UDC 621.311.29

ALI. M. JASIM[1,2], YU. A. SHEPETOV[2]

[1] ***Space and Communication Technology Center, Ministry of Science and Technology, Iraq***
[2] ***The National Airspace University named after N. E. Zhukovskiy «KhAI», Ukraine***

MAXIMUM POWER POINT TRACKING METHOD FOR SUBSATELLITE SOLAR POWER WORKING UNDER PARTIALLY SHADED CONDITIONS

The objective of this work is to study the features of the Maximum Power Point Tracking (MPPT) for subsatellite solar power under partial shading condition of its panels. Subsatellite power system operates in parallel with a much greater power system of main satellite. Simulation was performed with the help of Matlab/Simulink. Different methods of MPPT were considered. The results of the study allow us to conclude that conventional MPPT methods not well suited for solving the above problem due to the presence of multiple extreme in the power curve under partial shading of the few solar panels connected in parallel.

Keywords: *Photovoltaic system, maximum power point tracking, satellite power system, Matlab/Simulink.*

Introduction

One of directions of development of space technology is the use of complexes of multiple spacecraft, "main satellite"-"subsatellite". For example, "Sich-1M"-"KS5MF2" (Ukraine, 2004), "Sich-2M"-"Youth subsatellite" (Ukraine, currently being developed).

In this case, the power systems of both satellites can operate in stand-alone mode or in parallel on a common load. Technology of using PWM control operation in power system put new features for the control algorithms for their parallel working. Especially under uneven and variable illumination of PV panels, since most of subsatellites belong to the class of "micro" and do not have their own system of orientation of the panels [1, 2].

Closest analogue of this system is a grid connected ground solar power unit.

Traditional method fail to ensure successful tracking of the maximum power point under partial shading conditions (PSC). This performs in significant reduction in the power generated as well as the reliability of the photovoltaic energy production system. For the effective utilization of solar panel under partial shading condition (PSC), maximum power point tracking method (MPPT) is required.

Solar photovoltaic (SPV) power generation is a stand out amongst the most important headings in the field of new energy improvement. In SPV power generation system, the operating point has extensive effect on the conversion efficiency of PV systems, and hence the exploration on maximum power point tracking (MPPT) algorithm has been one of the hot issues constantly.

The MPPT tracks the optimal point at which maximum energy can be extricated from the panel. For working the PV at maximum power the conductance coordinating for the PV panel is done by varying the duty cycle of DC to DC converter associated with it [3, 4].

In this paper we investigate, in particular, the dependence of the output power of the subsatellite power system from the parameters of the control PWM signal when it is in parallel with the main power system under different lighting conditions of panels and different output voltage level.

Maximum power point tracking under partially shaded conditions

A MPPT technique is implemented with the use of a boost DC-DC converter in the following sections under partial shading conditions. The PV array is connected to a Maximum Power Point Tracking (MPPT) in order to optimize the DC output power of the PV array by varying the operating voltage of the PV array [5, 6]. Under partial shading conditions multiple local maxima will appear on the power-voltage characteristics of solar PV system in that only one will be global maximum power point [7].

Solar array has been simulated in MATLAB to investigate the characteristic curves subject to varied shading circumstances. Four solar module are connected in parallel to form a panel and, as it appears in Figure 1. Each module exposed to four light sources for full radiation having an open circuit voltage V_{OC}= 28.14 V and short circuit current I_{SC} = 9.42 A. The combination of each modules for full radiation to form a solar array of maximum power 238.5 W at V_M= 26.5 V and I_M= 9.

In this model, for simulating partial shading effect, it is considered each PV module has a bypass diode connected in parallel itself as shown in Figure 1, if there is no bypass diode across the module, there is a chance of avalanche breakdown causing hot spots on the solar cell and results the damage of solar cell.

For zero atmosphere for space power application i.e. 1350 W/m^2 the solar cell produces rated power. The irradiance value can be changed manually and the variation corresponding to irradiance variation can be observed. When the irradiance value decreases, the voltage and current level of solar array reduces hence the power output from the array reduces considerably.

Photovoltaic cells, usually considered to have the same characteristics, are arranged together in series and parallel to form arrays.

