Estimation of Different Configuration of Demonstration Space Solar Power Station

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Abstract: Development of engineering of solar space power system involves as a first stage the launch of demonstration space solar power plant (SSPP) based on the current satellite platforms and launch vehicles. The type of general-arrangement diagram of space segment of SSPP will be the class of transformable structure of photo convertors with maximum surface area. In this manuscript is carrying out analysis of different versions of transformable structures of photo convertors in PROTON launch vehicle use. It is proved that such kind of version would allow successfully implement demonstration SSPP with reasonable power of transferable laser energy to the ground receiving point.

Keywords: Space solar power plant, satellite, laser.

1. INTRODUCTION

The design development of the space power stations is very important today from modern power engineering point of view because of growing needs of modern civilization and also negative ecological impacts of the consequences of using the natural resources [1-12].

Space power station design work is carried out in all leading industrialized countries namely: USA, Japan, EU, China, Canada, India etc.

The design guidelines could be structured as follow:

- Explore the different strategies of SSPP structure composition taking into account optimal mass parameters and high efficiency.
- Developing of the key systems of SSPP – photo convertor with high efficiency, superlight structures, high efficiency SHF generators and laser emitter.
- Conducting of ground tests on power transmission based on laser or microwave emission.

However most of the teams which deal with SSPP developments believe that one of the most important key points in developing of SSPP technologies is conducting of demonstration space based experiment with the performances which are very close to the future actual SSPP [3-4].

Let us review the main technical requirements to such demo SSPP:

- Usage of the current market available launchers.
- Application of the current satellite platforms which provide maximum precision attitude.
- Creation of transformable structure of photo detector modules which have maximum rating and maximum allowable dimensions in order to space them under fairing of the launcher.
- Or – you usage of market available reflecting systems (which applicable for remote sensing and laser space communications) in order to provide the remote laser power transmission to the Earth.

The latest advances in modern electro optical and space technologies in the field of photo converter of sun and laser emission and in the field of laser generators (first of all from efficiency and capacity point of view) make it possible to produce the design of demonstration SSPP with the performance which could be used for actual application.

It should be taken into account that ground photo convertors of such SSPP will be operate under double mode: besides the conversion of laser emission they will operate as an general convertors of direct solar emission, it will allow us to increase the efficiency of the whole system.

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The great success in developments of laser generators namely diode and fiber lasers which operate in the range of 0.8–2.0 µm with high efficiency (up to 70%) and with high level capacity – through the light conductor with the diameter of 250 µm they transmit the capacity up to 50 kW and have small weight-size parameters of the laser itself. Taking into account the wavelength it is possible to create ground receiving units which convert laser emission with the smaller size (dozen meters) that on 3-4 orders less compare to microwave emission (dozens km). Such laser performances allow us to consider its application as power transmission channel for demonstration SSPP. For instance power transmission channel based of laser emission have been successfully used in remote power supply of unmanned vehicles [5-6].

The major factor which determine power possibilities of such demonstration SSPP is necessity of creation of oversize transformable photo convertors structure which will be based on the current space bus with suitable fairing (for example NPO Lavochkin Association space bus called “NAVIGATOR”).

On our opinion there are following key factors which determined different options of lay-out diagrams of demonstration SSPP:

- The necessity to have oversize photo convertors structure and cooling radiators.
- The necessity of using the available launcher fairings to accommodate transformable photo convertors structure and cooling radiators.
- The necessity of accommodation on the spacecraft oversize optic telescope to transfer the laser emission.

Based on analyses of available publications on design of oversize space structures some different technological solutions on its creation were chosen. (Figure **1**).

