DOI 10.31489/2023No1/65-72

UDC 629.78

ALGORITHM FOR FINDING MAXIMUM POWER POINT TRACKING WHEN SHADOWING OR FAILURE OF SOLAR PANEL PHOTO CELLS ON SATELLITES USING LOW ORBITS

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Solar cell shading or the failure of several photocells changes the output current-voltage characteristic. This paper discusses an algorithm for approaching and searching the maximum power generated on board the spacecraft, which is all-important for fast charging of the secondary sources of electrical energy since the time spent on the sunny side in low orbits are limited by time. Currently, algorithms for finding maximum power work in ideal cases, and simple and effective algorithms are needed in cases of solar panel shading or failure of photocell/cells. In this paper, a simulation of a solar panel in various conditions is carried out. An algorithm for constructing the output volt ampere characteristics of a solar cell and a solar panel is implemented. Experiments of various algorithms on real devices have also been carried out.

Keywords: Maximum power point tracking, Python, current, voltage, failure, shadowing effect, power supply system

Introduction

The number of satellites in low earth orbit is growing every year and will reach 100,000 satellites by 2030 [1]. The size of satellites is decreasing due to the development of technologies in the field of electronics, but the energy needs of the spacecraft are increasing due to the increase in the flight task. There is also a growing number of radar satellites that use an active payload and their consumption is much higher than that of optical spacecraft. Satellites in low orbits have a limited amount of time on the sunny side, so the challenge is to speed up the charge of the battery while passing through the consecrated part of the satellite's orbit [2]. The spacecraft power supply system uses two types of charge: direct energy transfer (DET-Direct Energy Transfer) [3]; maximum power point tracking (MPPT) method [4]. Direct Power Transfer - Without the usage of converters or regulators, power from the solar panel is sent directly to loads.

To select the optimal power from the solar panel, which depends on various parameters of the satellite, such as the angle of inclination of the solar panel relative to the sun, the temperature on the solar cells, efficiency, which is an integral parameter, service life and other criteria, the spacecraft power supply system uses the method of tracking the maximum power.

Solar cells often fail on spacecraft and for this purpose the MPPT search algorithm is needed. For shading cases, there are currently algorithms (MPPT algorithms for partial shading conditions) such as meta-heuristics, fuzzy logic based methods, numerical and mathematical application methods, hardware and modified conventional methods and etc. The onboard computer of the spacecraft is limited in computing power and the above algorithms require a lot of computing power. The developed algorithm reduces the load on the onboard computer.

1. Implementation of these algorithms on satellites KazEOSat - 1 and KazEOSat – 2

At the moment, JSC “National Company “Kazakhstan Gharysh Sapary” operates two optical remote sensing satellites KazEOSat - 1 - high resolution and KazEOSat - 2 - medium resolution, which is part of the space system of the Republic of Kazakhstan. The KazEOSat - 1 has a power supply system, which is

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implemented using direct energy transfer technology (DET) and the electrical architecture of the spacecraft is shown in Figure 1. The PCDU is a power control and distribution unit that uses a direct energy transfer system. The solar array generates energy, which is sent to the PCDU to charge the battery and supplies subsystems of the spacecraft with power:

- Onboard computer;
- Communication system (S-band and X-band);
- Attitude and orbit control system (reaction wheels, star tracker, GPS module, magnitorque and etc.).

