting systems. But the theoretically attainable density of the stream of concentrated solar radiation does not exceed 16 mW/m^2 and is insufficient for effectively pumping the lasers [16]. An analysis of the suitability of various substances to be used as active media for SPS lasers with optical pumping indicates that these substances can be divided into three groups:

1. Admitting optical pumping and radiating in the visible range.
2. Permitting pumping by visible light and radiating in the infrared range.
3. Pumping and radiating in the infrared range.

In the first group are molecular substances J_2, Na_2, Br_2, Te_2, Li_2, HgBr and the lasers with solutions of organic dyes. In the second group are

CF_3J, $Br+CO_2$, J_2+CO_2; in the third are CO, CO_2, N_2O, HF, DF, G_2H_2. Of greatest interest are the substances of the third group and in particular CO, CO_2, N_2O. The examined substances of the first and second group have considerable disadvantages: the former necessitates an excessively high density of the radiated stream; and the latter features unacceptably low transformation efficiency because the energy transformed in the process of pumping exceeds considerably emitted energy. The only exception is the molecular compound CF_3J, which is regarded as one of the possible active media [9]. At the same time, the cited results cannot be considered final because the search for suitable working substances is going on.

Advantages:

- smaller ray divergence (1-10 micrometres)
- possibility of using mirror relay stations.

Shortcomings:

- high level of laser absorption by the Earth's atmosphere.

4. Modern projects

The USA is a historical leader in experimenting and demonstrating cableless energy transmission. Developments in radio in the 1950s have led to discussions on the development of microwaves in aviation. G. Brown [16] from Rayton Corp. with the assistance of the US Air Force was the first to construct a series of electrically powered helicopters for a demonstration of the advantages of microwave driving and directing flying vehicles (FV).

Nevertheless, the SPS projects were not implemented because no state was yet ready to fund such stations due to military estimates which indicated that such programs would be inoperable [16].

But the recent power black-outs in California made the USA take a fresh look at the power supply problem. Now the situation is rather complicated and the need of electricity needs is outrunning available resources. According to NASA's plan (www.sel.noaa.gov/info/SolarMax.pdf), in 2006-2007, the International Space Station will be used to test cableless power transmission. Besides, it is planned that at the same time the first trial electric station of 100 kW should be built. By 2011-2012, NASA plans the launch into outer space of a platform which would be essentially a megawatt electric station and would be capable of transmitting power both to other space vehicles and to the Earth. In future, the output of the electric station will grow and, according to preliminary calculations, in 15-20 years it will reach 10 MWatt (http://spacepwr.jpl.nasa.gov/solar.htm).

In 1994, Japan launched a 100-year plan called "Action Plan – Earth 21" [17]. It aims to reduce carbon dioxide in the Earth's atmosphere through the so-called carbon sinks. The program seeks to give electric power to photovoltaic systems based on the Earth and in space.

This blueprint [18] envisages the installation of systems, which could provide power from space to the world electric grid in 2040 at the earliest.

The ground plan envisages a series of solar power satellites, each of which will transmit 1GW of electric power to ground-based stations. The satellites will use microwave radiation of 2.45 GHz [18].

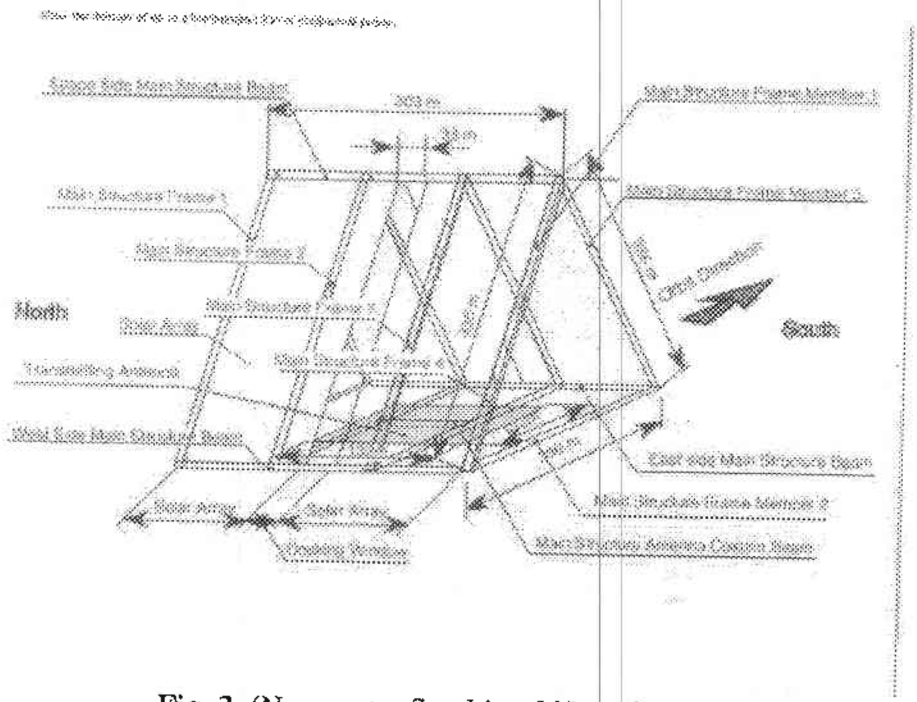

Fig. 3. (Nagamoto, Sasaki and Naruo)

SPS-2000 is a frame constructed of light aluminum in the shape of a triangular prism, sized approximately 300 m, carrying about 18 hectares of amorphous silicon batteries in a saddle-like configuration so as to render unnecessary active directing [19]. One square of the 130-metre phase transmitting antenna is connected to a satellite side facing the Earth in the lower part and provides about 10 MW of 2.45 GHz energy with a ray whose cross-section diameter is about 2 km to the Earth's surface [18]. The beam could be directed ± 30° to the West or to the East and can supply energy within 200 sec. to the receiving antenna within 3° of latitude from the equator. This provides for the supply of up to several hundred kW of continuous energy. A 1,100-km high equatorial orbit will be used. This choice minimizes transport expenses and the distance for transmitting energy from space [18].

5. Conclusion

SPS design and construction is a challenging techno-scientific task. Of the developed projects, the most discussed ones are SPSs processing solar power and transmitting energy in the form of microwave rays. Notwithstanding the large investments, the development of new branches of science and new technologies, the efficiency of the more-promising projects for the transmission of solar energy on the basis of powerful lasers is not as yet sufficiently well studied.

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ПРОБЛЕМИ И ИДЕИ ЗА РАЗВИТИЕТО НА СПЪТНИКОВИ СЛЪНЧЕВИ ЕЛЕКТРОЦЕНТРАЛИ

Милен Цветков

Резюме

Слънчевата радиация е възобновяем и екологично чист енергиен източник. Количеството на слънчевата енергия е огромно, но използването на този източник за производството на електричество е свързано с големи трудности, като основните са ниската гъстота на слънчевата радиация върху земната повърхност и непостоянният характер на тази радиация (облачност, нощ). Един от начините за преодоляване на тези пречки са вече разработените енергийни акумулатори и комбинираните слънчево-топлинни енергийни системи, както и устройствата за концентриране на слънчевата енергия и увеличаване на гъстотата ѝ. За съжаление, тези решения не са широко приложими и не са конкурентноспособни на обикновените електростанции. Отказът от наземните слънчеви електроцентрали, обаче, и поставянето им на геосинхронна или нискоекваториална орбита, може да доведе до съвсем различни резултати.