Fore options of layout diagrams for space segment of SSPP have been reviewed:

- SC diagram with the panel which consist of standardized hexagonal modules;
- SC diagram with the panel which consist of standardized quadrilateral modules;
- SC diagram with roll out panels of photo convertors based on pneumatically hardened structures;

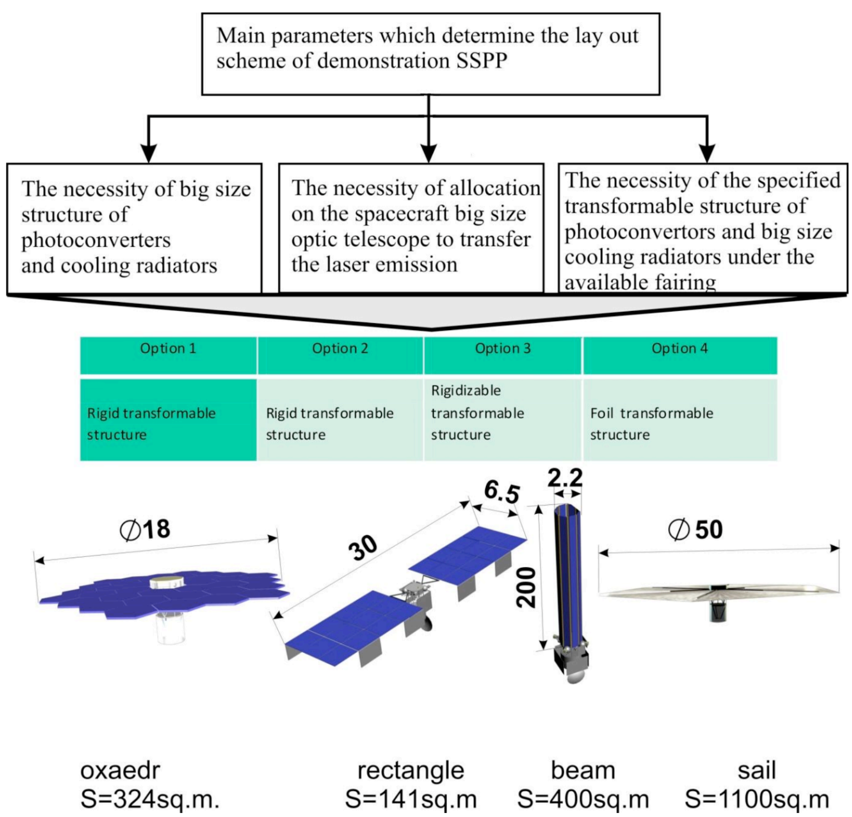

Figure 1: The main requirements to the space segment of demonstration SSPP and possible layout diagrams.

- SC diagram with rollout flexible photo convertors based on solar sail design.

The lay out diagrams of demonstration SSPP would be determined from one site by space bus possibilities where the key factor will be volume of the space under fairing for accommodation of transformable photo-emission modules panels with maximum square and from the other site by design of the panel modules. Such module panel is quite new design for space unit and takes some new technological solutions.

2. PHOTOEMISSION MODULE

The key system of space segment of SSPP is independent autonomous panel element – photoemission module. Its design and main parameters as follow:

- The structure should have the size which allow to accommodate it under the available fairing and the thickness should be minimum in order to accommodate the maximum sets of such modules under the fairing.
- Such photoemission module will have electric and thermal interfaces which are totally independent from the systems of basic module of space bus. Status information of photoemission module will transfer *via* radio link to basic module. Status information of photo transmission module will be transferred through radio channel to the satellite bus. Such architecture will allow to increase the reliability of the whole SSPP.

Intended use of the panel of photoemission modules is conversion of solar emission with the help of photo convertors into electric power then its accumulation and usage for fiber laser pumping. The emissions of fiber lasers will summarize at basic module then directed to controlled mirror system to transfer the collected power to Earth. One side of the panel consist of high efficiency photo convertors and the other consist of high efficiency radiator. Within the space of this structure (Figure **2a**) be locate the following:

- control system;
- condenser system (super capacitors);
- distributed system of light diode fiber laser pumping;