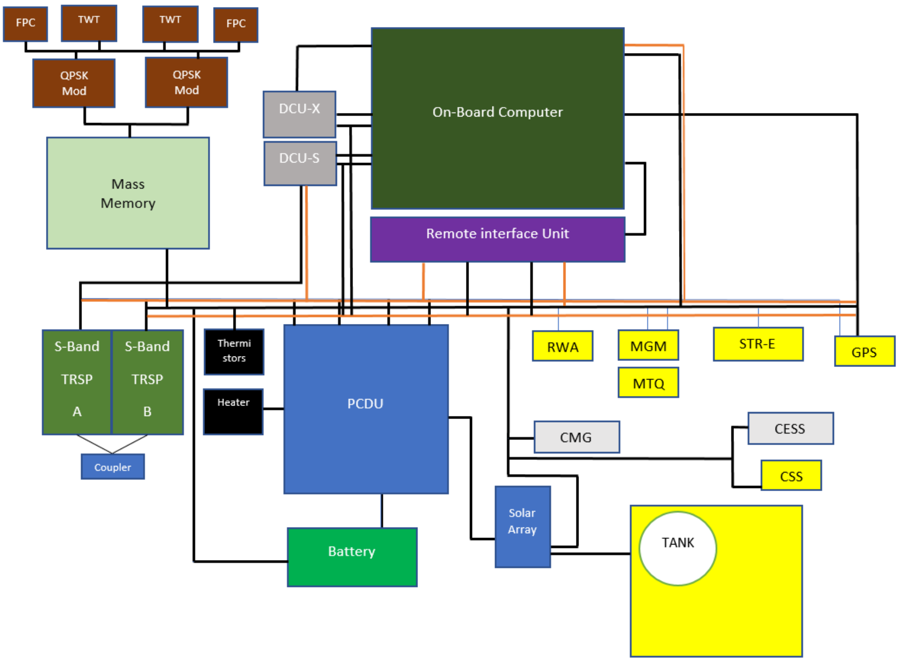

Fig.1. Electrical architecture of the KazEOSat -1.

The KazEOSat-2 satellite power supply system is shown in Figure 2, this spacecraft has an MPPT charge system [5].

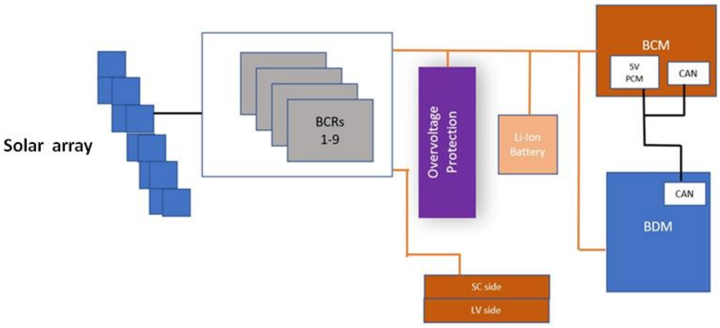

Fig.2. Electrical architecture of the KazEOSat – 2.

On the satellite KazEOSat - 2, the solar array generates an electric current, which is directed to the battery charge regulator (BCR), BCR has the MPPT algorithm installed. Further, the current with maximum power charges the battery and part of the energy is directed to the energy distribution module.

2. MPPT algorithms (methods)

There are numerous MPPT methods available at the moment for locating a spot with the greatest power. The most popular ones are:

- Perturb and observe method (P-&-O) [6];

- Incremental conductance method (IC) [7];
- Current sweep method (CS) [8];
- Constant voltage method (CV) [9];
- Temperature method [10].

Currently, satellites use the P-&-O method and the IC Method, since these algorithms are more stable in finding MPPT. These algorithms have been modeled in Python for a photocell and a solar panel. The photocell's electrical circuit is shown in Figure 3 [11 - 12].

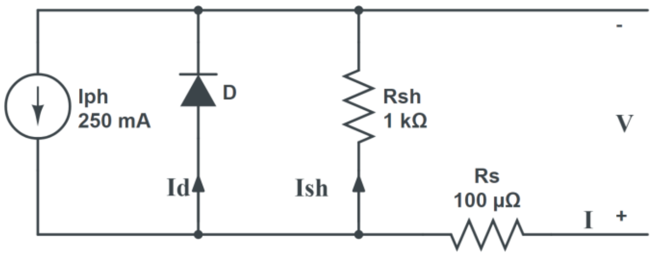

Fig.3. The electrical circuit of the photocell.

The code is implemented in Python [13] for simulating a solar cell at various incident light intensities and temperatures in the form of a diagram shown in Figure 4.

