Modelling characteristics of photovoltaic module load for various light intensity and wavelength

Abstract. The photovoltaic modules of various technological solutions have been tested for varying radiation intensity and four wavelength ranges. Characteristics of the power generated by the modules of various technological solutions vs. varying load have been determined (Modeling characteristics of photovoltaic module load for various light intensity and wavelength).

Keywords: photovoltaic module, light wavelength, load power, LED diode.

Introduction
Taking into account that the photovoltaic modules still have relatively low efficiency, the research that might improve their parameters becomes important. Figure 1 presents maximal theoretical and practical efficiency of selected photovoltaic cells. It becomes clear that in all the presented cases significant possibilities of improvement appear. They depend to large degree on absorption effectiveness of the semiconductors they are made of [1,2]. The crystalline silicon is distinguished by such effectiveness in the broadest wavelength range (mainly in visible and infrared light) [3].

Spectrum of solar radiation encloses the wavelength from 0.1 to 1000μm. Each wavelength corresponds to a definite energy. Predominating part of the energy falls to the ranges absorbed by crystalline silicon. Silicon absorbs visible light (from 0.38 to 0.78 μm) that makes 48 per cent of the energy, and a part of infrared energy in the range up to about 1.1 μm. The whole range of infrared radiation (up to 4 μm)transmits about 45.5 per cent of the solar radiation energy [4,5].

Absorption ability of the cells may be improved with the help of a transparent antireflection layer of proper thickness and index of refraction. The best result may be achieved with the use of multi-layer antireflection coats. They should be distinguished by large value of the absorption coefficient and low emission coefficient, that is particularly important [3].

Very good absorption ability occurs in case of the tandem-type cells made of semiconductor material layers in the form of a grid. This is due to various spectrum characteristics of the material used in them. The proposed model having 26 layers is distinguished by the efficiency exceeding 35 per cent [6]. Efficiency of a 70-layer model reaches even 40 per cent. Such cells are designed mainly based on the arsenic and gallium compounds.

Operation tests
The tests have been made for silicon modules of maximal power 20 W. Table 1 specifies basic parameters of the considered modules under the conditions of AM 1.5 spectral distribution of solar radiation (Air Mass 1.5 corresponds to the distribution for apparent sun altitude of 42º), for the insolation of S=1000W/m² and temperature t=25°C.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Monocrystalline SUNSET SM 20</td>
<td>20,8</td>
<td>1,28</td>
<td>17,2</td>
<td>1,16</td>
</tr>
<tr>
<td>Monocrystalline lorentz LA-20-12S</td>
<td>22,3</td>
<td>1,30</td>
<td>17,3</td>
<td>1,20</td>
</tr>
<tr>
<td>Monocrystalline USL 20</td>
<td>21</td>
<td>1,30</td>
<td>17,0</td>
<td>1,19</td>
</tr>
<tr>
<td>Monocrystalline SUNTECH STP020-12/cb</td>
<td>21,7</td>
<td>1,26</td>
<td>17,6</td>
<td>1,14</td>
</tr>
<tr>
<td>Polycrystalline SUNTECH STP020-12 Cb</td>
<td>21,7</td>
<td>1,26</td>
<td>17,6</td>
<td>1,14</td>
</tr>
<tr>
<td>Amorphous Shell ST20</td>
<td>22,9</td>
<td>1,54</td>
<td>15,6</td>
<td>1,29</td>
</tr>
</tbody>
</table>

*PMM – Maximal power point – i.e. the point characterizing maximal power emitted at the load resistance [7]"
thermo-transfer method. Figure 2 presents maximal values of the diode normalization factors vs. the wavelength.

![Figure 2](image)

**Fig. 2.** Maximal values of the diode normalization factors vs. the wavelength for the following diodes: a) blue, b) green, c) red, and d) yellow.

The module operation has been tested for various visible light ranges: \( \lambda = 465 - 470 \text{nm} \), \( \lambda = 515 - 525 \text{nm} \), \( \lambda = 588 - 592 \text{nm} \), \( \lambda = 620 - 630 \text{nm} \). The measurement has been carried out in the light intensity range from 20 to 140 lx. Various load resistance values have been taken into account.

Variation of the power generated at the load of each of the modules has been determined.