Cells connected in parallel increase the current and cells connected in series provide greater output voltages [3, 4, 6].

The equivalent circuit of PV array under partial shading conditions (PSC) can be described as illustrated in Figure 1.

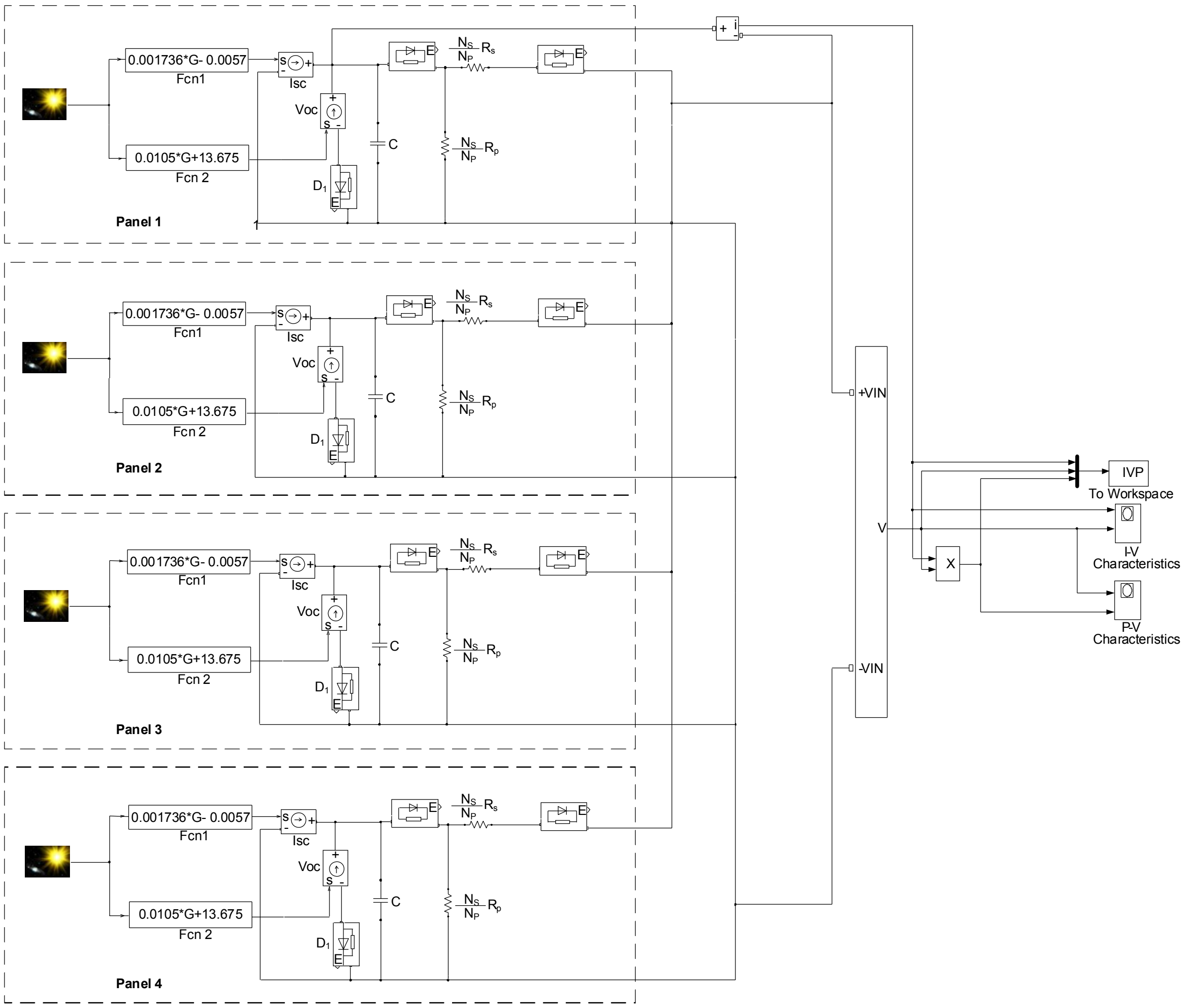


Fig. 1. Simulation diagram for of PV array under partial shading conditions (PSC)

System description

The satellite power system consist of two stages "main satellite"-"subsatellite". The DC-DC boost converter, which will raise the relatively low solar voltage to a level suitable voltage for the DC link. The system formation of solar power subsatellite system, is shown above in Figure 1.