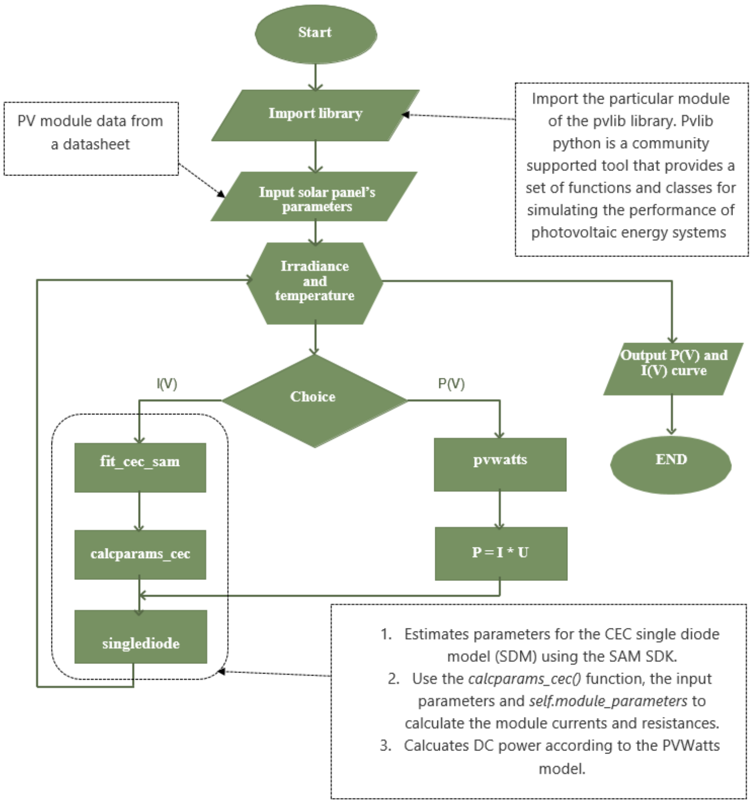

Fig.4. The python code algorithm for solar panels in the form of the diagram

The relationship between current and voltage in proportion to light intensity is seen in Figure 5. Figure 6 is showed the simulation results of the dependence between voltage and current at different temperatures on a photovoltaic cell. Figure 7 is showed the dependence of the maximum power and voltage on the different angles.

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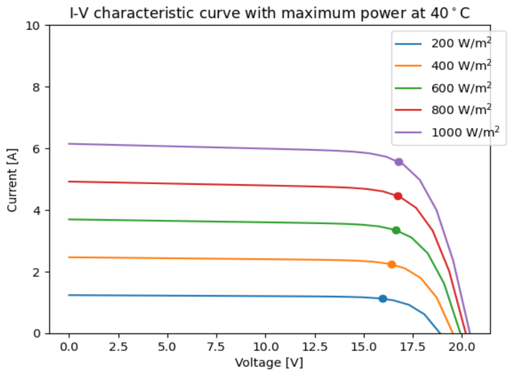


Fig.5. The relationship between current and voltage about light intensity.

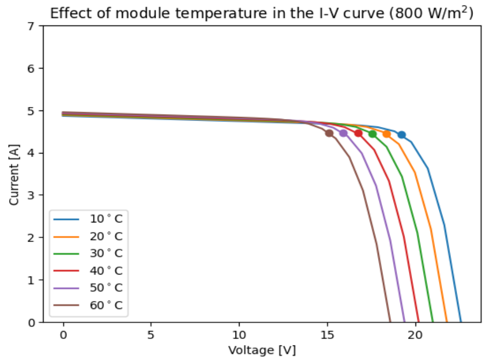


Fig.6. Simulation results of dependence between voltage and current at different temperatures

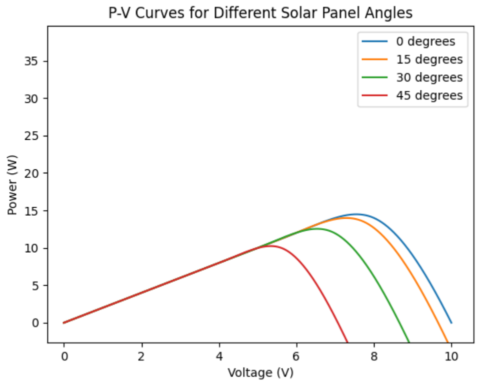


Fig.7. Simulation results of dependence of the maximum power and voltage on the different angles

Figure 8 presents the electrical circuit to simulate the solar panel [14 - 15].