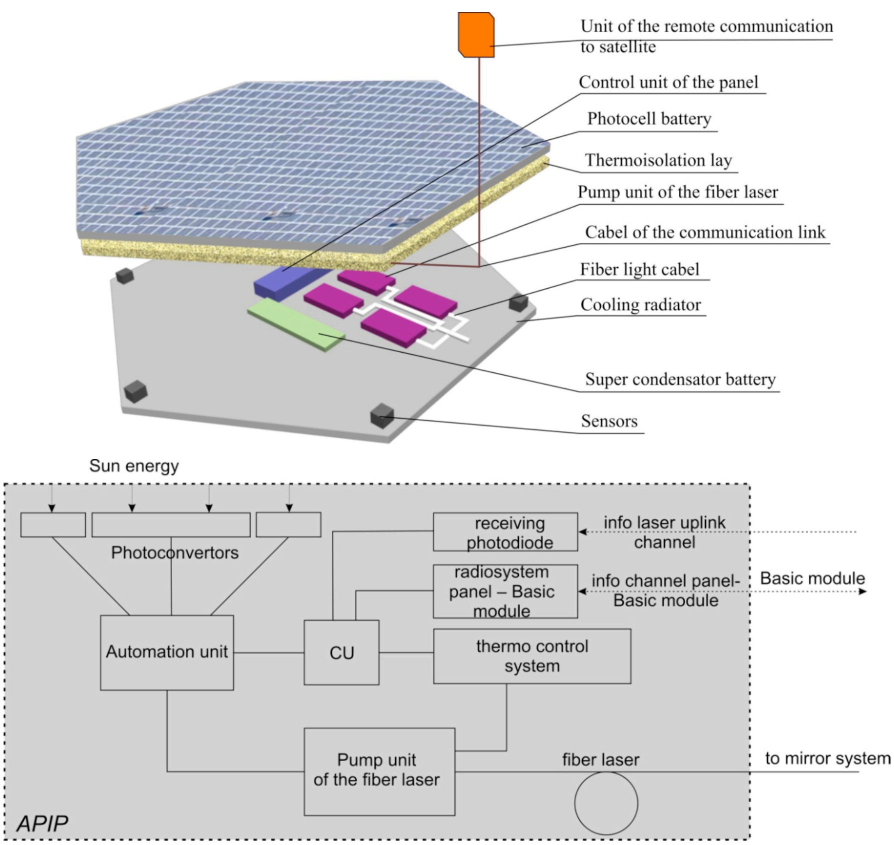

Figure 2: Design of photo convertors panel (**a**) and functional diagram of autonomous photoemission panel (**b**).

- fiber lasers;
- system of sensors;
- communication unit with basic module.

Detailed functional diagram of the module which describe main parts of the module and communication lines between them are shown on the Figure **2b**. One of the key problem is thermal control mode of the module because the operable temperature range should not be out of from minus 70 up to 90 °C. As per thermal calculations to provide this thermal mode is possible first of all by optimization of optoelectronic units accommodation which obtained by distributed light diode fiber laser pumping.

For high efficiency operation of the demonstration SSPP requires panels of photoemission modules with maximum available area in order to create maximum power. Therefore in this publication four options of layout diagrams of SC for the fairing of launcher "Proton" have been considered.

The choice of operational orbit for demonstration SSPP is stipulated by the following conditions:

- Low altitude to transfer power in order to avoid creation of big mirror systems and provide the required pointing accuracy of the laser transmission power channel.
- Quite a long over flight time along the ground photo detector site.

Such kind of orbit is high elliptical orbit type "Molniya". The control complexity at this orbit much more compare to geostationary orbit and high speed and high accuracy pointing of laser beam are required.

3. RIGID TRANSFORMABLE STRUCTURE WITH HORIZONTAL PLACEMENT

This option-horizontal placement of the photoemission modules panel is presented at Figure **3**. This diagram has shown standardizated hexagonal photoemission modules. The dimensions of this panel of modules are very close to the fairing sizing. The thickness of the module is determined by production technology of photo convertors and parts of fiber laser and lay in the range of 60÷80 mm.

The advantages of this diagram as follow:

- High level of standardization which allow to organize mass production.