Hybrid methods MPPT

In the case that different MPPs exist because of the partial shading, the ordinary strategies of MPPT methods may converge to local MPPs rather than the GPmax. This is because in these methods the global and local peaks can't be recognized [7]. The local MPPs and GPmax show the same characteristic, derivative of power with respect to voltage is zero (dP/dV= 0) [2], in this manner the MPP controller is not ready to recognize the real MPP and consequently extracted power of the PV system decreases significantly.

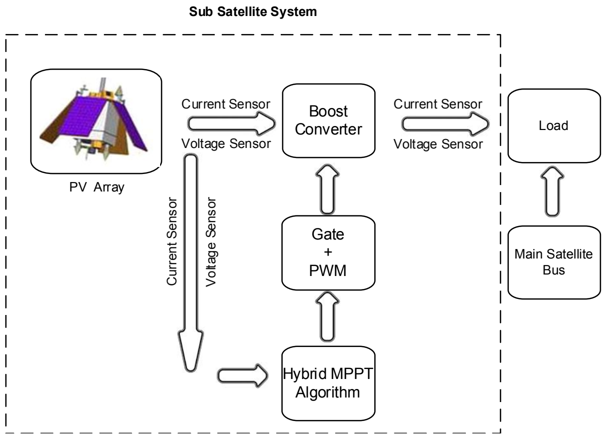


Fig. 2. General block diagram of configuration of Solar Power Subsatellite (SPS) System

A few tests on the PV array utilizing Matlab/Simulink has been satisfied to accept fulfillment condition that permit us to know whether there is partially shading.

It has been obtained some results in conclusion of simulations; when irradiation varies as uniform on the entire PV array, the difference between the proportion of powers (P_1/P_2) and proportion currents (I_1/I_2) are very slight; the proportion of current is calculated by the ratio of the previous measured the current of the PV array Ipv(k-1) to the present measured current of the PV array Ipv(k) and the proportion of power is calculated by ratio of previous the power of the PV power P(k-1) to the present power of the PV array P(k) [2]. However, under PSC, the mentioned difference dramatically varies, not stable. If variation of the current and the power of the PV array are observed, it allows detecting when PSC occurs.

$$(P(k)/P(k-1))-(Ipv(k)/Ipv(k-1)) > \text{Total difference}, \qquad (1)$$

where, P(k) - present power of the PV array,
P(k-1) - previous power of the PV array,
Ipv(k) - present current of the PV array,
Ipv(k-1) - previous current of the PV array.

In order to explain this, the characteristic of the PV array model is examined in the simulation environment for in cases of PSC and uniform insolation. For this study, the model consists of four PV modules connected in serial. The total output power of the PV array can be expressed simply as in Eq. (3).

$$P_T=P_1+P_2+P_3+P_4, \qquad (2)$$

where, P_T - the total output power of the PV array,
P_i - output power of PV modules.

In case of under uniform insolation, each PV module produced the same power and the total output of power can be calculated as in Eq. (2) since the every module's voltage is approximately the same value.

$$P_i=V_{M_i}\cdot I_{PV}, \qquad (3)$$

where, P_i - power at first maximum PV power,
V_{Mi} - voltage at first maximum PV power,
I_{PV} - current of PV module.

Substitute Eq. (3) by Eq. (2) can be expressed simply as in Eq. (4),

$$P_T=V_{M_1}\cdot I_{PV}+V_{M_2}\cdot I_{PV}+V_{M_3}\cdot I_{PV}+V_{M_4}\cdot I_{PV}, \qquad (4)$$

$$V_{M_1}\cong V_{M_2}\cong V_{M_3}\cong V_{M_4} \qquad (5)$$

$$P_T=4\cdot P_M, \qquad (6)$$

where, P_M - power at maximum PV power.

