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EXPERIMENTAL MODELING OF SATELLITE SOLAR POWER SYSTEM BASED ON PULSE WIDTH MODULATION CONTROLLED BOOST CONVERTER

The object of this work is the experimental confirmation of the properties of the satellite solar plant based of photovoltaic (PV) converters with a DC-DC Converter controlled by pulse-width modulation (PWM) device for constant tracking of maximum power point (MPP) of the power plant. The results of the experiment confirmed simulation results, derived previously through using the mathematical model in Matlab/Simulink. In the work is proposed new more effective algorithm for solar PV MPP tracking based on combination of few known methods. First working point is chosen by the open-circuit voltage coefficient, next points are searched by the hill-climbing method.

Keywords: *Satellite Solar Power System (SSPS), Photovoltaic (PV) Converter, Maximum Power Point Tracking (MPPT), Boost Converter.*

Introduction

Today, space industry is a standout amongst the most costly industries and the countries incur considerable expenses in this industry. One of this industry's equipment is satellite. The development of space technology is the use of complexes of multiple spacecraft, "main satellite"-"subsatellite". The SSPS is considered as an essential part of the satellite, because no power will mean an end to the mission. Many countries are interested in making of small satellites. They are launched in Low Earth Orbit (LEO) having Low mass and small size. On the basis of mass and size they are characterized in Nano, Pico, and Micro. Micro satellites have mass in between 10 kg and 100 kg [1]. The SSPS of a Micro-Satellite should fulfill the power requirements for the entire satellite subsystems.

The main task of the solar power satellite is to provide the other subsystems with a reliable and continuous power source. Normally on a Micro-Satellite four solar panels are mounted on the external four faces.

At a time single panel is exposed to the sun and therefore it should be sufficient to meet all the power requirements of the satellite. The main components of this system of satellite are photovoltaic panels, batteries and regulators which lead to conversion from solar energy to electrical power, energy storage in batteries, regulation of the electrical power, distribution the power to other subsystem. Due to the fact the satellites are not available in the space, it is vital to be able to analyze its behavior.

Therefore, the simulators are used to simulate the behavior of each part of satellites, one of these parts is subsystem in satellites.

Despite of decreasing the expenses of PV panels in the past decades, they are still expensive also installing PV panels are time consuming. Output power of panels depends on irradiance and the temperature of environment and these parameters depend on to time, season and weather situation so the test condition is uncontrollable, hard and unreachable. Using this method will lead to cheaper capacity changing in electrical power system of satellite [2].

The power demand of the satellite shall be provided dynamically with respect to the related system and subsystem of the satellite. The power need of a satellite related to system/subsystem are defined and involved in simulation in order to calculate total satellite nominal and maximum power need along the mission. The SPS provides direct current (DC) power for all the subsystems by the use of solar panels when the satellite is in direct sunlight and by two Lithium Polymer batteries when the Sun is eclipsed.

Operating conditions as well as the solar cell and array design quality determine the working of a PV array system. DC-DC power converter is interesting for power applications in particular. The major functions of the system control are maximizing the energy transferred from the PV arrays to the load. This paper basically discusses designs the experimental modeling of the solar power satellite, under PWM control by the method of coefficient of open-circuit voltage [2].

System Configuration

The basic components of the SSPS are the energy source, energy conversion, power regulation, storage battery and control, Fig.1 shows a simple block diagram of these components. While Fig.2 shows a simple imitator structure block diagram.