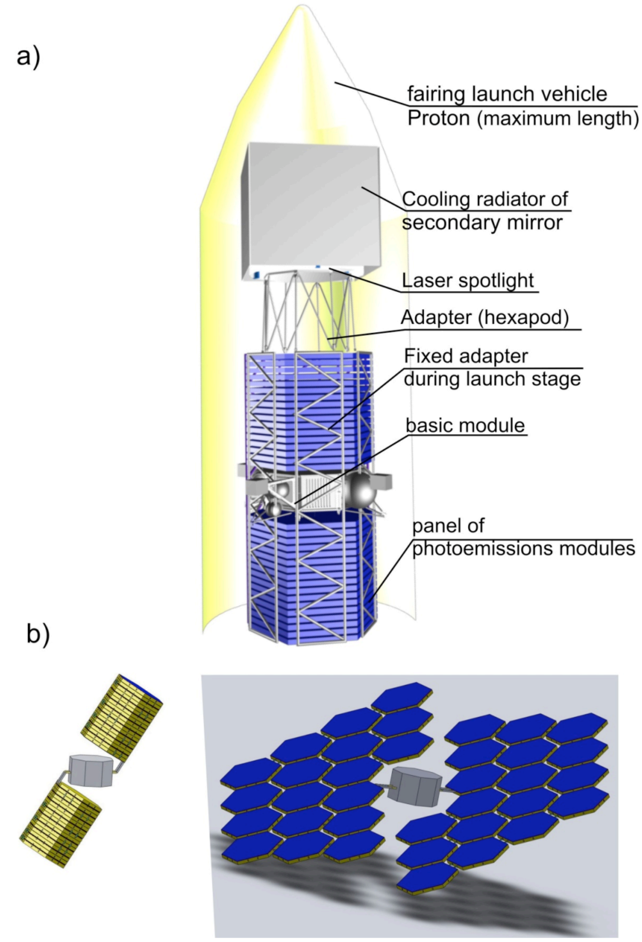

Figure 3: SSPP diagram with horizontal placement (**a**) and deployment procedure of photoemission modules panels (**b**).

- The possibility to hold autonomous tests of the module itself and expand its results over the whole modules panel of the demonstration SSPP.
- The possibility of accommodation of high efficiency thin-film photo convertors based on gallium arsenide [7].

The spacecraft consist of space bus, hexapod, laser fiber optic projector and system of rigid hexagonal coupled plates with the thickness up to 60mm of photo-laser convertors with total area up to 300 m^2.

The panels of photoemission module storage under fairing Figured as hexahedron type is quite complicated because it would be executed in perpendicular direction which opposite the flight axis. Therefore the panel will get side loads during orbital injection and lead to weight growing of the whole structure.

To deploy the spacecraft on the orbit it requires special mechanical structures. The panels of the photoemission module must be sliced in order to create the gap between the frame (hexapod) with fiber-optic laser search light and spacecraft bus. This gap will be determined by attraction mechanism of the assembled part "frame – fiber-optic laser search-light" to the spacecraft bus.

Threefold deployable structure of the photoemission module panel which create multi-link chain will be not rigid enough. But based on autonomous photoemission modules it is not necessary to have a rigid link between modules within the panel structure because emission of fiber-optic laser will transfer through many light-guard optic fibers which have any configuration and allocate within the mirror system. Deployment of hexahedron photoemission modules is quite difficult stage from attitude point of view of the spacecraft (dynamic control).

After deployment of the photoemission modules panel spacecraft will be oriented itself on the Sun with the help of reaction wheel. After this the electric propulsion system will switch on and spacecraft will be placed from intermediate orbit into working orbit [8].

After injection of SSPP into working orbit the spacecraft with hex sides panels will be orient on the Sun then with the help of radio link will found the power receiver point and will operate in the small power mode time to time switch on the mode of max achieved power. To trace the receiver position and compensate the spacecraft vibration hexapod will be used.

Hexapod is special mechanism based on six sections frame with liner drive mechanism in the rod links. Joint move of the drives will allow us to get high accuracy orientation of the frame area (mirror system of laser search light) in the space (such technic very often use in astronomy units and tooling).

4. RIGID TRANSFORMABLE STRUCTURE WITH VERTICAL POSITIONING

Let us consider the following type of configuration of demonstration SSPP which based on vertical placement of photoemission modules under fairing (Figure **4**).