The PV current at the MPP (IMPP) produced by the shaded module can be characterized as in Eq. (2), where SF is Shading Factor, which is rate of the light of the shaded module to fully irradiation of the module, the degree of shading may differ depending on the intensity of filtering the daylight. This variety is modelled by a shading factor. A shading factor of one means that shadowing object filters out all available irradiance. As opposed to this, a shading factor of zero means that there is no shading absolutely [7]. The current at the maximum power point tracking (IMPPT) roughly linearly related to with short circuit current (ISC) of the PV array [2-5]. Where, K is a proportionality constant [2-5]. It has been simulated considering that ISC of PV module changes with the shading factor relatively and supposed that cells of every module are working under the same irradiance.

In this status every module has same voltage value, hence the PV array power can be computed as in (8).

$$I_{PV}=I_{MPP}=K\cdot I_{SC}\cdot I_{PV_2}=I_{MPP_2}=SF\cdot K\cdot I_{SC}, \qquad (7)$$

where, I_{MPP} - PV current at maximum PV power,
K - proportionality constant,
I_{SC} - short circuit current of PV module.

$$P_{T_2}=SF\cdot P_T=SF\cdot 4\cdot P_M, \qquad (8)$$

where SF - Shading Factor

The Proposed MPPT algorithm in this paper, incremental conductance (IncCond) method with direct control is chosen as the key calculation and indirect method short circuit current [2, 4, 5].

Accordingly, this paper proposed intelligent algorithm that is equipped for tracking GPmax under PSC. The flowchart of the algorithm is appeared in Fig. 3.

This method can identify the unoriginal-MPP. Scanning progress starts as soon as this function satisfies. In this checking procedure we record the all MPPs and duty cycle (D) all through all the operating points by changing duty cycle.

Simulation results

To confirm the proposed technique, simulations are performed for the PV array contains four parallel modules as shown in Figure (1) also, it is exposed different insolation conditions as appeared in Table 1. To test operation of the proposed technique, state of changing irradiation of was modeled as appeared in Table 1, and temperature of 25 °C has been maintained in these analyses.

Table 1

Test operation of the proposed technique under different irradiation

Panel	Irradiance, W/m^2			
	A	**B**	**C**	**D**
1	1350	675	1350	1350
2	1350	675	1350	1000
3	1350	675	1000	675
4	1350	675	675	350

Simulation of the P-V curve Fig. 4 (a) and I-V curve Fig. 4 (b) of PV module under PSC are represented in Figure 4.

