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Laboratory Stand for Examining the Influence of Environmental Conditions on Electrical Parameters of Photovoltaic Cells

Abstract. *The aim of this article is to present a method of investigating the influence of operating conditions on electrical parameters of photovoltaic cells. Described laboratory stand is based on a climatic chamber cooperating with a number of meters, sensors, adjustable load units and data acquisition software. Introduced measuring system enables to conduct PV cells tests across the operating temperature range (-20 ÷ 100)°C for irradiance ranging from 700 W/m^2 to 1600 W/m^2.*

Streszczenie. *Celem niniejszego artykułu jest zaprezentowanie metody badania wpływu warunków środowiskowych na parametry elektryczne ogniw fotowoltaicznych. Przedstawione stanowisko laboratoryjne działa w oparciu o komorę klimatyczną, współpracującą z szeregiem mierników oraz czujników, zespołem regulowanego obciążenia oraz oprogramowaniem do akwizycji danych. (**Stanowisko laboratoryjne do badania wpływu warunków środowiskowych na parametry elektryczne ogniw fotowoltaicznych**).*

Keywords: photovoltaic cells measurements, effect of environmental conditions, laboratory stand, climatic chamber.
Słowa kluczowe: pomiary ogniw fotowoltaicznych, wpływ warunków środowiskowych, stanowisko laboratoryjne, komora klimatyczna.

Introduction

Results of the research carried out on certain semiconductor structures in the aspect of their potential application in the process of photovoltaic cells production have been the subject of discussion in our previous works [1, 2]. On the basis of conducted experiments, which included material properties tests, it has been shown that there exists the range of operating temperatures where resistivity and capacity of the Ne^+ ion-implanted and annealed Si remain constant, but only for certain, relatively low values of post-implantation annealing temperature of tested samples. As it has been concluded, implementing reported observations into the process of photovoltaic cells production could have resulted in certain improvements connected with operating characteristics of commercial PV modules. In particular, it has been assumed to be possible to reduce the tendency to degradation of their electrical parameters with increasing temperature, by introducing some modifications into the crystal lattice of substrate material and therefore weakening the temperature dependences described in [3, 4].

However, in order to make an objective assessment of propriety of the mentioned assumptions it is necessary to perform research aimed at experimental verification and comparative analysis of electrical parameters of standard as well as modified solar cells, taking into account as wide range of different operating conditions as it is possible. As it is known, parameters of photovoltaic devices should be determined and compared at Standard Test Conditions (STC), with respect to the specific methods, described in international standards [5, 6]. As it was defined, observing the principles of STC means conducting solar tests in the temperature of 25°C, at the irradiance level of 1000 W/m^2 and the precise spectral distribution of incident light (AM1,5).

Nonetheless, in terms of real photovoltaic applications the STC appears to be insufficient reference point. Authors of the article [4] underlined that this is due to the fact, that basing on the measurements obtained at the STC it is impossible to estimate how much energy will be produced by a photovoltaic cell or module at the place of its operation, when it could be exposed to the environmental condition significantly different than the STC. The reason of such situation is a strong dependence of actual power generated in a PV cell on the series of factors, such as the sunlight irradiance, as well as the light beam spectral content and the angle of its incidence, but also the cell operating temperature [7]. All those parameters depend on geographical location, time and season. For that reason, as it was concluded in [8], in order to elaborate an effective procedure of solar energy rating it is crucial to be able to measure parameters of photovoltaic devices over a wide range of environmental conditions. Consequently, this leads to the conclusion that there is a necessity to develop the method of determining the effect of various climatic conditions on the electrical characteristics of photovoltaic cells. This article describes the laboratory stand, based on the solar simulation method, dedicated to conducting measurements of electrical parameters of photovoltaic cells across the wide range of variable operating conditions.

Experiment

Experimental part of the work has been carried out taking advantage of the research facility which photograph is shown in the figure 1. Presented laboratory stand, which has been used to conduct measurements of electrical parameters of sample PV cells, consists of a number of instruments and circuits that ensure performing the tests in a repetitive way. Primarily, this has been possible by controlling conditions, in which the tested samples had been measured, such as operating temperature of the cell, simulated sunlight irradiance and angle of incidence.

