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Development of a device for measuring current-voltage and power-voltage characteristics of experimental solar cells

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Abstract. This article presents the implementation of an experimental device for measuring volt-ampere and volt-watt characteristics based on the current and voltage sensor INA219. The characteristics obtained on the experimental device are similar in terms of the values obtained using the Keithley 2450 meter source, whose accuracy is 10^{-9} A. However, due to problems with the calibration of the manual potentiometer, it is not possible to get a smoother line. The research results are used to develop an autonomous system that takes into account the illumination and surface temperature of the solar cell and the radiation background of the environment.

Keywords: photovoltaics, solar energy, Arduino Uno, volt-ampere characteristic, volt-watt characteristic

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Разработка устройства для измерения вольт-амперных и вольт-ваттных характеристик экспериментальных солнечных элементов

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Аннотация. В данной статье представлена реализация экспериментального устройства для измерения вольт-амперных и вольт-ваттных характеристик на основе датчика тока и напряжения INA219. Характеристики, полученные на экспериментальном устройстве близки по значениям, полученным с помощью источника измерителя Keithley 2450, точность которого составляет 10^{-9} А. Однако из-за проблем с калибровкой ручного потенциометра не удается получить более плавную линию. Результаты исследований используются для разработки автономной системы, учитывающей освещенность и температуру поверхности солнечного элемента и радиационного фона окружающей среды.

Ключевые слова: фотовольтаика, солнечная энергетика, Arduino Uno, вольт-амперная характеристика, вольт-ваттная характеристика

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Introduction

As a rule, the parameters of solar cells are measured using measuring instruments or a solar simulator at an air mass of 1.5 solar spectrum (AM1.5) with a total radiation power of 1000 W/m^2 and a temperature of 25 degrees Celsius for the Earth. Solar cells intended for space applications are usually characterized by the use of the solar spectrum of the air mass AM0 with a spectral brightness of 1366.1 W/m2 [1–3]. Compared to sunlight, solar simulators have limitations. The light generated by the sun simulator does not meet the spectrum standard, is spatially heterogeneous and unstable in time [4–5].

Using a voltage and current sensor at the output using a potentiometer, it is possible to measure the main parameters of solar cells - no-load voltage and short-circuit current. However, external conditions can affect the characteristics of a solar cell in different ways. To assess the influence of external conditions on the parameters of solar cells, it is often necessary to make repeated measurements of the parameters. Therefore, this study proposes a simple method for determining characteristics using an Arduino UNO microcontroller with an Atmega328 microchip with a frequency of 16 MHz with a clock cycle of about 62.5 ns, a linear potentiometer with a nominal value of 1 kOhm and an INA219 sensor for determining the characteristics of a solar cell [6, 7, 11]. One of the disadvantages of this device is the low accuracy of the measuring module.

However, at the same time, it has a low cost compared to other measuring devices, the cost of which can be hundreds of thousands of rubles. In addition, this device is easy to operate: you can quickly replace a failed module or rewrite the program to make the use of the device more comfortable.

Materials and Methods

The measuring system in this work was used to measure voltage, output current and register them at different resistance in a potentiometer to obtain a voltage characteristic of a solar cell.

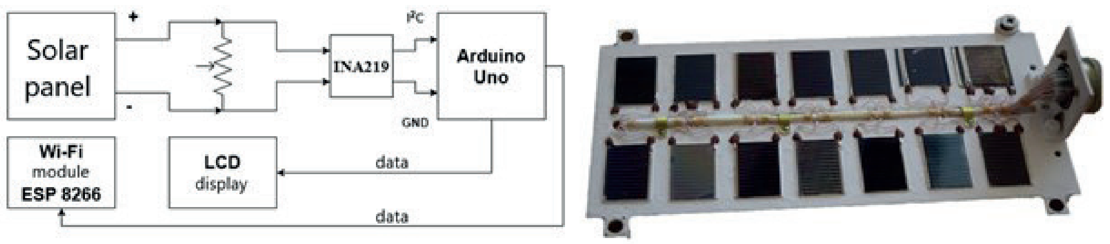

Fig. 1. An experimental photovoltaic module and a diagram of a device for measuring current-voltage and volt-watt characteristics

Figure 1 shows a complete schematic diagram of a measuring system and an experimental solar panel with 14 photovoltaic cells based on por-Si and SiC using Arduino Uno as a microcontroller. The measuring stand is connected to the photovoltaic module via the RS-32 connector. The potentiometer acts as a resistive load. The voltage and current sensor measures the voltage of the potentiometer as the total resistance of the solar cell. Theoretically, when the resistance of the potentiometer is zero, there is no voltage difference between them, the current can flow without loss. When the resistance of the potentiometer changes almost infinitely, the resistance blocks the current, and the voltage difference on the potentiometer becomes possible as a parameter. AC sensors measure the value of current and voltage in real time, and the resistance of the potentiometer is adjusted to a slow change so that the microcontroller can process and record the measured voltage and current data from the sensors.