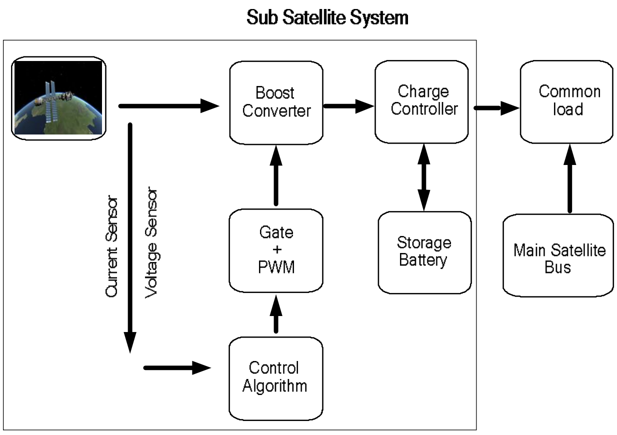


Fig. 1. Block Diagram of Configuration of Solar Power Satellite System

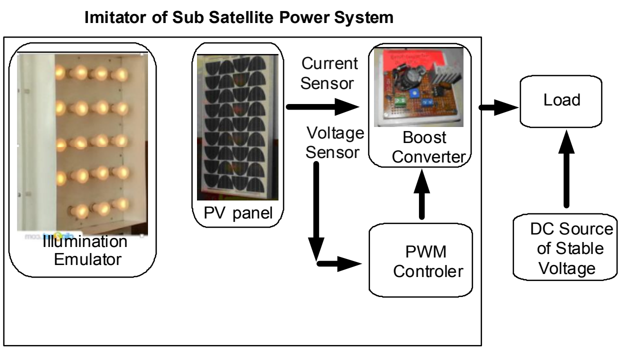


Fig. 2. Block Diagram of Imitator Structure

Solar illumination emulator

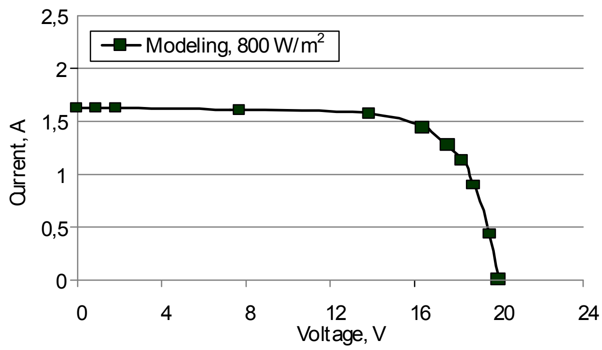
This expression describes the electrical behavior and determines the relationship between voltage and current supplied by a photovoltaic cell. Described model of the PV unit was realized as simulink model based on real measurements data from solar panel educational bench in school laboratory in National Airspace University «KhAI», the Department of space technology and alternative energy sources with Si PV cell manufactured by Siemens Corp. [3]. Fig.3 shows a simple solar illumination emulator block diagram.

A photovoltaic cell can be modeled as a current source connected in parallel with a single diode and a resistance (R_p). The shunt resistance R_p, as a representative of all losses verified inside the cell, as an effect of the parasitic currents. And a resistance is connected in series to them (R_s). Current source produces a constant current. This current is proportional to the intensity of the light falling upon the cell [4].

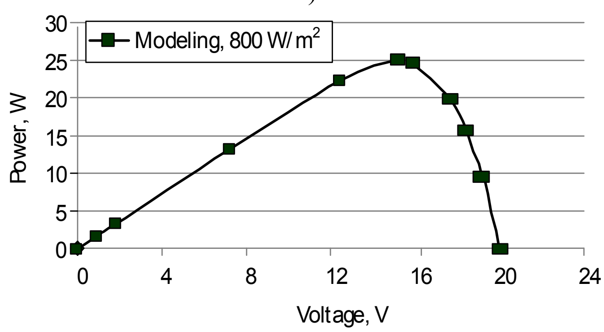
Fig. 3. Solar Illumination Emulator

Maximum power point tracker

Module exposed to light sources for full radiation (800 W/m^2) having an open circuit voltage V_{OC}= 20.1 V and short circuit current I_{SC} = 1.62 A. The radiation to form a solar array of maximum power 25 W. When the irradiance value decreases, the voltage and current level of solar array reduces hence the power output from the array reduces considerably. Simulation of the I-V Fig.4a) and P-V Fig.4b) characteristic curves are plotted for solar irradiance equals 800 W/m^2 are represented in Fig. 4.



a)



b)

Fig. 4. Simulation of I-V curve: a) & P-V curve; b) of PV module under changing illumination

For Maximum Power Point of the solar panels varies with environmental conditions and is not constant. So in order to operate solar panels at MPP, Boost converter with MPPT is used to extract maximum power from it and also improves efficiency [5]. Technologies of PV systems are in rapid development and its role in the globally have been increasing, environmental friendliness and free from pollution. When sunlight shines on the PV array, DC electricity is generated by Photovoltaic (PV) systems.