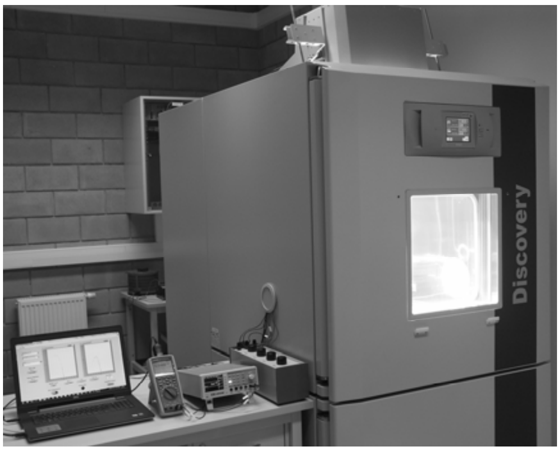

Fig.1. Photograph of the laboratory stand for investigating the influence of environmental conditions on electrical parameters of PV cells

The main element of the laboratory stand was the Discovery DY600C type climate chamber, inside which measured photovoltaic cells have been located. The tested cells have been mounted on a supporting construction, which was designed in a way that provides a possibility of changing the relative position of the device under test with respect to the light source installed in the ceiling of the chamber. Specifically, the inclination angle of the tested cell relative to the horizontal plane and the distance from the light source could have been adjusted in the respective ranges from 0° to 75° in steps of 15° and from 55 cm to 90 cm in steps of 5 cm. In order to obtain a sufficient values of the irradiance on the surface of tested devices, the lighting system SUN BF 2500W has been used. This sun simulation system is based on a metal halide lamp of the maximum power of 2,5 kW, capable to reproduce the full sunlight spectrum. A feature of the light source output power adjustment has been implemented directly into the climatic chamber controller, whereas measurements of the irradiance have been carried out using the second class pyranometer Delta Ohm LP 471 PYRA 03.5, cooperating with the portable photo-radiometer Delta Ohm HD2302.0. For uninterrupted monitoring of the irradiance level inside the chamber, the radiometric probe has been also located on the supporting construction described above, in direct neighbourhood of the tested cell. In order to accurately determine the operating temperature of the PV cell, without making a shade on it at the same time, the PT100 temperature sensor has been placed directly under the surface of the tested sample. Values of the temperature from the sensor have been read by a temperature transducer which has been connected with an analog input of the climatic chamber controller.

Introducing the solutions and using the devices described above have enabled to create in a controlled way specific environmental conditions and to maintain them in the unchanged, precisely-defined state during conducting the measurements of electrical parameters of PV cells. In particular, constructed laboratory stand allows to adjust the operating temperature of the cell in the range of (-20 ÷ 100)°C and the irradiance on the surface of the cell in the range of (700 ÷ 1600) W/m^2 (for a sample located in the distance of 75 cm from the light source). Measurements of electrical parameters of PV cells have been performed under the conditions of variable temperature and irradiance that have been changed within the ranges specified above. After each testing session the operating temperature has been increased by 5°C ±0,5°C. Subsequently, when the whole temperature range has been covered for the specific value of the irradiance, then the irradiance has been increased by an average step of 100 W/m^2 ±5 W/m^2.

The main testing circuit consisted of the examined solar cell which has been connected in series with a current-sense-type shunt resistor of the constant resistance R_C = 3 mΩ and with an adjustable load of the resistance ranging from 0 Ω to 10 Ω. Measurements of the current flowing in the circuit have been realized by recording the voltage drop across the shunt resistor using the Hameg HMC8012 multimeter. Simultaneously, the voltage of the tested PV cell has been also recorded, using the Fluke 289 multimeter connected directly to its terminals. Both multimeters have been connected to a computer via the USB interface. All the test leads have had the insulation allowing for being operated at the temperatures ranging from -80°C to 135°C and have been brought out from the climate chamber through thermally insulated portholes. In order to minimize the negative impact of the water condensing on the tested cells and the supporting construction, the climate chamber has been equipped with an air dehumidification function. The figure 2 presents the diagram of the laboratory stand.