A microcontroller is used in the system to record the sensor output. For this microprocessor, it is necessary to enable an algorithm for compatibility with an LED display and calculation of the electrical power generated by a solar cell by multiplying the voltage and current read by sensors in real time. The microcontroller is powered by a 9 V battery, while the INA219 sensor, LED display and SIM800L module are powered by a microcontroller.

Applied assembly of a measuring device based on Arduino Uno with ATmega328. This microchip uses a quartz oscillator with a frequency of 16 MHz and a clock cycle of about 62.5 ns. This microcontroller provides digital communication for the sensor using a USB connection, so serial connection of the monitor to a PC for real-time monitoring can be more convenient [8–10].

A 90 watt lamp placed at a height of 23 cm was used to illuminate the solar cell. Three solar cells made on the basis of porous silicon with antireflection coatings, with a power of less than 1 W and an area of less than 0.0012 m^2 were selected for measurement. Since this study focuses on low-power solar cells and low-cost operation, spatial uniformity is neglected. During prolonged measurement (more than 5 minutes), the solar cells heated up, which could lead to distortion of the characteristics. With a high measurement speed of the current-voltage characteristic, the measurement accuracy also decreases, thereby increasing the error.

The experiment was conducted to determine the characteristics of experimental solar cells with an average power of 0.15 watts. Measurements of current-voltage and volt-watt characteristics were obtained both using an experimental device and using a Keithley 2450 measuring source (Fig. 2).

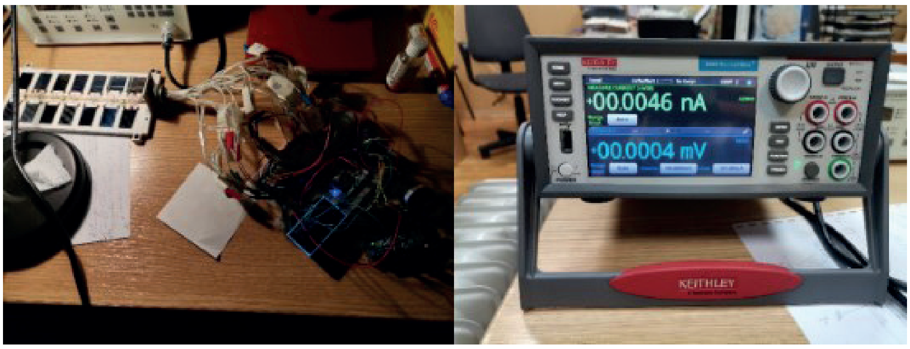

Fig. 2. Prototype of a device for measuring the current–voltage characteristics of solar cells (left) and a Keithley 2450 source meter (right)

Results and Discussion

Three solar cells were selected for the experiment, the data for which are presented in Table:

Table

A brief description of each solar cell

Name	Short description
Solar cell №1	Polished silicon with a porous layer, ZnS antireflection coating
Solar cell №5	Textured silicon with a porous layer, ZnS antireflection coating
Solar cell №6	Polished silicon with a porous layer, ZnS antireflection coating

Figures 3, 4, 5 show the volt-ampere and volt-watt characteristics of solar cells №1, №5, №6 obtained using an experimental device (green curves) and a Keithley 2450 meter source (blue curves).

Since the potentiometer in the experimental device has a nominal value of 1 kOhm, the resistance measurement step is 100 ohms, which results in about 10 points on the graph. The measurement accuracy of the experimental device is less than that of the Keithley 2450, which also does not allow for a smoother green line. Thus, the use of a manual potentiometer allows you to obtain curves close to the values obtained using the Keithley 2450 meter source, whose accuracy is 10^{-9} A.

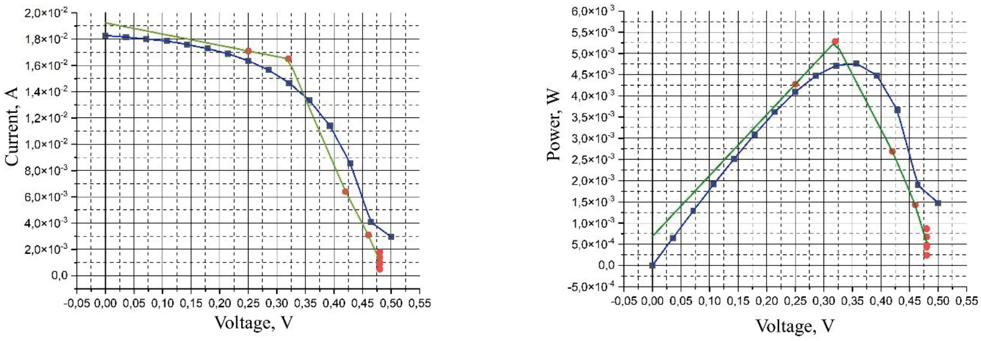

Fig. 3. Comparison of measurement results of volt-ampere and volt-watt curves of solar cell № 1. Blue curves – Keithlev 2450 source meter, green curves – experimental device