It is common that the efficiency of a solar cell is very low. Some methods are used so as to match the source and load properly, thereby increasing the efficiency of solar cell. One such method is the Maximum Power Point Tracking MPPT. This is a technique used to obtain the maximum possible power from a varying source. In photovoltaic systems the I-V curve is non-linear, thereby increasing the efficiency of solar cell [2, 4].

Pulse width modulation (PWM)

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a processor's digital outputs. The switching scheme applied is unipolar. The PWM signal is used to control ON/OFF switching state of the IGBTs (insulated-gate bipolar transistor) will function in driver model that created to control the switching scheme. The duty cycle D of a square wave is modulated to encode a specific analog signal level by using a higher resolution counter. The benefit of choosing the PWM over analog control increases noise immunity [4, 5].

The input voltage V_{in} (solar array voltage) can be less than the output main bus voltage V_{bus}. A chopped output main bus voltage is produced by the switch S operation at high frequencies. Adjusting the on/off duty cycle of the switching controls the power flow. The equation (1) determines the average output DC source voltage V_{bus}.

$$\frac{V_{bus}}{V_{in}} = \frac{I_{in}}{I_{bus}} = \frac{1}{1-D}, \qquad (1)$$

where I_{in} - solar array current;

I_{bus} – main bus current.

Used boost converter and experimental bench shown in Fig. 5 and Fig. 6.The DC-DC converter is a boost converter type used to step up the PV voltage to the level of the DC link. The DC-DC converter is controlled so as to track the maximum power point of the PV array and to transfer the energy to the load.

Fig. 5. A simple experiment boost converter

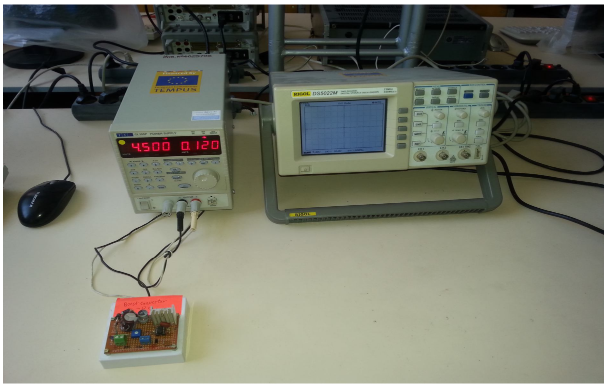


Fig. 6. Experimental bench

There are several converters that are able to handle this task. The Boost converter is considered for the analysis. The Boost converter is more suited to the MPPT because a continuous current is drawn from the solar array in both switch situations.

Storage battery and charge controller

The solar panel provide power to the DC-bus during daylight, but during solar eclipse the solar panel cannot provide power and therefore we need to have batteries.

Batteries are charged from power distribution and when solar eclipse occurs or in case of low solar power; batteries also provide power to power distribution through bidirectional load switch. So it charges batteries on a control signal from the power conditioning controller.

The charge controller performs the following three main functions [4]: 1) it prevents the overcharging of the battery bank; 2) it prevents over discharge of the batteries, and 3) it performs system monitoring.

Results of experiments

Output power of DC source voltage V_{bus} unit is strongly depended from the value of the duty cycle (D), and for each value of DC source voltage V_{bus} of satellite there is corresponded certain value of duty cycle which provides maximum output power of main bus voltage V_{bus} (Fig 7).