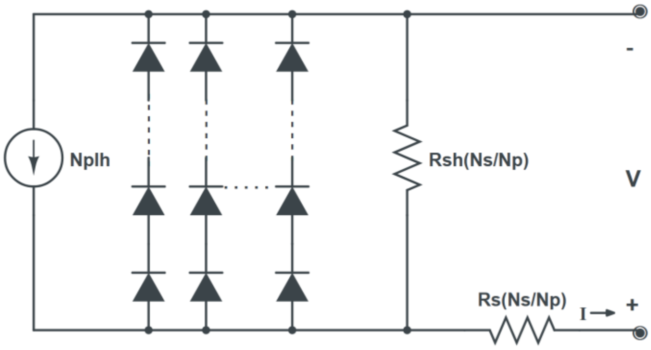
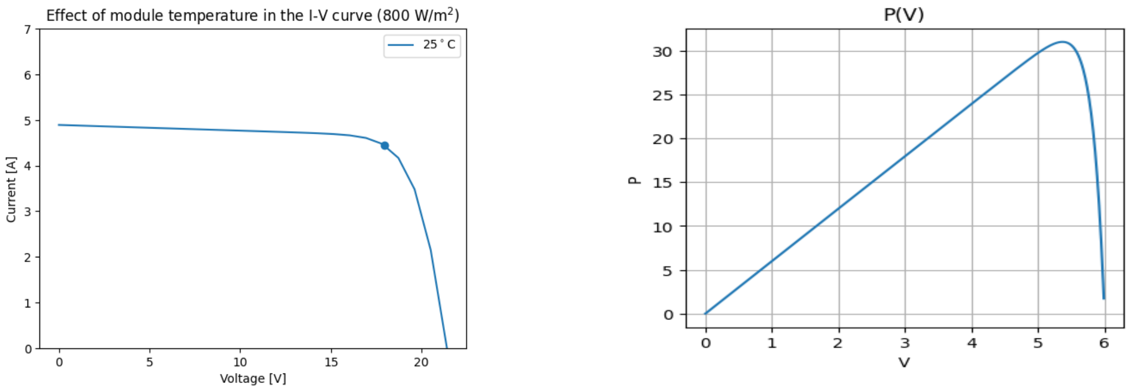


Fig.8. The electrical circuit of the solar panel.

Simulation outcomes are shown in Figure 9, which shows the dependence of current on voltage and power on voltage. These graphs are obtained by simulating the solar panel, under conditions when all photocells are working properly. The dependence of current on voltage is shown in Figure 9 a) and Figure 9 b) shows the curve of power on voltage.

Experiments were also carried out with real devices for the implementation of MPPT algorithms. A power board and a controller that is developed using the high-performance automotive grade microcontroller (TMS 470) make up the hardware and software complex for optimizing the search and selection of the greatest output power from the primary sources of satellites.



a) b)

Fig.9. The results of the simulation of the solar panel.

Figure 10 depicts the power board which was made with the help of the CADSTAR software, which is used to design printed circuit boards. A Gerber file that comprises numerous topological elements was created for the fabrication of printed circuit boards. Figure 11 shows the TMS 470, which realizes algorithms to find MPPT.

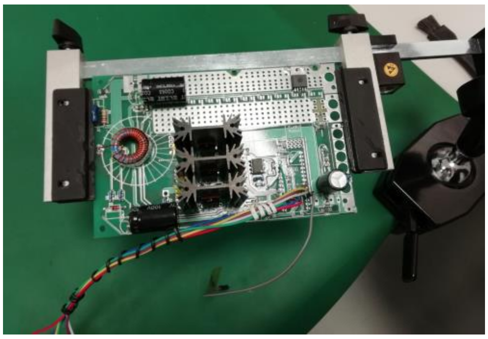


Fig.10. The power board.

Fig.11. The TMS 470.

The MPPT controller measures current, voltage, and battery voltage. The algorithm for determining the maximum power point then generates a PWM signal to create a duty cycle using the control of MOSFETs based on the input data. The MPPT controller's operation is based on locating the solar panel's maximum power point. The following factors influence where the maximum power point is located: Environment temperature; Solar panel lighting.

The power board assembly, TMS 470, electronic load, and power source are all depicted in Figure 12. On this assembly, all electrical testing has been performed. The results of defining the maximum power of the assembled devices are shown in Figure 13.

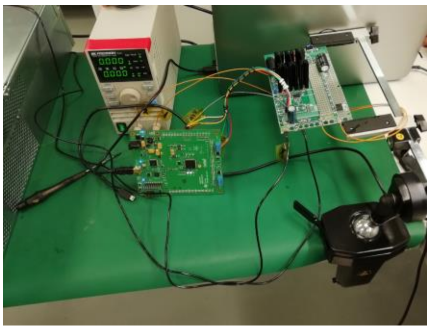


Fig.12. The assembly of controller and power boards.