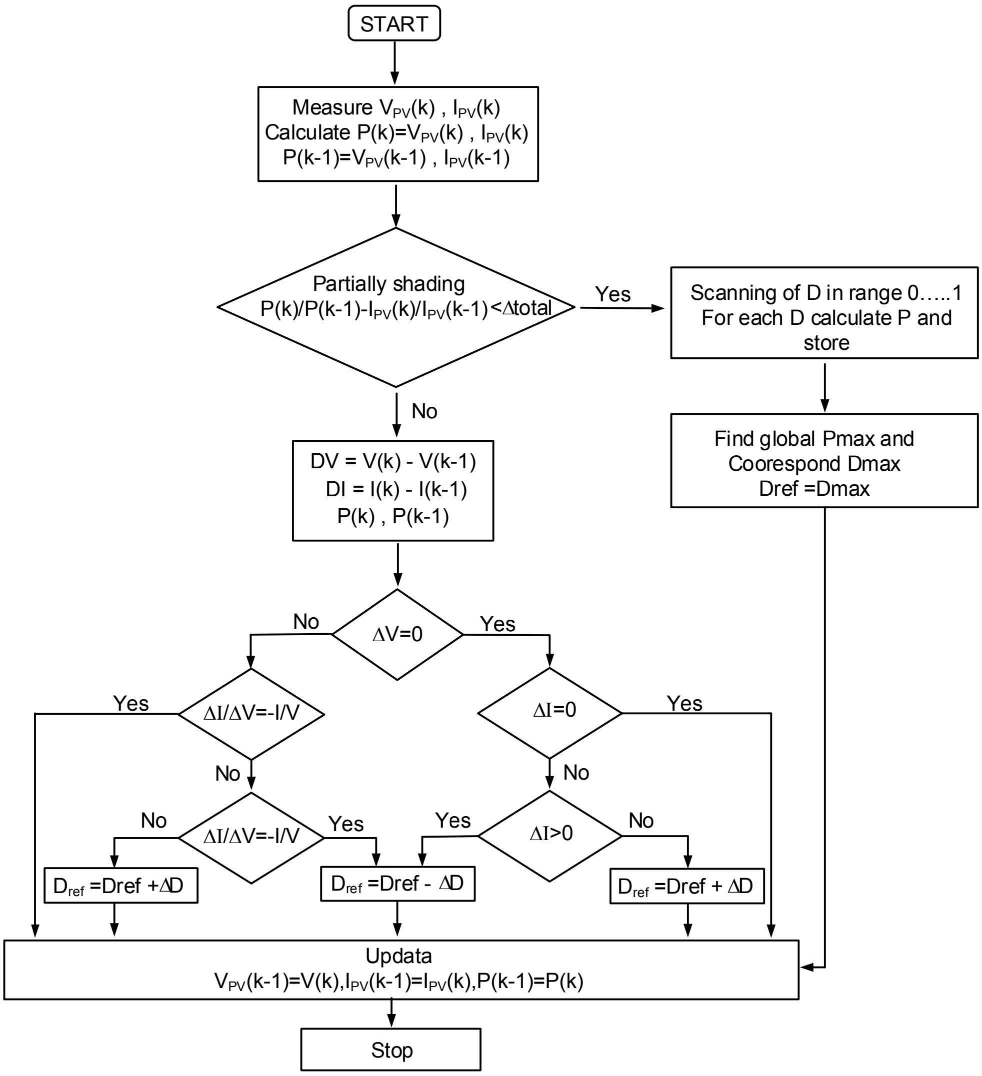
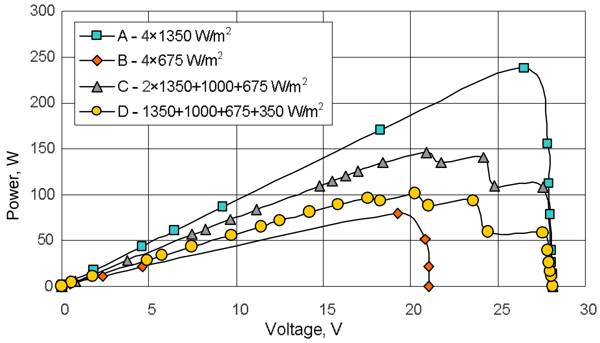
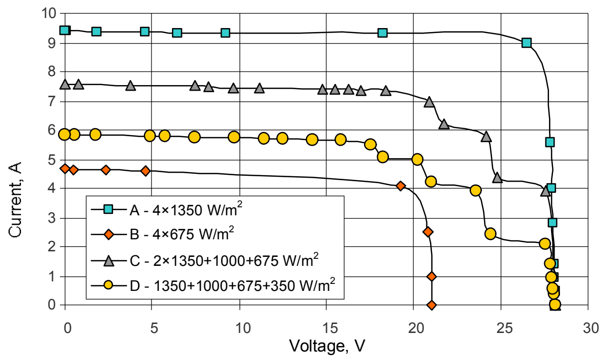


Fig. 3. Flowchart for the proposed MPPT control algorithm



a)



b)

Fig. 4. Simulation of P-V curve: a – & I-V curve; b – of PV module under partial shading conditions (PSC)

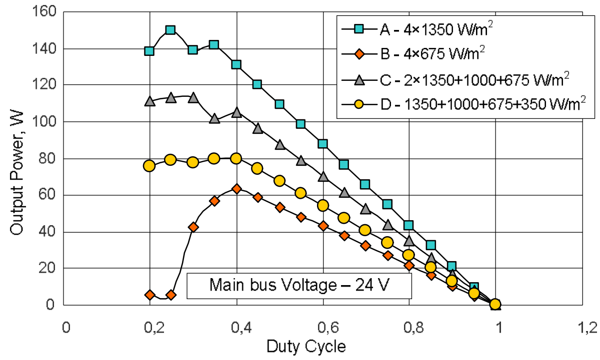
The results of the equation are organized in Table 2 as indicated by the estimations values of power and current which are obtained from Fig. (3).