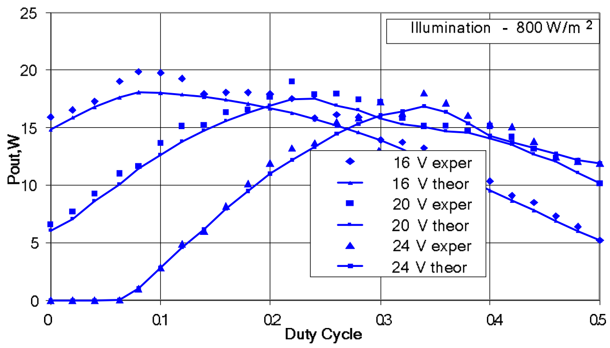


Fig. 7. Output power as function from duty cycle for different dc source voltage V_{bus} of satellite

With increasing of DC source voltage V_{bus} the value of duty cycle decrease too.

In the same manner for each value of sunshine illumination there is corresponded certain value of duty cycle which provides maximum output power (Fig.8).

With increasing of illumination the optimal duty cycle decreases.

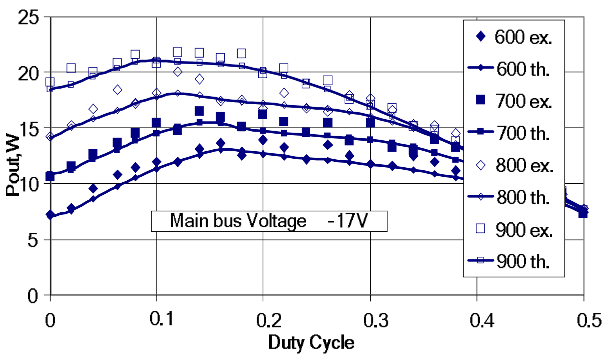


Fig. 8. Output power as function from duty cycle for different Illumination

Thus the problem of control of studying the PV unit consists in finding for each moment of optimal duty cycle which correspond to changeable external parameters (illumination and DC source voltage V_{bus} of satellite) for providing maximum output power. The matrix of optimal duty cycle is shown on in table 1.

There are also exist the losses of power due to dissipate energy under transformation (Fig. 9). They are more with duty cycle increasing. But all the same, this loss is repaid through increasing of output power.

Regulator transformation efficiency (Fig. 10). Was calculated as the ratio between output and input power for certain external conditions.

Table 1

Matrix of values of optimal duty cycle providing maximum output power of satellite

DC Voltage, V	Illumination, W/m²				
	600	**700**	**800**	**900**	**1000**
14	0,01	0,01	0,01	0,01	0,01
15	0,11	0,06	0,03	0,01	0,01
16	**0,15**	**0,12**	0,09	0,068	0,01
17	0,19	0,168	**0,14**	**0,11**	**0,08**
18	0,22	0,21	0,182	0,153	0,123
19	**0,24**	0,244	0,223	0,2	0,165
20	0,26	**0,27**	0,26	0,235	0,2
21	0,29	0,3	0,31	0,267	0,241
22	0,31	0,324	**0,34**	0,3	0,27
23	0,337	0,345	0,36	**0,318**	0,29
24	0,35	0,362	0,376	0,34	**0,3**
25	0,37	0,38	0,39	0,359	0,322
26	0,38	0,39	0,4	0,37	0,34