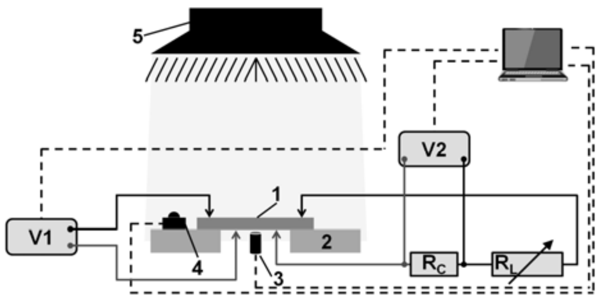

Fig.2. Schematic diagram of the laboratory stand: 1 – solar cell, 2 – supporting construction, 3 – temperature sensor, 4 – pyranometer, 5 – light source, $V1$ – Fluke 289, $V2$ – Hameg HMC8012, R_C – shunt resistor, R_L – adjustable load

Computer software for data acquisition was also an integral part of the laboratory stand. It was either originally developed (fig.3) or provided with the test equipment. A duty cycle of the climate chamber has been controlled by the Winkratos software, which was bundled with the chamber. This software has allowed to specify current parameters of the chamber and record the operating conditions of the PV cell under test.

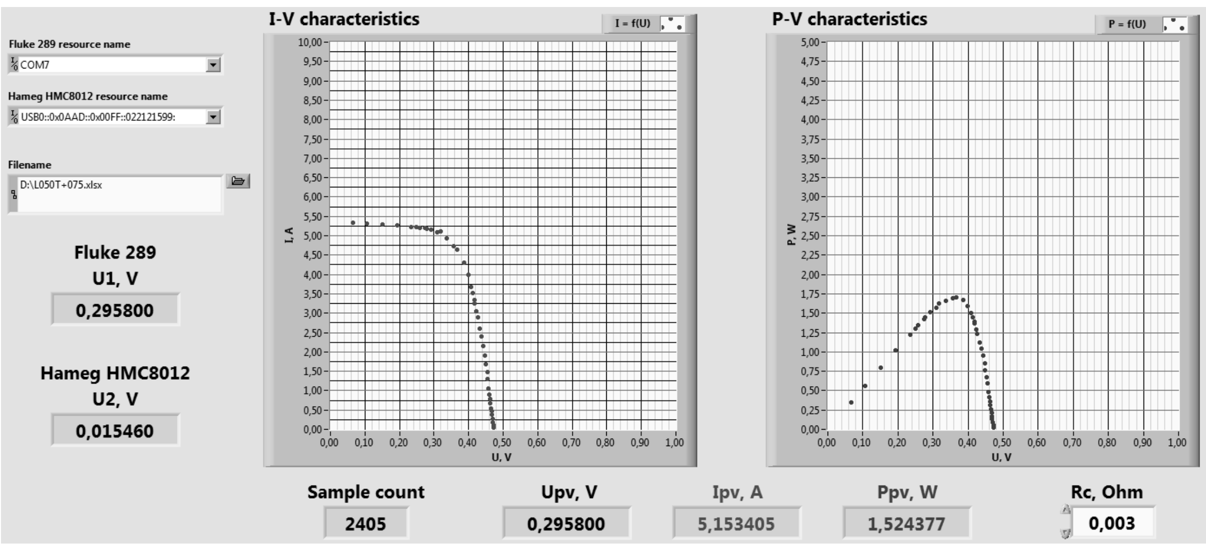

Fig.3. The main window of the PV Cells Meter software

Additionally, in order to record the electrical characteristics of the examined solar cells the PV Cells Meter software was designed and developed in the Lab View programming environment. The task of this application was to synchronously read values of the voltages measured by both multimeters and simultaneously calculate values of the current flowing in the test circuit and the momentary power of the cell. All recorded and calculated data have been saved in a spreadsheets, for the purposes of further processing. Moreover, for an immediate evaluation of obtained results the PV Cells Meter software has been equipped with a feature of graphical presentation of recorded data, in the form of graphs based on the calculated current and power as a function of the PV cell voltage. As long as the application has been running, the characteristics were updated after each triggering of the measurement recording function. Finally, when the program stops, it has been possible to export the charts to image files. A screenshot of the PV Cells Meter software interface is presented in the figure 3.