Table 2

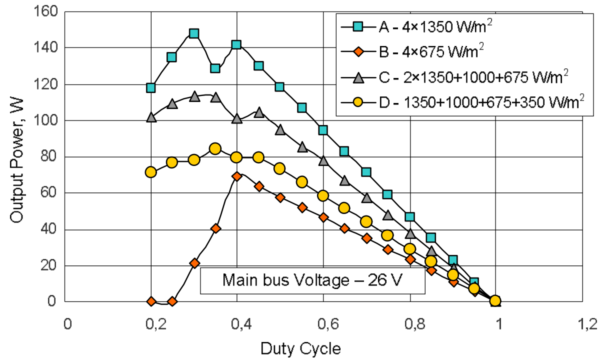
Outcome of the proposed algorithm

Power, W	Con.1	238.5	238.5	238.5	238.5	238.5	238.5
I_{PV}, A	Con.2	79.13	140.3	108	96.46	92.91	57.96
I_{PV}, A	Con.1	9	9	9	9	9	9
	Con.2	4.1	5.8	3.9	5.49	3.94	2.1
Proportion value	P_1/P_2	3	1.7	2.21	2.47	2.57	4.115
	I_1/I_2	2.19	1.55	2.31	1.64	2.28	4.28
Difference Δtotal	$P1/P2-I_1/I_2$	0.81	0.15	0.1	0.83	0.29	0.165

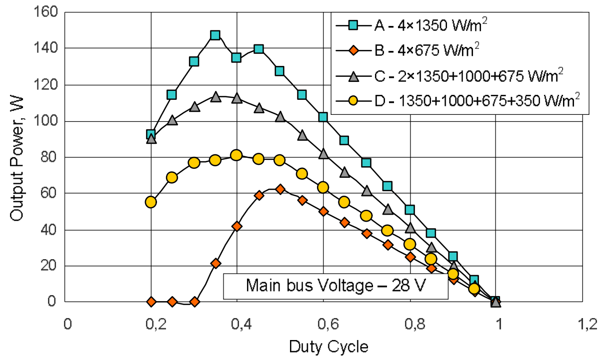
Under partial shading conditions (PSC), output power of PV unit is strongly depended from the value of the duty cycle, there is corresponded certain value of duty cycle which provides maximum output power level and different output voltage 24,26,28,30 volts as shown in Figure 5.



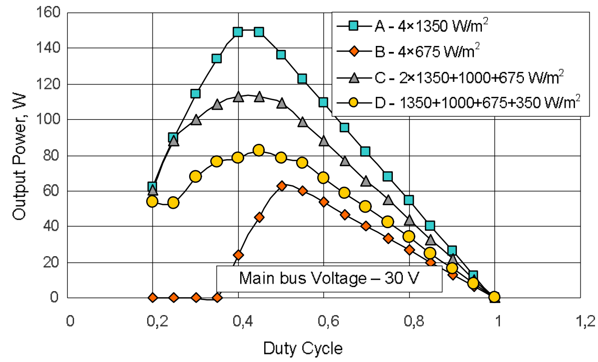
a)



b)



c)



d)

Fig. 5. Output power at voltage =24: a – & at voltage =26; b – & at voltage =28; c – & at voltage =30; d – as function from duty cycle under partial shading conditions (PSC)

Conclusions

As we can see at Figure 5 each curve in dependence P_{out} from Duty Cycle have obvious extreme. Location of this extreme is defined of main bus voltage and illumination conditions. So, right controlling of working of subsatellite power system demands of defining in each moment of right value of Duty Cycle which provides maximal output power on the load.

The proposed technique for tracking maximum power point of photovoltaic arrays that has better performance even under partial shading condition than the conventional tracking algorithms. To accept the execution of the proposed algorithm, simulations concentrates on have been performed. For the present introduces study, boost converter is utilized as the DC-DC interface for MPP tracking observe in conjunction with PWM (pulse width modulation). The outcomes have demonstrated that the proposed approach has a capacity tracking MPPs accurately under partial shading conditions.