The load was provided by a decade resistor. The measurements have been made with the use of digital multimeters, the Sinometer luxmeter, HT Italia pyranometer, and touchless thermometer.

Figure 3 shows the tested monocrystalline and polycrystalline photovoltaic modules SUNTECH STP 020-12/cb and pyranometer.

![Figure 3](image)

**Fig. 3.** The tested monocrystalline and polycrystalline photovoltaic modules SUNTECH STP 020-12/cb and pyranometer.

**Results of the measurement**

Example results of the measurement are presented in Figures 4, 5, 6.

![Figure 4](image)

**Fig. 4.** Load characteristics of the modules for \( E_x = 23 \text{ lx} \), (a) \( \lambda = 620-630 \text{ nm} \), (b) \( \lambda = 588-592 \text{ nm} \), (c) \( \lambda = 515-525 \text{ nm} \), (d) \( \lambda = 465-470 \text{ nm} \). Denotation: (1) STP020-12/Cb mono, (2) LA20-12S, (3) SUNSET SM20, (4) STP020-12/Cb poly, (5) Shell ST20, (6) USL 20W.

![Figure 5](image)

**Fig. 5.** Load characteristics of the modules for \( E_x = 80 \text{ lx} \), (a) \( \lambda = 620-630 \text{ nm} \), (b) \( \lambda = 588-592 \text{ nm} \), (c) \( \lambda = 515-525 \text{ nm} \), (d) \( \lambda = 465-470 \text{ nm} \). Denotation: (1) STP020-12/Cb mono, (2) LA20-12S, (3) SUNSET SM20, (4) STP020-12/Cb poly, (5) Shell ST20, (6) USL 20W.
630 nm, (b) SM20, (c) STP020-12/Cb poly, (d) Shell ST20, (e) USL 20W

5. The tests show that in case of lower light intensity (e.g. 20 lx) the higher power is generated under the load conditions by the SUNTECH monocrystalline module. This is a case of larger wavelength values, from 588 to 630 nm. The next in the rank is the SUNSET SM20 module, distinguished by the best characteristics in the range from 465 to 515 nm.

6. In case of lower light intensity (80lx) the characteristics of the SUNTECH and SUNSET SM20 monocrystalline modules are more advantageous, with SUNTECH being particularly better for higher wavelength.

7. In case of 140 lx the SUNTECH module remains better for higher loads. On the other hand, SUNSET SM20 generates maximum power in case of shorter wavelength under lower load level.

8. The worst parameters appeared in case of the SUNTECH polycrystalline module, particularly for shorter wavelength values. For larger loads the module-generated power shows decreasing tendency. Lower efficiency is caused by structural defects that decrease the distance of minority carriers (the photo-current density). Further decrease is a result of dropping short-circuit current, caused by the grain boundaries and the voltage of the open circuit [4, 6].

9. Relatively good results obtained with the amorphous Shell module may be explained by the fact that in nearly entire range of the visible light spectrum the absorption coefficient of hydrogenated amorphous silicon a:Si:H exceeds its value of the crystalline one. In case of light intensity of 140 lx its load characteristics is similar to the one of monocrystalline modules. In doped layers of amorphous silicon the absorption coefficient is still higher. Under AM1 conditions the layer of hydrogenated amorphous silicon of the thickness approximately equal to 1μm is sufficient for absorbing nearly a whole solar radiation of the power exceeding the energy gap of a:Si:H. Dependence of the light absorption coefficient vs. the wavelength is shown, among others, in [12].

10. Operation characteristics of the modules depend to an important degree on outside conditions. Nevertheless, the effect of the production technology [13] should not be omitted.

**REFERENCES**


[8] Zaremba K., Parameters of model luminaire with high power LED Przegląd Elektrotechniczny, (2003), nr 4, s.234-236.


Authors: dr hab.inż. Grażyna Frydrychowicz-Jastrzębska, Prof. Politechniki Poznańskiej, Politechnika Poznańska, Instytut Elektrotechniki i Elektroniki Przemysłowej ul. Piotrowo 3a, 60-959 Poznań e-mail:grazyna.jastrzebska@put.poznan.pl

mgr inż. Tadaszak Mikolaj , Solaris Bus & Coach S.A. ul. Obornicka 48, Boleszow - Osiedle, 62-005 Owińska e-mail:mikolaj.tadaszak@gmail.com