The impact of the solar radiation on silicon solar cells

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Abstract

This work deals with the impact of the solar radiation on silicon solar cells. The Solar cells are usually characterized under standard test conditions (STC), which do not resemble to realistic operation conditions, especially for indoor applications where the cells operate at much lower irradiances than for outdoor applications. In this work a commercially available poly-crystalline module is tested under real operating conditions. The tests were carried out under different cell temperature, solar radiation and air mass conditions.

1. Introduction

The conversion of solar radiation into electricity in solar cells is direct, without additional equipment and without pollution of natural environment. Silicon solar panels are made of different materials such as mono-crystalline, poly-crystalline and amorphous structures. Material and structure that will be chosen are dependent on relation between the cost and efficiency of energy conversion. In general it can be concluded that higher efficiency of solar cells gives the higher cost of their production. In order to reduce production costs and increase efficiency of solar cells the new materials are already tested such as semiconductors [1] - [3].

The basic parameter of solar cell quality which has an impact on its lifetime is solar cell efficiency. The main factors that determine the conversion efficiency are the following: the type of semiconductor material, the incompatibility of solar radiation with the solar cell absorption, spectrum sensitivity of photoelement and the construction of the solar cells. The efficiency can be increased mainly by increasing the fill factor coefficient $FF$ of photoelement by more advanced technology, a decrease of reflection by the application of antireflection layers, choice of more suitable semiconductor, decrease in temperature of absorbing surface, etc. [4].

The aim of the work is to evaluate the silicon solar module. The efficiency of a solar module under various climatic conditions will be evaluated. Silicon is used as the core material in most of the photovoltaic modules currently available. Mono-crystalline and poly-crystalline modules achieve high cell efficiencies (12–16%), while thin-film silicon modules achieve efficiencies of 4–7.5% [5].

Solar cells are usually characterized under standard test conditions (STC) according to the IEC norm [2], which is 1000 W/m$^2$ perpendicular irradiance with a AM=1.5 global spectrum at 25°C cell temperature. Although this is a satisfactory procedure, to get comparable cells performance data, it does not represent the real conditions under which solar cells work, either for outdoor or for indoor applications.

The solar cell efficiency $\eta$ is limited by numerous factors such as available power density of solar radiation $G$, the contact network, resistance, reflection, etc. Power density of solar radiation by increasing the wavelength of the light is falling. This is shown in Figure 1. Depending upon the materials and the technology used, solar cells are better or worse at converting the different colour bands of sunlight into electricity. The spectral sensitivity describes the wavelength range in which a cell works most efficiently and influences the efficiency under different irradiance conditions. Sunlight has the greatest energy in the visible light range between 0.4 $\mu$m and 0.8 $\mu$m. While crystalline solar cells are particularly sensitive to long wavelength solar radiation, amorphous silicon cells can absorb short wavelength light optimally [6].

![Fig.1. Spectral sensitivity of different solar cell](image-url)

Power density (relative intensity)

wavelength [\(\mu\text{m}\)]

Solar spectrum (AM – 1.5)

Cool white fluorescent light

Amorphous Si solar cell

Crystalline – Si solar cell

Visible level
2. The experimental system

Since the solar cell is like a semiconductor diode, the diode characteristic is typical for them. This gives the relation between current and voltage at different electrical circuit resistance, which connects the electrodes of solar cell. In this work the term \( I-U \) characteristic will be used instead of diode characteristic for better understanding. Because of comparison of different types of solar cells, international standards (Standard Test Conditions STC) are made for solar cell testing conditions. The STC for measuring the characteristics of the solar cells are:

- the solar radiation has to be \( G=1000 \text{ W/m}^2 \),
- the air mass factor (AM) (SIST EN 60904-3:2001) has to be 1.5,
- the cell temperature (SIST EN 60904-3:2001) has to be \( T=25 \pm 2^\circ \text{C} \) and
- the incidence angle (SIST EN 60904-3:2001) between the sunbeams and the normal to the surface of the PV module has to be 90°.

Each \( I-U \) characteristic of solar cells, which is shown in Figure 2, has some specific data:

- open circuit voltage, \( U_{oc} \) is the maximum voltage at zero current. \( U_{oc} \) increases logarithmically with increased sunlight,
- short circuit current, \( I_{sc} \) is the maximum current, at zero voltage. Note that \( I_{sc} \) is directly proportional to the available sunlight and
- the maximum power point of a cell is graphically given by the largest rectangle that can be filled under the \( I-U \) characteristic. This is shown in Figure 2.