The spacecraft consist of satellite bus, hexapod, fiber optic search light and system of rigid tetrahedral coupled photoemission modules with the thickness of 40-60 mm and total area around 140 m^2.

Placing of the photoemission modules panels under this type of fairing is very similar to the placing of solar

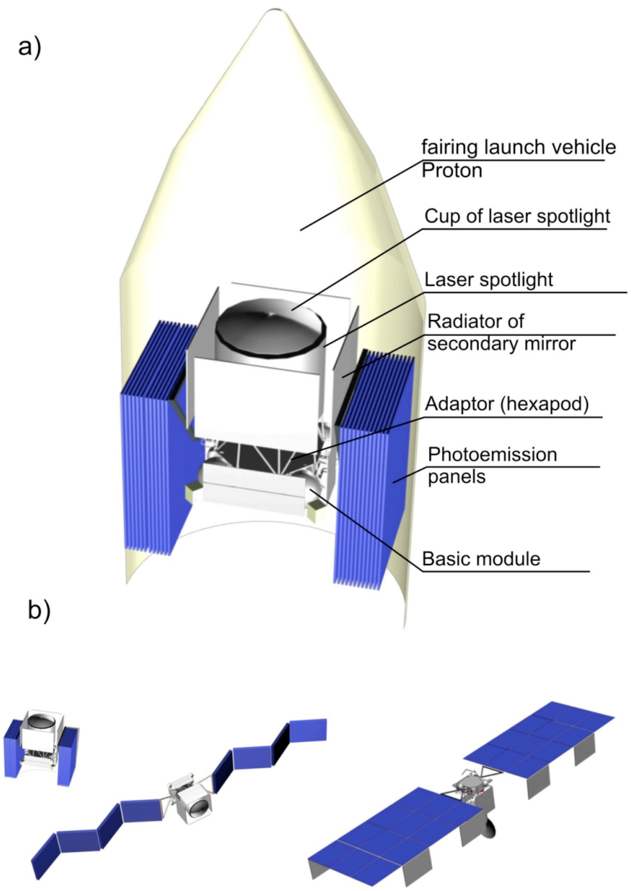

Figure 4: The layout of SSPP with vertical packing of the panels of photoemission modules (**a**) and deployment procedure of photoemission modules (**b**).

arrays. The panels are placed along the flight direction axes and get longitude loads during launch phase.

Configuration under fairing and method of placing of photoemission modules panel is very traditional. Deployable panel design of photoemission modules which create the multi-link-chain will be rigid enough because the quantity of the links in chain do not exceed 4.

The deployment procedure of rectangular panels of photoemission modules is conventional. To deploy it properly the springs and cable compensator of the deployment dynamic will be used.

After the deployment of the panels the spacecraft will be oriented on the Sun with the help of engine flywheel. After this the electric propulsion system will switch on and spacecraft will be placed on operational orbit from transfer or low orbit.

After the final orbital injection the spacecraft will be oriented on the Sun, with the help of radio equipment will find the power receiving point and operate at the small power mode with periodically switching on maximum power mode. To trace the position of receiving point and compensate the vibration of spacecraft will be fulfilled with the help of special system which based on hexapod. Such particular structure of the panel is quite rigid but its deployment compare to the above mentioned type is simpler and well developed on conventional solar arrays. The production technology of photoemission modules is the same as per above mentioned type.

5. FLEXIBLE HARDENED STRUCTURE OF THE PANEL OF PHOTOEMISSION MODULES

Next type is using technology of hardened structure to create big size panel of photoemission modules (Figure **5**).