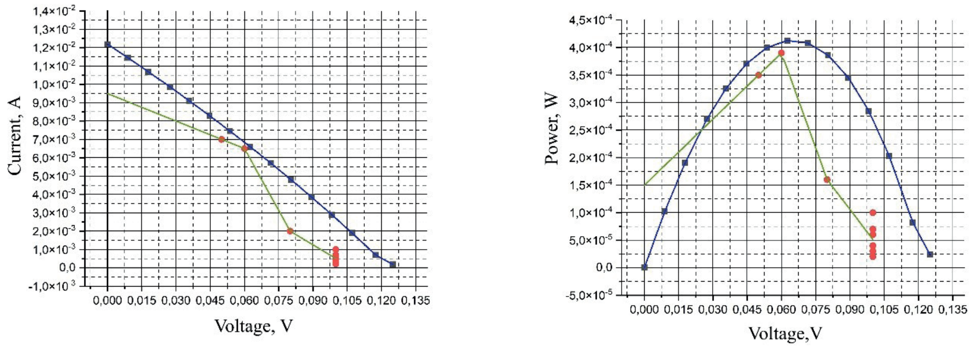

Fig. 4. Comparison of measurement results of volt-ampere and volt-watt curves of solar cell № 5. Blue curves – Keithley 2450 source meter, green curves – experimental device

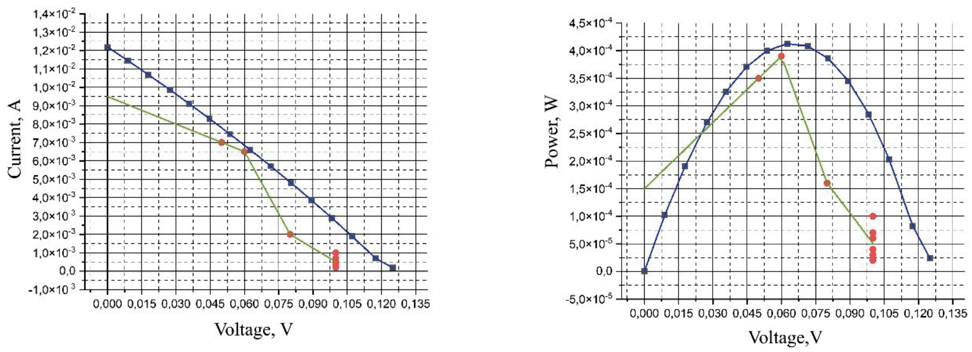

Fig. 5 Comparison of measurement results of volt-ampere and volt-watt curves of solar cell № 6. Blue curves – Keithley 2450 source meter, green curves – experimental device

In the further modification of the assembly of the experimental device, a calibrated potentiometer X9C103S is used. The device consists of an array of resistors (99 resistive elements), a control unit and non-volatile memory. The device can be used as a three-pin potentiometer or as a variable resistor with two outputs in various applications ranging from control to signal processing.

A fiberglass substrate was developed with the possibility of quick connection of modules by the "sandwich" method with the possibility of connecting additional modules if necessary, the final assembly of the measuring device is shown in Figure 6.

This system allows you to connect batteries, which will make this system completely autonomous. As an option, it is supposed to use a module with lithium batteries with a capacity of 16340. Also, this board allows you to reduce the dimensions of the device, as well as add temperature and humidity sensors, as well as a device for radiation monitoring. It is planned to use a single-board computer as the main platform. This device is being prepared to be sent for testing to the Pamir mountain system, Tajikistan.

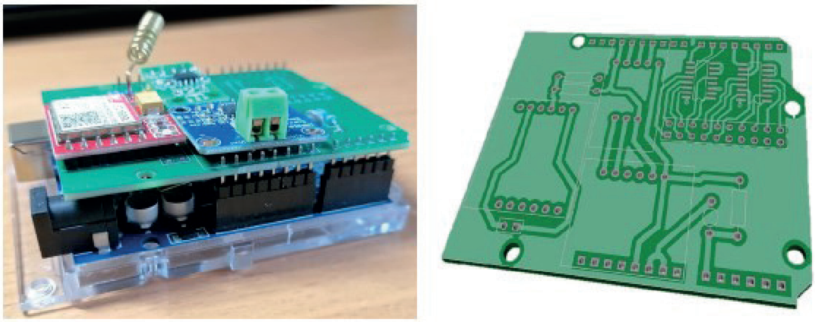

Fig. 6. Final assembly of an experimental device for measuring current-voltage and volt-watt characteristics (left); a fiberglass substrate for connecting modules (right)

Conclusion

The experimental device obtained makes it possible to obtain the volt-ampere and volt-watt characteristics of low-power solar cells with a small error compared to the measurements obtained on the Keithley 2450 measuring source. The measurement error occurs due to the lack of proper calibration of the potentiometer, as well as a large measurement step. Measurements should be carried out from 3 to 5 minutes to avoid heating of the semiconductor solar cell, as well as to improve the measurement accuracy. According to the research results, a device is being developed taking into account these errors on the printed circuit board, which allows to reduce the dimensions of the device, as well as add temperature, humidity sensors, as well as a device for radiation monitoring.

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