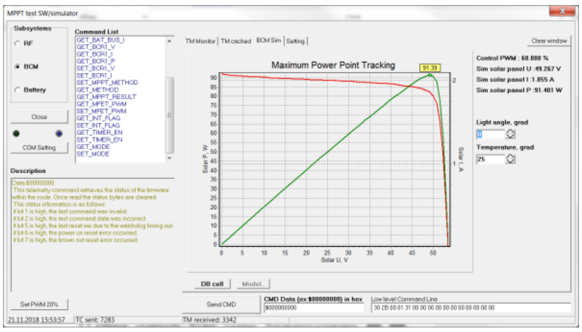


Fig.13. The results of the assembled devices.

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Used algorithms search for maximum power and charge the spacecraft battery with the appropriate current and voltage, which is equal to the MPPT. The algorithms find the pick of power when the solar panel is not shaded or there is no photocell/cells failure.

3. MPPT algorithm for shading or failure of a photocell/cells

The satellite's solar panel may be obscured by the structure or the solar array elements may fail. Robust algorithms are needed that work in all cases, including the worst. This article shows a solution for finding the MPPT when a panel is shaded or a photocell or multiple elements fail. In these cases, the panel has different current-voltage characteristics, which are shown in Figures 14 and 15.

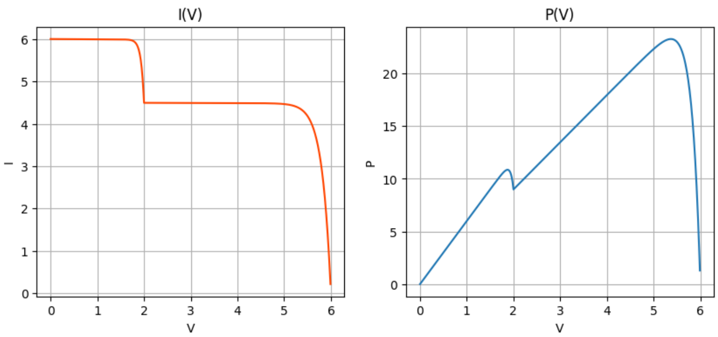


Fig.14. The results of shaded or a photocell or multiple elements fail.

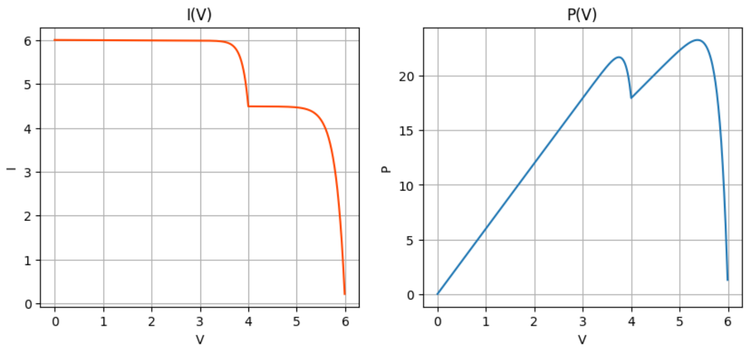
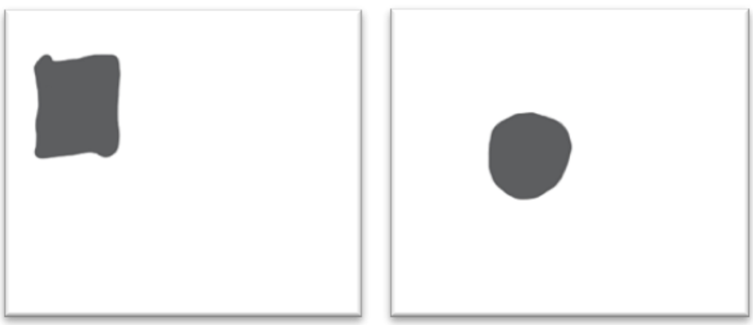


Fig.15. The results of shaded or failure of a photocell/cells.