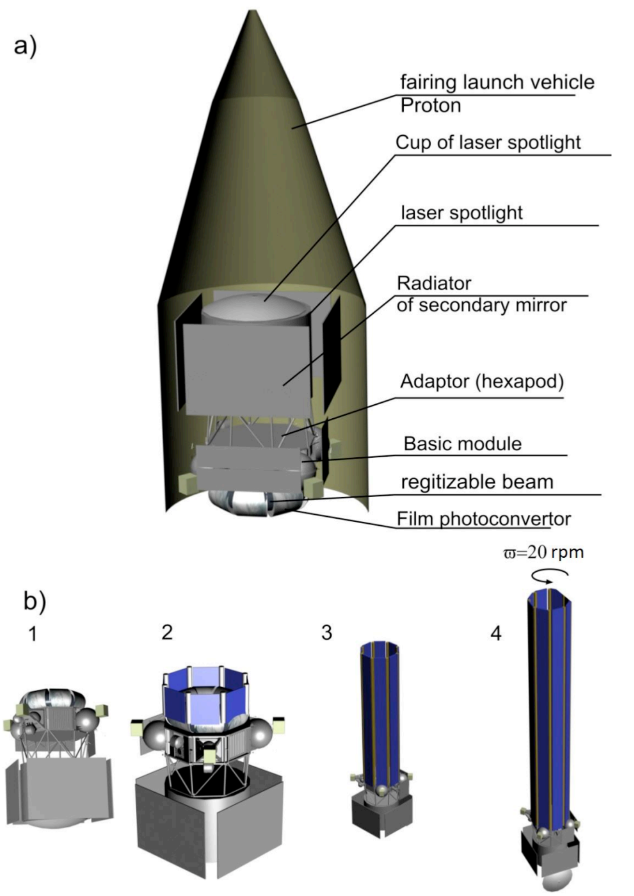

Figure 5: Layout diagram of SSPP with hardened structure of panel of photoemission module (**a**) and deployable scheme of hardened structure (**b**).

This type is based on technology which has been started developing for creation of large size light space structures. This technology based on using polymer inflatable hardened materials [9].

Such kind technology will allow to use the payload volume under fairing with maximum efficiency.

Spacecraft consist of satellite bus, hexapod, fiber-laser spotlight and system of photo convertors plates with the thickness of 20 μm which create linked photoemission modules with total area up to 300 m² structured on hardened rods.

Packaging of filmed photoemission modules and hardened rods of bellows or drum type is unconventional because it's located in perpendicular direction against of flight axe and accept the lateral loads during launch.

In order to finalize the layout of deployed spacecraft it is required additional mechanical complications of design. We have to add pneumatic inflatable system of hardened rods in order to create structure while opening and keep pressure till the harden process will be finished. Alongside with rods opening the deployment of photoemission modules will be fulfilled and layout of fiber light cables.

Deployable structure of the panels of photoemission modules which create space framework is quite rigid.

Here we can use two different type of photo convertors:

- Flexible film photo convertors based on CIGS with thickness of 5-10 μm and expected efficiency up to 20% [7].
- Thin film multilayer structure based on GaAs as mosaic structure on the film of hardened structure.

Deployment of hardened panels of photoemission modules is one of the most complication moment from spacecraft attitude point of view (dynamic control).

After the deployment of all systems SC will be oriented on the Sun with the help of engine flywheel. After this the electric propulsion system will switch on and spacecraft will be placed on operational orbit from transfer or low orbit.

After placing SSPP on operational orbit SC with hardened panels will oriented on Sun. By doing so the gravitation orientation will take place in the mode of slow rotation of whole SC. Then with the help of radio equipment will find the power receiving point and operate at the small power mode with periodically switching on maximum power mode. To trace the position of receiving point and compensate the vibration of spacecraft will be fulfilled with the help of special system which based on hexapod with mirror system of laser spotlight which is similar to the above mentioned type.

6. FILM TRANSFORMABLE STRUCTURE BASED ON SOLAR SAIL

Finally the forth type which is based on Solar sail design. Here is the thin film photo convertors and fiber laser which built in boom arm of the deployable curtain of photo convertors are applied (Figure **6**).

