Space solar power stations. Problems of energy generation and using its on the earth surface and nearest cosmos

OA Sinkevich, DN Gerasimov and VV Glazkov
National Research University «Moscow Power Engineering Institute», Russia, 111250 Moscow, Krasnokazarmennaya 14
oleg.sinkevich@itf.mpei.ac.ru

Abstract. Three important physical and technical problems for solar power stations (SPS) are considered: collection of solar energy and effective conversion of this energy to electricity in space power stations, energy transportation by the microwave beam to the Earth surface and direct utilization of the microwave beam energy for global environmental problems. Effectiveness of solar energy conversion into electricity in space power stations using gas and steam turbines plants, and magneto-hydrodynamic generator (MHDG) are analyzed. The closed cycle MHDG working on non-equilibrium magnetized plasmas of inert gases seeded with the alkaline metal vapors are considered. The special emphases are placed on MHDG and gas-turbine installations that are operating without compressor. Also opportunities for using the produced by space power stations energy for ecological needs on Earth and in Space are discussed.

1. Space power stations as the future of the earth civilization
In 2030 the developing world will demand power at the level of 250–300 TW [1–5]. In order to preserve natural resources and support the standard level of life the industrially developed countries have to find a renewable, predictable, economical and reliable source of energy. The solar energy collected on earth is still not economically competitive with nonrenewable energy sources. So only SPS are capable to supply all needed power at the 250-300 TW level renewably and predictably. Concepts of space power systems, including their economics, are discussed in literature [5–25]. Space power stations with unit power 10-100 GW placed in a geostationary Earth orbit [6–19] should convert the solar energy to the electric power and then transport it to the surface of the Earth by a microwave (MW) beam. On the Earth surface this energy is converted into the conventional electrical power for terrestrial use. Microwave beams from space power stations could supply power to remote users [9–16] (sub-polar areas of the Earth, deserts and mountain areas, consumers in the seas and ocean, etc.).

Creation of space power stations will allow development of new technologies for an outer space exploration [4–10]. The construction of space power stations will enable allow to strengthen the global energy supply stability of the world, to reduce expenses of energy, to develop industrial application of solar energy not only for satisfying the needs of the population and the industry, but also for the maintaining ecological equilibrium of Earth: for the destruction of industrial and household waste products, for the managements of atmospheric processes, etc. [6–22]. Opportunities of using the combined solar - nuclear energy are discussed. We propose to use the MHDG on non-equilibrium magnetized plasma. As the heat-carrier for a nuclear reactor on fast neutrons will be used the Na-K eutectic melt (22,8% Na-78,2% K). This Na-K eutectic melt vapor are used in the MHDG cycle, where non-equilibrium plasmas of Na-K eutectic melts vapors and He will be obtained by means of microwave radiation in the special ionizer established in the entrance of channel.

Here we will not analyze the economic aspects of solar power stations but will consider three
technical problems: a) solar energy collection and its effective conversion to electricity in space power stations, b) transportation and direct conversion of the microwave beam energy into conditioned AC or DC on the surface of the Earth, c) utilization of the microwave beam energy for generation of local electric discharges in an Earth atmosphere and for influence on hurricanes and tornados [23-35].

It is very important to do overall analysis of effectiveness of solar power conversion into electricity in space power systems considering not only the traditional technologies that are based on the photo cell installations, the gas–cooled nuclear and combined nuclear–thermonuclear installations [21–25]. Space power stations with unit power 10-100 GW placed in a geostationary Earth orbit, should convert the sunlight energy to the electric power and then transport it to the surface of the Earth by microwave or laser beams. On Earth the microwave beam energy is converted into electrical power for terrestrial use.

Besides direct conversion of the microwave beam energy into conditioned AC or DC, another technology to use the microwave radiation energy that is based on the storage of the microwave beam energy in underground heat storage systems is proposed. These heat storage systems consist of the special underground cavity, filled with water or other heat carriers where microwave beams are absorbed heating the heat carrier inside the mine to a condition of liquid–vapor mixture. The vapor is transported from the underground heat storage to the steam turbine. The stored energy is converted to electricity using the conventional steam turbine cycle. The procedure is the same as the one taking place on geothermal power stations. The efficiency of the power stations converting the microwave beam energy into electric current of standard parameters is higher (around 30–40 %) than other known ways of microwave radiation conversion into AC and seems not to be the limit.