Figure 16 a) corresponds to the results in figure 14. Figure 16 b) corresponds to the results in figure 15.



a) b)

Fig.16. Shaded or failure sectors in the solar panel

The foregoing algorithms for discovering MPPT start to fail when shading or failure of the photocell/cells in Figure 14 and 15 occur because numerous maxima arise, and there is no longer a search for the global maximum that is required for quick secondary source of charging. Nowadays, there are algorithms for finding MPPT during shading and failure photocell/cells, but they are very difficult to implement and put a lot of load on the controller when searching [16 - 17]. Figure 17 shows the implementation of the methods for finding the maximum power in the event of darkening or loss of photocells.

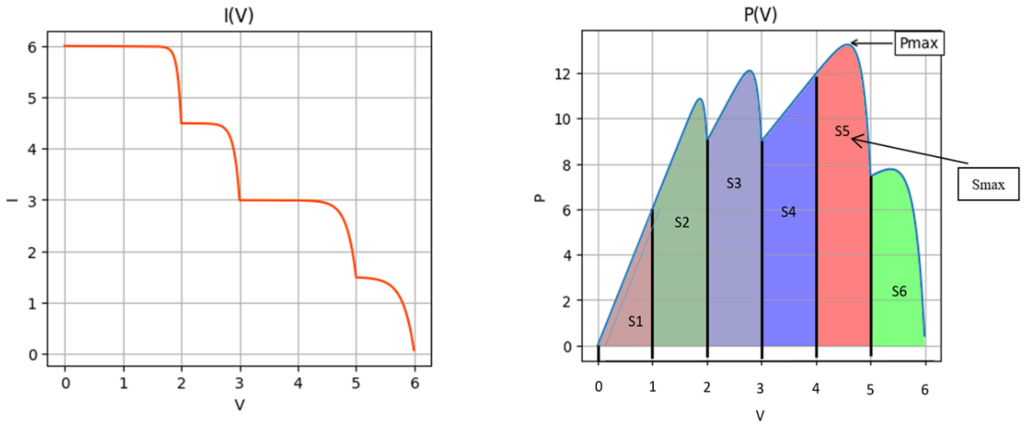


Fig. 17. MPPT algorithm in case of darkening or loss of an element/elements

The implementation of finding the MPPT in cases of shading or loss of photocells is shown in Figure 18. According to Figure 17, the voltage axis is divided into equal parts by steps that are multiples of the open circuit voltage of the solar cell or cells linked in series.

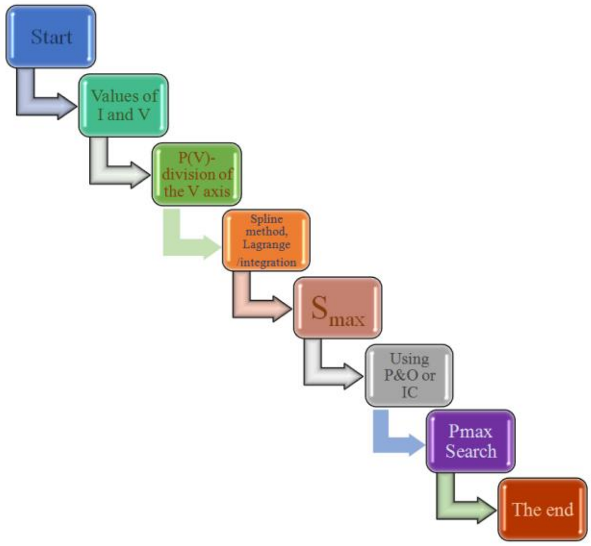


Fig. 18. Algorithm to find MPPT for worse case

The function will then be recovered using interpolation techniques (such as splines [18], Lagrange polynomials [19], etc.). The area of each graph segment will be calculated using integration. The largest area is determined by comparing the areas to one another. The MPPT is established in the region where the maximum area is established utilizing the P-&-O or IC methods.

Conclusion

In the event of darkening or photoconverter failure, algorithms for determining the MPPT were examined. The proposed MPPT search algorithm uses minimal mathematical formulas that will not load the controller's work. And this algorithm can be used on board the spacecraft without taking into account temperature changes on the solar battery and also the period of active existence. As a result of the analysis of the literature, it can be concluded that the proposed solution is relevant, optimal and will be used in future missions on spacecraft, as well as on ground-based solar stations.

Acknowledgments (or Funding)

The work was carried out within the framework of the research project № BR109018/0221 funded by the Ministry of Digital Development, Innovations and Aerospace Industry of the Republic of Kazakhstan

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Article accepted for publication 20.03.2023