Also the results of the study allow us to conclude that conventional MPPT methods not well suited for solving the above problem due to the presence of multiple extrema in the power curve under partial shading of the few solar panels connected in parallel. Possible additional losses can amount to 7-9 % of the output power.

References (GOST 7.1:2006)

1. Masatoshi, U. 3-Port Converter Integrating a Boost Converter and Switched Capacitor Converter for a Single-Cell Battery Power System in a Small Satellite [Text] / U. Masatoshi, K. Akio // ECCE Asia Downunder (ECCE Asia), IEEE. – 2013. – P. 747–752.

2. Jasim, Ali. M. Methods of photovoltaic power control mode [Text] / Ali. M. Jasim, Yu. A. Shepetov // Авиацийно-космичская техника и технология. – 2015. – № 2(119). – С. 86–90.

3. Jasim, Ali. M. Mathematical Model of PV module with pulse width modulation control [Text] / Ali. M. Jasim, Yu. A. Shepetov // Авиационно-космическая техника и технология. – 2015. – № 2(120). – С. 60–66.

4. Jasim, M. An Intelligent Technique By Using The Method of Constant Coefficient of Short Circuit Current Under Pulse Width Modulation Control of The Photovoltaic Power System [Text] / Ali. M. Jasim, Yu. A. Shepetov // London Review of Education and Science. – 2016. – № 1(19), Vol. 3. – P. 873–886.

5. Jasim, M. Mathematical modeling of a solar power plant under PWM control by the method of constant coeicient of short circuit current [Text] / Ali. M. Jasim, Yu. A. Shepetov // American Journal of Science and Technologies. – 2016. – № 1(21), Vol. 2 – P. 903–913.

6. Jasim, Ali. M. The Influence of Irradiation on Performance of Several Factors of Photovoltaic Solar Cell [Text] / Ali. M. Jasim, Yu. A. Shepetov // Yale Journal of Science and Education. – 2016. – № 1(19). – P. 441–451.

7. Al-Motasem, I. Aldaoudeyeh. Photovoltaic-battery scheme to enhance PV array characteristics in partial shading conditions [Text] / I. Al-Motasem // Journal of Institution of Engineering and Technology (IET) Renewable Power Generation. – 2016. – Vol. 10. – P. 108–155.

References (BSI)

1. Masatoshi, Uno., Akio, Kukita., 3-Port Converter Integrating a Boost Converter and Switched Capacitor Converter for a Single-Cell Battery Power System in a Small Satellite, *ECCE Asia Downunder (ECCE Asia)*, *IEEE*, 2013, pp. 747-752. doi: 10.1109/ECCE-Asia.2013.6579185.

2. Jasim, Ali. M., Shepetov, Yu. A. Methods of photovoltaic power control mode. *Aviacijno-kosmicna tehnika i tehnologia - Aerospace technic and technology*, 2015, no. 2, pp. 51-57.

3. Jasim, Ali. M., Shepetov, Yu. A. Mathematical Model of PV model with pulse width modulation control. *Aviacijno-kosmicna tehnika i tehnologia - Aerospace technic and technology*, 2015, no. 2, pp. 51-57.

4. Jasim, Ali. M., Shepetov, Yu. A. An Intelligent Technique By Using The Method of Constant Coefficient of Short Circuit Current Under Pulse Width Modulation Control of The Photovoltaic Power System. *London Review of Education and Science*, 2016, no. 1(19), vol. 3, “Imperial College Press”, pp. 873-886.

5. Jasim, Ali. M., Shepetov, Yu. A. Mathematical modeling of a solar power plant under PWM control by the method of constant coeicient of short circuit current. *American Journal of Science and Technologies*, 2016, no. 1. (21), vol. 2I. “Princeton University Press”, pp. 903-913.

6. Jasim, Ali. M., Shepetov, Yu. A. The Influence of Irradiation on Performance of Several Factors of Photovoltaic Solar Cell, *Yale Journal of Science and Education*, 2016, no. 1(19), pp. 441-451.