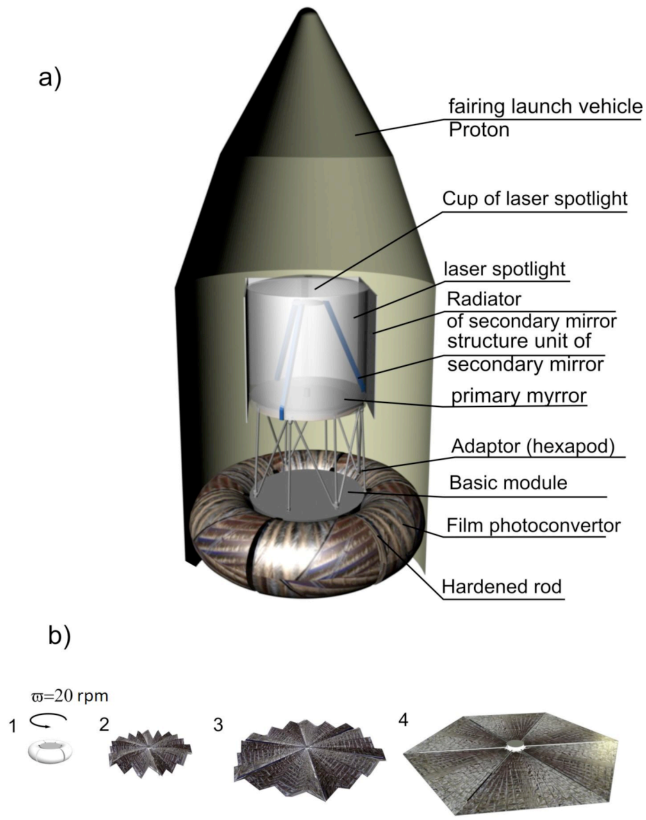

Figure 6: Configuration of SSPP with flexible film photo convertors (**a**) and deployment procedure of thin film photo convertors structure (**b**).

This type is used the following main factors:

- Utilization of thin film photo convertors based on CIGS with the thickness of 5 µm and expected efficiency up to 20%.
- This particular thickness will allow to package under fairing quite large area of film photo convertors.
- Utilization of deployable procedure which based on solar sail technology [10-11].

Spacecraft consist of satellite bus, hexapod, fiber-laser spotlight and system of film photo convertors with the thickness of 20 µm which create linked photoemission modules with total area up to 1000 m².

Packing of photo laser convertors is under fairing around satellite bus with 6 stiff strength elements of plate type.

To finalize the layout of deployed SC is required some mechanical complications. Photo convertors panels (thin film with optical glass fiber) must be opened under action of centrifugal stresses. To this end the twist nozzle must be implemented into design of the SC. Deployable structure of thin film photo convertors with spring parts is quite simple and symmetrical.

The openings of the curtain of thin film photo convertors at the rotation mode provide the stabilization of the whole system from attitude of SC point of view.

When the opening has happened SC will be oriented on Sun with the help of engine flywheel. After this the electric propulsion system will switch on and spacecraft will be placed on operational orbit from transfer or low orbit.

After the final injection into operational orbit the spacecraft with thin film convertors will be oriented on the Sun, with the help of radio equipment will find the power receiving point and operate at the small power mode with periodically switching on maximum power mode. To trace the position of receiving point and compensate the vibration of spacecraft will be fulfilled with the help of special system based on hexapod which control mirror system of laser spotlight.

7. COMPARATIVE ANALYSIS OF DIFFERENT TYPES OF TRANSFORMABLE STRUCTURES OF DEMONSTRATION SSPP

Considered in the article different type of configuration of SSPP could be the base for further developments of design work to create demonstration SSPP. On Figure **7** there are comparison results of all configuration types of demonstration SSPP with regard to main parameters which determined the efficiency of such power station.