Solar power stations with unit power 10–100 GW could allow creating the global system of protection against destructive effects of hurricanes and tornados. Space power stations as the future of the Earth civilization. Problems concerning the use of the energy delivered from space power stations by the MW beam to generate local electric discharges in an Earth atmosphere and to influence on hurricanes and tornados are discussed.

Nowadays there are a number of global environmental problems concerning the influence of industrial emissions on the atmosphere, destructions produced by hurricanes, and tornados. Even rather small impact on these processes demands huge expenses of energy that is inaccessible from the power resources located on a surface of the Earth. Frequently these energy requirements arise in the places located far from energy generation sources. The solar power stations with unit power 10–100 GW, located in a geostationary orbit, could supply controlled energy outburst in the needed place and time. The most reliable SPS can be based on use solar and a nuclear energy (figure 1a). These SPS, except of solar batteries and thermoelectric generators, could be using MHD, gas-turbine, and steam converters (figure 1b).

2. Cycles for conversion of solar energy into electricity in space power stations

In the vicinity of Earth we can receive 1.366 kW/m² of solar radiation. It is possible to transmit solar radiation to the working gases using solar concentrators and special heat exchangers. Space gas turbine installations developed up to now are expected to provide the specific weight characteristic at a level of 10–200 kg/kW [16,17], and in the long term this parameter can achieve values about 5 kg/kW. But for realization of the large–scale space power projects it is necessary to enhance the specific weight characteristic up to 0.1–0.5 kg/kW. Combined solar energy conversion systems for space power stations can consist of solar batteries, the solar energy concentrators, heat exchangers, and power generation systems. Generation systems for SPS that are including MHD–generator (MHDG), gas turbine and steam turbine are discussed in [26, 27, 34].

Example of the cycle including MHD–generator, the gas turbine and the steam turbine is shown on figure 2. We propose for space power stations two types of MHD–generator coupled with the gas turbine. One is the MHDG working on thermo-convection flow created by the solar radiation [29-31].
This is the closed compressorless cycle MHDG working on inert gas heated up to 3500 – 4000 K. The second type of the closed cycle MHDG works on the non–equilibrium magnetized plasmas of alkaline seeded inert gases. In the non–equilibrium magnetized plasma the electron temperature is higher than the atom-ion temperature and the Hall parameter $\Omega$ is higher than the critical one $\Omega_{cr} > 1$. The maintenance of non-equilibrium conductivity in the MHDG channel limits the working gas inlet pressure at the level 10 atm. If $\Omega > \Omega_{cr}$ the ionization instability is developing in plasma and the ionization turbulence occurs. The special method of calculation of the conductivity under ionization turbulence was developed by our research team.

Figure 1. a) The solar power station conceptual design; b) Power generation cycles of SPS: 1-2-3-4-1 is the MHD–generator; 5-6-7-8-9-10-5 is the gas turbine cycle; 11-12-13-14-15-16-17-11 is the steam turbine Brighton cycles.

The space power station using MHDG coupled with gas turbine is capable to provide high thermodynamic efficiency at temperatures 2500–4000 K. Cesium seeded helium and cesium or potassium seeded argon were considered as a working gas. The estimation of overall weight characteristics for the solar space power station based on combined closed cycle MHDG and gas turbine cycle can attain the specific weight characteristic 2–5 kg/W. Example of this cycle containing MHDG, the gas turbine and the steam turbine cycles is shown on Figure 2. The closed cycle MHDG can be used not only for the direct conversion of a solar energy to electricity, but also for powering the solar station maneuvering devices.

The gas turbine works on inert gas–helium and provides the main power output in the cycle. Turbine exhaust heat is transferred to steam turbine cycle in a heat exchanger. In this heat exchanger cesium is heated and evaporated. The cesium vapor is used in the steam turbine, and after the turbine the cesium steam at temperature 750 – 790K goes to the condenser where it is cooled down to temperature 350K. Estimations show that the greatest feasibility has the nuclear installation with the direct conversion of the thermal energy into electricity by means of the closed cycle MHDG. The powerful space nuclear installation demands the solution of problems of solar station radiation safety, so more attractive is the idea to use MHDG on the thermo-convection flow or the compressor–less closed cycle MHDG with non–equilibrium turbulent plasma coupled with the gas turbine. These options promise higher thermal efficiency and reduced size of solar power station.