Analysis of the obtained results

In order to verify assumed capabilities of the laboratory stand and evaluate the developed method of conducting research several tests have been carried out on a standard photovoltaic cell made of monocrystalline silicon. According to the datasheet, nominal parameters of the cell declared by its manufacturer as obtained at the STC were as follows. Nominal open-circuit voltage U_{oc} = 0,57 V, nominal short-circuit current I_{sc} = 7,85 A and nominal power of the cell at maximum power point (MPP) P_{max} = 3,25 W. Experimental measurements have been performed according to the procedure described in the previous paragraph. Results obtained for the irradiance E = 1000 W/m^2, within the cell operating temperature range (-20 ÷ 100)°C have been presented below.

Dependences of the output current I and the momentary power P as a function of the voltage U of the tested cell are shown in the figures 4 and 5. Demonstrated characteristics have been recorded for six different values of the operating temperature. Analysis of these plots leads to the statement that in the considered case has occurred an expected and continuous tendency to deterioration of the electricity generating capabilities with increasing temperature.

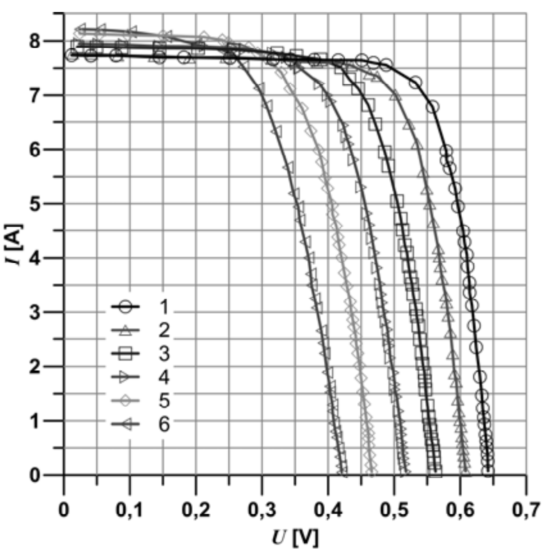

Fig.4. I–V characteristics of c-Si solar cell recorded at the irradiance E = 1000 W/m^2 for different operating temperatures: 1 – -20°C, 2 – 0°C, 3 – 25°C, 4 – 50°C, 5 – 75°C, 6 – 100°C

As it can be seen the value of U_{oc} significantly decreases from 0,64 V at -20°C to 0,42 V at 100°C, whereas the value of I_{sc} increases slightly from 7,73 A to 8,21 A for the respective values of temperature (fig.4). Simultaneously, similar trend appears when the values of voltage and current recorded at MPP (U_{mp}, I_{mp}) are considered. Respectively, the value of U_{mp} descends from 0,53 V to 0,29 V, whereas the value of I_{mp} rises from 7,21 A to 7,23 A. Consequently, it is possible to observe a noticeable shift of the current-voltage characteristics across the considered temperature range, what is strictly correlated with a displacement of the MPP (fig.5). As it has been shown in the figure 5, the maximum power point relocates towards the lower voltages as the temperature increases. Moreover, the rise of the operating temperature negatively affects the absolute value of maximum power produced by the cell (P_{max}).

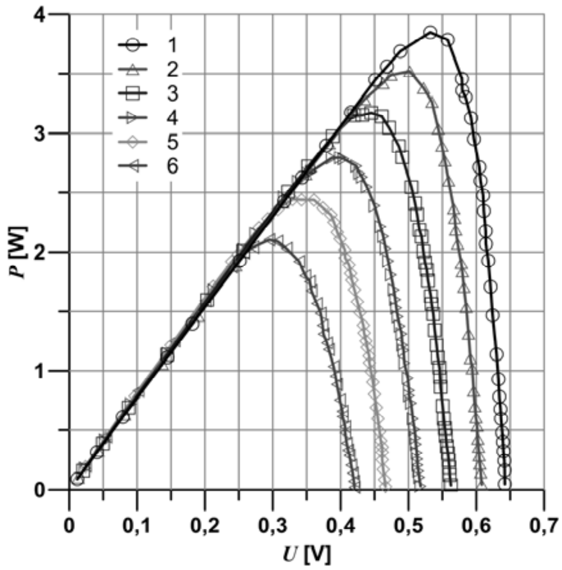

Fig.5. P–V characteristics of c-Si solar cell recorded at the irradiance E = 1000 W/m^2 for different operating temperatures: 1 – -20°C, 2 – 0°C, 3 – 25°C, 4 – 50°C, 5 – 75°C, 6 – 100°C