As we can see from Figure **7** the composition of systems of different configuration types is similar. As to the predicted level of electric power capacity all four types will ensure realization of demonstration experiment. Film system (type 4) is different compare to the others with injection mechanism – twist nozzle is

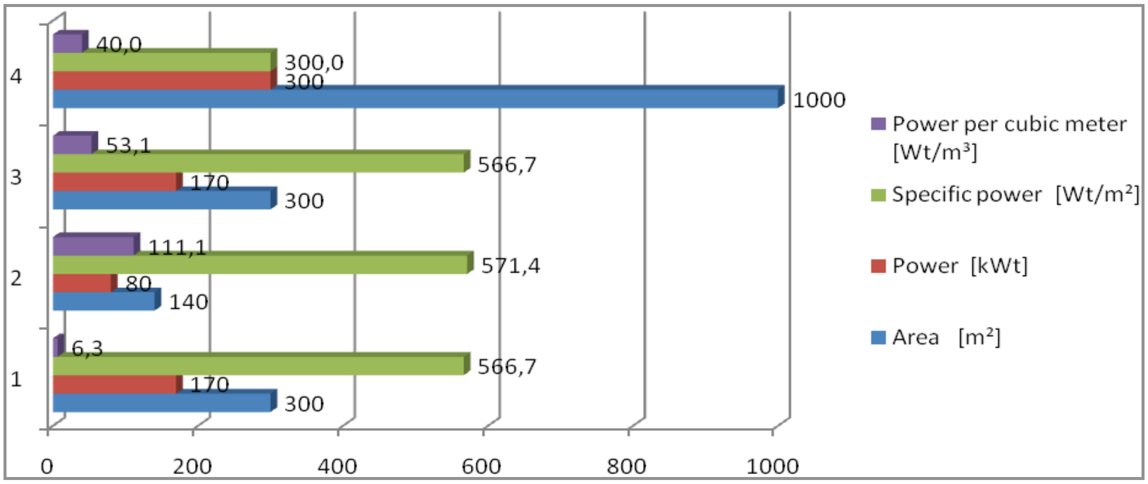

Figure 7: Comparative parameters of different types of configuration of demonstration SSPP.

implemented and it uses as actuator of opening. But this type is more complicated from mechanical point of view then others. Type 3 uses pneumatic system which consist of gas cylinder. This type is quite complicated for installation of photo convertors plates. Type 1 is more attractive but it requires complicated deployment system of panels of modules.

At the moment more preferable type is number 2. This type is based on well developed technology of deployment of solar arrays of large modern SC and will allow immediately to start preliminary design of demonstration SSPP.

Additional expenditure will require production of special equipment for ground testing (stand equipment, clean facilities with proper volume), training of stuff who have the experience with the above described structures. Specific feasibility report will be prepared after preliminary design review stage.

At this stage the analyses which done in the article has shown that there are some design solutions based on technical findings of the modern space rocket industry and will allow to start realization of the project – Demonstration solar space power station.

Carrying out of the project on creation of demonstration space power station will allow not only fulfill the flight test of such space complex but will get the hybrid solar space power station on the Earth which operate from Sun and laser emissions. Demonstration experiment based on real space conditions is one of the most important key point to create the first pilot industrial space power station because only based on its results it is possible to confirm the validity of assumptions made during theoretical investigations.

The International Specialized Exhibition EXPO - one of the most important international forum dedicated to the theme "Energy of the Future" will be held in Kazakhstan in 2017. The idea to hold EXPO in Astana belongs to the President of Kazakhstan Nursultan Nazarbayev.

The project on creation of a space solar power station in our opinion is a promising direction in energy, energy conservation and energy efficiency - the development scenario of innovative technologies and equipment implementation in the energy sector and, as a result, economic growth and sustainable development of countries around the world.

In this regard, with the support of the National Scientific and Technological Holding "Parasat", we are performing the work on creation of a working model of space solar power station and the current stand of energy transfer, which are expected to be presented at EXPO 2017.

EXPO will be held in Kazakhstan for the first time. As it was noted in the Paris headquarters of the International Exhibitions Bureau, the choice is not accidental. EXPO in Astana is a fundamental phase of the Kazakhstan Development Strategy until 2050 - the embodiment of the ideas of the President to establish a welfare society based on a strong state in the long term, an attempt to save the Earth planet for our descendants.

8. CONCLUSION

In this manuscript the possibility reduction to practice of demonstration SSPP based on current satellite platforms and launch vehicle PROTON has been shown in different types of transformable photo convertors structure and mirror system to transfer laser emission.

Materials of this assumption could be the base for reduction to practice of solar space energy.

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