7. Al-Motasem, I. Aldaoudeyeh. Photovoltaic-battery scheme to enhance PV array characteristics in partial shading conditions, *Journal of Institution of Engineering and Technology (IET) Renewable Power Generation*, 2016, vol. 10, is. 1, pp. 108-155.

Поступила в редакцию 28.10.2016, рассмотрена на редколлегии 7.12.2016

ОТСЛЕЖИВАНИЕ ТОЧКИ МАКСИМАЛЬНОЙ МОЩНОСТИ СОЛНЕЧНОЙ ЭНЕРГОСИСТЕМЫ СУБСПУТНИКА, РАБОТАЮЩЕЙ В УСЛОВИЯХ ЧАСТИЧНОГО ЗАТЕНЕНИЯ ПАНЕЛЕЙ

Али М. Джасим, Ю.А.Шепетов

Целью данной работы является изучение особенностей отслеживания точки максимальной мощности (ОТММ) для солнечной энергосистемы субспутника в условиях частичного затенения панелей. Энергосистема субспутника работает параллельно с гораздо большей по мощности системой электропитания основного спутника. Моделирование проводилось с помощью Matlab/Simulink. Были рассмотрены различные методы ОТММ. Результаты исследования позволяют сделать вывод о том, что обычные методы ОТММ не вполне подходят для решения рассматриваемой задачи из-за наличия нескольких экстремумов на кривой мощности в условиях частичного затенения нескольких солнечных панелей, включенных параллельно.

Ключевые слова: фотоэлектрическая энергоустановка, отслеживание точки максимальной мощности, спутниковая энергоустановка, Matlab/Simulink.

ВІДСТЕЖЕННЯ ТОЧКИ МАКСИМАЛЬНОЇ ПОТУЖНОСТІ СОНЯЧНОЇ ЕНЕРГОСИСТЕМИ СУБСПУТНИКА, ЩО ПРАЦЮЄ В УМОВАХ ЧАСТКОВОГО ЗАТІНЕННЯ ПАНЕЛЕЙ

Алі М. Джасім, Ю. О. Шепетов

Метою даної роботи є вивчення особливостей відстеження точки максимальної потужності (ВТМП) для сонячної енергосистеми субспутника в умовах часткового затінення панелей. Енергосистема субспутника працює паралельно з системою набагато більшої потужності електроживлення основного супутника. Моделювання проводилося за допомогою Matlab/Simulink. Були розглянуті різні методи ВТМП. Результати дослідження дозволяють зробити висновок про те, що звичайні методи ВТМП не цілком підходять для вирішення розглянутої задачі за наявності декількох екстремумів на кривій потужності в умовах часткового затінення декількох сонячних панелей включених паралельно.

Ключові слова: фотоелектрична енергоустановка, відстеження точки максимальної потужності, супутникова енергоустановка, Matlab/Simulink.

Али Махмуд Джасим – старший инженер центра космических и коммуникационных технологий Министерства науки и технологий, Багдад, Ирак; аспирант каф. космической техники и нетрадиционных источников энергии, Национальный аэрокосмический университет им. Н. Е. Жуковского «Харьковский авиационный институт», Харьков, Украина, e-mail: eng.alimahmood71@yahoo.com.

Шепетов Юрий Алексеевич – канд. техн. наук, доцент, доцент каф. космической техники и нетрадиционных источников энергии, Национальный аэрокосмический университет им. Н.Е. Жуковского «Харьковский авиационный институт», Харьков, Украина, e-mail: shepetov9@d4.khai.edu.

Ali Mahmood Jasim – chief engineer of Space and Communication Technology Center, Ministery of Science and Technology, Baghdad, Iraq; PhD student of the Department of Space Technology and Nonconvential Energy Sources, National Aerospace University named after N. Ye. Zhukovsky “KhAI”, Kharkov, Ukraine, e-mail: eng.alimahmood71@yahoo.com.

Shepetov Yuri Alekseevich – Candidate of Technical Science, Associate Professor of the Department of Space Technology and Nonconvential Energy Sources, National Aerospace University named after N. Ye. Zhukovsky “KhAI”, Kharkov, Ukraine, e-mail: shepetov9@d4.khai.edu.