The table 1 presents the values of P_{max} recorded at various temperatures, as well as the relative percentage change ratios of P_{max} in relation to the one measured at 25°C. As it can be seen, P_{max} is inversely proportional to the cell's temperature and its relative drop is considerable. Particularly, the data collected in the table 1 demonstrate that between 25°C and 100°C P_{max} decreases by over 30%, whereas its absolute value changes across the whole temperature range from 3,85 W to 2,10 W what corresponds with the value of relative temperature coefficient of P_{max} equal to 0,46 %/°C.

Table 1. Decrease of the maximum power of c-Si solar cell with increasing operating temperature

T [°C]	P_{max} [W]	ΔP_{max} [%]
-20	3,85	+21,45
0	3,52	+11,04
25	3,17	0,00
50	2,79	-11,99
75	2,44	-23,03
100	2,10	-33,75

The temperature dependences of the electrical parameters of the tested PV cell, which have been illustrated in the figures 4 and 5 and shown in the table 1 directly affect the efficiency of photoelectric generation under conditions of variable ambient temperature. In order to determine the strength of this correlation in case of the tested cell, calculations of the efficiency η have been performed for all considered values of the operating temperature.

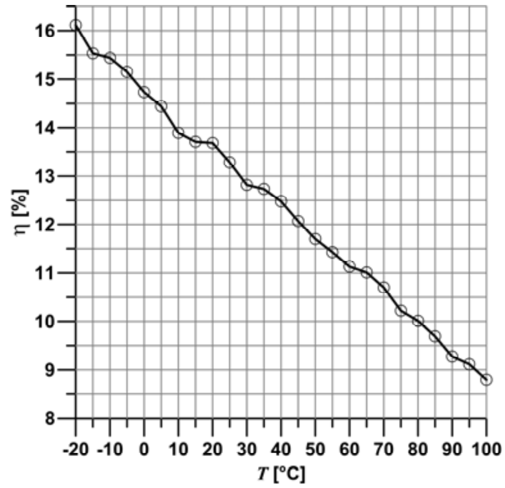

Fig.6. Efficiency of c-Si solar cell vs. operating temperature, recorded at the irradiance $E = 1000$ W/m^2

As expected, the plot presented in the figure 6 is a constantly decreasing function of increasing temperature. In particular, the efficiency η, which has been calculated according to the formula suggested in [7], reaches the maximum value of 16,11% at -20°C and decreases along with the temperature increase to the value of 8,79% at 100°C (fig.6). Similar dependency applies to the fill factor, which changes respectively in the range from 0,78 to 0,61.

Conclusions

The aim of this article was to present the method of investigating the effect of operating conditions on the electrical parameters of photovoltaic cells. Using the laboratory stand described in this work the measurements of basic electrical characteristics of sample photovoltaic cell made of monocrystalline silicon was carried out. Analysis of the obtained results showed the following. Firstly, the electrical characteristics of the tested sample, recorded under the environmental conditions that corresponds to the standard test conditions, are in substantial coincidence with the nominal parameters of the tested object, what validates suitability of the applied research method. Secondly, increasing temperature has an adverse influence on all recorded parameters of the cell, what especially results in significant decrease of the efficiency, which in case of the tested cell was reduced by over 30%.

Considering the issues and conclusions discussed in this paper it is possible to state that the proposed research method is correct. Therefore, as a continuation of the undertaken research process, it is justified to conduct further experimental studies and computer simulations of models of photovoltaic cells made in different technologies, in order to prepare a detailed comparative analysis of the effect of temperature on their performance. Results of planned activities will help to determine the type and the method of modification of the base material used in the photovoltaic cells production process and enable to verify elaborated solutions. In conclusion, our next works will be associated with developing technologies aimed at improving the efficiency of commonly used silicon photovoltaic cells operating under conditions of high temperature.

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