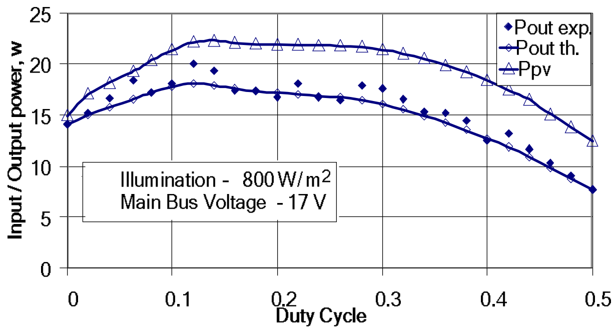


Fig. 9. The relationship between input and output power of regulator

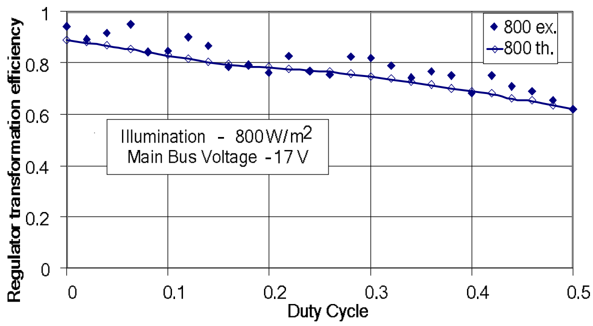


Fig. 10. Regulator Transformation Efficiency

Conclusions

Solar Power System (SSPS) is the only independent module working in the satellite. It needs to be fast, reliable and efficient. It can be considered as a knowledge based artificial intelligence system that has to take decision based on the scenario at the moment. In future, we can take up this concept to larger space crafts as well and make it autonomous. The maximum efficiency in terms of power harvested from the panel and transferred to the output thanks to the MPPT algorithm. The results of the experiment confirmed simulation results, derived previously through using the mathematical model in Matlab/Simulink [2,3]. In the work is proposed new more effective algorithm for solar PV MPP tracking based on combination of few known methods. First working point is choosed by the voltage coefficient, next points are searched by the hill-climbing method.

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ЭКСПЕРИМЕНТАЛЬНОЕ МОДЕЛИРОВАНИЕ СПУТНИКОВОЙ СОЛНЕЧНОЙ ЭНЕРГОУСТАНОВКИ С ПРЕОБРАЗОВАТЕЛЕМ НАПРЯЖЕНИЯ ПОД ШИМ-УПРАВЛЕНИЕМ

Али М. Джасим, Ю. А. Шепетов

Целью данной работы является экспериментальное подтверждение свойств спутниковой солнечной энергоустановки на основе фотоэлектрических преобразователей (ФЭП) с DC-DC конвертером управляемым устройством широтно-импульсной модуляции (ШИМ) для постоянного отслеживания точки максимальной мощности (ТММ) энергоустановки. Результаты эксперимента подтвердили результаты моделирования, полученные ранее с помощью математической модели в среде MATLAB/Simulink. В работе предлагается новый, более эффективный алгоритм для отслеживания ТММ солнечной энергоустановки на основе ФЭП, основанный на сочетании нескольких известных методов. Первая рабочая точка выбирается в соответствии с коэффициентом напряжения холостого хода, следующие точки находятся по методу восхождения по выпуклой поверхности.

Ключевые слова: солнечная энергоустановка, фотоэлектрический преобразователь, отслеживание точки максимальной мощности, преобразователь напряжения.

ЕКСПЕРИМЕНТАЛЬНЕ МОДЕЛЮВАННЯ СУПУТНИКОВОЇ СОНЯЧНОЇ ЕНЕРГОУСТАНОВКИ З ПЕРЕТВОРЮВАЧЕМ НАПРУГИ ПІД ШІМ-КЕРУВАННЯМ

Алі М. Джасім, Ю. О. Шепетов

Метою даної роботи є експериментальне підтвердження властивостей супутникової сонячної енергоустановки на основі фотоелектричних перетворювачів (ФЕП) з DC-DC конвертером керованим пристроєм широтно-імпульсної модуляції (ШІМ) для постійного відстеження точки максимальної потужності (ТМП) енергоустановки. Результати експерименту підтвердили результати моделювання, отримані раніше з допомогою математичної моделі в середовищі MATLAB/Simulink. В роботі пропонується новий, більш ефективний алгоритм для відстеження ТМП сонячної енергоустановки на основі ФЕП, заснований на поєднанні декількох відомих методів. Перша робоча точка обирається у відповідності з коефіцієнтом напруги холостого ходу, наступні точки знаходяться за методом сходження по опуклій поверхні.

Ключові слова: сонячна енергоустановка, фотоелектричний перетворювач, відстеження точки максимальної потужності, перетворювач напруги.

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