The heat removal system is supposed to use special string systems from the mono-disperse charged drops or the panels radiating thermal energy in space. Problems of construction of heat condensers for the Space power systems are discussed in [6, 23, 24, 38]. Specific capacity of thermal radiation is proportional to $T^4$, therefore high temperature of "cooler" essentially reduces the weight of radiating panels and provides the advantage of space application of the MHDG as a topping above the gas or steam turbine cycle. Calculations of this cycle show, that temperature of the radiating panels cooling a
working gas has optimum value 350K.

The scheme of the solar power station including the MHDG and gas turbine working on pure helium in a temperature range from 2000 to 800 K is presented on figure 2a (proposed by P.P. Ivanov). The MHD generator cycle is marked by figures 1─2─3─4─1: 1─2 is the process where a working gas is compressed, 2─3 is the process in the solar heat exchanger where the sunlight energy is used to heat the cesium seeded from temperature T10 up to temperature T5, 3─4 is the process in the MHDG channel, 4─1 is the process of working gas cooling in the heat exchanger. In this heat exchanger the working gas helium of the gas turbine cycle is heated from temperature T10 up to temperature T11. The MHD generator works on helium plasma with the 1% volumetric of cesium seeding. The working gas flow rate is 1 kg/s.

The gas turbine cycle is marked by figures 5─6─7─8─9─10─11─5: 5─6 is the process in the gas turbine, 6─7 is the process in the regenerative heat exchanger in which the temperature of a working gas falls from T6 down to temperature T7, 7─8 is the isobaric process in the radiative heat exchanger in which the temperature of a working gas falls from T7 down to temperature T8, 8─9 is the process of working gas in the compressor, 9─10 is the process where working gas is heated in a regenerative heat exchanger from temperature T9 up to T10. The gas turbine part of the scheme includes: the gas turbine working on helium (the flow rate of the working gas 0.21 kg/s), the heat exchanger 12─13, receiving heat from the heat exchanger 3─4 of the MHD loop and the regenerative heat exchanger 14─15, coolers 15─9 and 10─11, and two-stage helium compressor 9─10, 11─12. The third steam turbine cycle is not included in this figure. The computer program was developed for the calculation of the thermodynamic characteristics of the energy conversion cycle and parametric optimization studies were carried out. Thermal efficiency of the considered MHDG and gas turbine cycle could be about 70 %.

Figure 2. a) The solar power station block including the MHD generator and gas turbine; b) the closed cycle MHD–generator working on thermo–convection flow created by the solar radiation: 1. Solar radiation; 2 Gas rum-jet engine; 3 MW ionized of the working gas; 4 MHDG channel; 5 Magnetic system; 6 Heath exchanger.

On figure 2b the closed cycle MHD–generator (proposed by V.V. Glazkov [31, 32]) working on thermo–convection flow created by the solar radiation is presented. The special gas rum jet engine placed inside the closed loop creates the thermo-convection flow. This gas rum jet engine differs from the conventional air rum jet engine for a long time applied in aircrafts and rockets and using a fuel and an oxidizer for creation the gas flow during the process of combustion. The gas solar radiated jet engine works in the closed loop due to solar energy supply with the constant mass. It is possible to develop the similar gas rum jet engine operating on the MW and the laser radiation or using the
plasma torches. The gas ram jet can also include the nuclear sources, which heat up the working medium up to necessary temperatures without supplying mass.

The closed cycle MHDG on the thermo-convection flow is capable to work on inert gases seeded alkaline metal vapors with temperature about 2000 K. Nuclear power driven compressorless closed loop MHD–device for space application was examined as well [28 – 31]. The scheme resembles to well-known nuclear ramjet engine with its loop artificially closed and MHD energy conversion device inserted into the loop. Working medium for MHDG is alkali metal seeded inert gas. Similar closed–loop scheme for the gaseous nuclear reactor with UF₆ as working medium is also proposed. Numerical modeling of these energy conversion schemes for subsonic gas velocity level in the loop yields cycle efficiency about 15%. Now closed loop energy conversion scheme with two–phase working medium is developing.

3. Use of energy of a solar power station for the ecological purposes

Despite the successful solution of technical and economic aspects of energy generation in space power stations, there are many other problems that must be solved. For instance, it is necessary to have more fundamental data about the interaction of powerful microwave radiation with atmosphere, the influence of MW radiation on chemical reactions in the top and bottom layers of the Earth atmosphere, the weather conditions and the biological objects in the field of microwave radiation etc. The surface of the Earth has always been exposed to destructive influence of tsunami, hurricanes and tornado. These effects existed forever, but recent consequences from them become more essential. Recently due to the increase of the population density and to appearance of many ecologically dangerous industrial targets (atomic power stations, chemical production factories, dams etc.) hurricanes and tornados may cause dangerous ecological accidents.

The problems of artificial impact on hurricanes and tornados have long ago become an issue of discussion in the literature [27, 34]. But even rather weak impacts on these atmospheric formations demand the huge energy expenses. All types of influence on hurricanes and tornados need the high-energy input and this energy input must be directed to the right place at the right time. And these energy expenses are needed in the places remote from the basic sources of energy production and must be delivered in a short time. However, the detailed analysis of technical aspects shows that the impact on hurricanes and tornados is not fantastic. Similar problems were discussed earlier in connection with the ozone layer restoration [35]. Now the mankind has the necessary intellectual and technical resources, allowing the study of power sources capable to carry out impact on the global processes occurring on the Earth. The electric power, generated on space solar power stations might be transported by the MW beams in any place on the Earth surface or ocean at any time. By means of the directed MW beam it is possible to generate the local electric discharges in an Earth atmosphere and to use them for various purposes [49–62].

Discharges generated by MW beams going from space power stations in the Earth atmosphere can be used for impact on hurricanes and tornados. The impact is only possible on the initial stage of hurricane origin even having high-energy resources from space solar power stations. In the initial stage of hurricane origin much less energy is required, but it is necessary to know precisely the place of the hurricane origin and the way to supply energy.

Influence on a tornado can be realized by creation of the high turbulent zones on the way of its movement. The high turbulent zones can provide faster attenuation of vortices or change the direction of tornado propagation. Creation of the artificial turbulent zones on the way of the tornado movement can demand relatively little energy. These artificial turbulent zones can be created around the protected object for a short time using MW discharges. Other influence on a tornado can be done by splitting the initial vortex into a series of smaller vortices and by directing the small vortices movement to intensive turbulence zones. The artificial intensive turbulence provides faster attenuation of vortices.

Now in many countries of the world the creation of laser lightning-protection systems (see the review [50–59] and its references) are investigated. According to theoretical estimations and preliminary experiences [20–22, 24–29] on artificial initiation of electric discharges in a humid atmosphere by means of the MW or laser radiation, now the implementation of technologies providing generation of small vortices is technically possible. Comparison of the laser and MW methods of generation of vortices demonstrates perceptivity of the MW discharges for intensification of processes in an atmosphere.
4. Conclusions

Within the framework of this paper the following conceptual problems are considered:

1. Ways of the solar energy utilization on the space power stations with unit power 1–100 GW placed in a geostationary Earth orbit. Effectiveness of solar power conversion into electricity in space power stations is discussed. The following is considered: gas turbine installations with MHD–generators, combined cycle installations with MHDG. The special closed cycle MHDG working on thermo–convective flows and using non–equilibrium magnetized plasmas of alkaline metal seeded by inert gases is presented. Numerical calculations of the thermodynamic efficiency of new cycles were carried out.

2. Conversion of the microwave beam energy transported to the Earth surface from space power stations is discussed. New technology of the microwave radiation conversion into conditioned AC or DC is proposed. This technology is based on storage of the microwave beam energy on the special underground cavity, filled with water or other heat carriers. The microwave beam is absorbed by the water filled antenna.

3. Utilization of the microwave beam energy received from the space power stations for the ecological purposes (impact on hurricanes, tornados, and the creation of lightning–protection systems) are discussed.

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