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Where \( I_{mpp} \) is the maximum power point (MPP) current, \( U_{mpp} \) is MPP voltage, \( I_{sc} \) is short circuit current while \( U_{oc} \) is open circuit voltage. \( A_{pv} \) is solar cell area, \( P_{mpp} \) is MPP power, \( \eta_{max} \) is the maximum cell efficiency while \( FF \) is the fill factor coefficient.

The outdoor \( I-U \) characteristic measuring system was used to take a collection of current–voltage data sets for the individual modules under real operating conditions. Each data set consists of approximately 300 current/voltage pairs measured and stored over a period of about 5 s. The experiments were done so that during the individual \( I-U \) characteristic scans global solar irradiance (\( G \)) and cell temperature (\( T \)) were sufficiently constant. Simultaneously the global solar irradiance, the cell temperature, and other electrical and environmental parameters are acquired. With the maximum power point determined from the measured current/voltage data pairs, the cell efficiency is calculated via cell area and global normal irradiance. The efficiency \( \eta \) is in general a function of:

\[
\eta = f(G, T, \text{AM})
\]

where \( G \) is the global irradiation, \( T \) the cell temperature and AM the relative air mass.

The concept, software program and system equipment for this outdoor \( I-U \) characteristic measuring system was developed at the Faculty of electrical engineering and computer science (FERI), University of Maribor, Slovenia (see Figure 3).

3. Results

Poly-crystalline solar module was tested under real conditions. Poly-crystalline solar module was bought on the open market and was randomly selected out of a batch of about 50 modules. The
electrical data of tested poly-crystalline module are given in table 1. Current/voltage (IU) characteristics were acquired outdoors under different climatic conditions for this module, providing efficiencies at varying ambient and cell temperatures, irradiances and air masses. A typical IU characteristics scan is shown in Fig. 4.

<table>
<thead>
<tr>
<th>Tab 1. Electrical data</th>
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<tbody>
<tr>
<td>Maximum Power (Pmax)</td>
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<tr>
<td>Open circuit Voltage (V∞)</td>
</tr>
<tr>
<td>Open circuit Current (Isc)</td>
</tr>
<tr>
<td>Maximum power Voltage (Vmp)</td>
</tr>
<tr>
<td>Maximum power Current (Vmp)</td>
</tr>
<tr>
<td>Nominal Operating Cell Temperature (NOCT)</td>
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<tr>
<td>Dimensions</td>
</tr>
</tbody>
</table>

Figures 4 and 5 show IU and PU characteristics measured before degradation at irradiance of approximately 986 W/m² and air mass of about 1.45. Ambient temperature was 33.1°C and wind speed around 10.9 m/s, resulting in a cell temperature of 56.27°C. These conditions resulted in a module efficiency of 13.82%.

<table>
<thead>
<tr>
<th>Tab 2. The results of IU and PU characteristics which are shown in Figures 4 and 5</th>
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</thead>
<tbody>
<tr>
<td>Poly-crystalline modules</td>
</tr>
<tr>
<td>The solar radiation G</td>
</tr>
<tr>
<td>The cell temperature T</td>
</tr>
<tr>
<td>The air mass AM</td>
</tr>
<tr>
<td>The cell efficiency</td>
</tr>
<tr>
<td>MPP power P_mpp</td>
</tr>
<tr>
<td>Measured points</td>
</tr>
</tbody>
</table>

Through the measurements the characteristic of efficiency η of poly-crystalline solar cell was determined as a function of the intensity of solar radiation G, shown in Figure 6. Figure 6 shows that the efficiency of poly-crystalline solar cell by the intensity of solar radiation increases to a certain value. The maximum efficiency of poly-crystalline solar cell is achieved by the intensity of solar radiation of 800 W/m² and it is 14.3%.

On one of the test days, 145 IU -scans were taken at constant irradiance and air mass but varying cell temperature. Figure 7 shows the result of the measurements. This kind of test would give an indication on the temperature coefficient of cell efficiency.

Characteristic, shown in Figure 7 is drawn by the program package Matlab based on the measurements of poly-crystalline solar cell. The characteristic of solar cell efficiency as a function of temperature T of solar cell shows that the efficiency of solar cell decreases linearly by the increasing temperature. The efficiency of poly-crystalline solar cell is approximately 17 %, at a temperature of 10 °C, while only 10 % at a temperature of 60 °C, as shown in Figure 7.
In addition, measurements were carried out at changing irradiance, and with cell temperature and air mass also changing simultaneously. A total of 145 scans were carried out in August 2011. Figure 8 shows the results in 3D representation.

Figure 8 shows the efficiency of poly-crystalline solar cell as a function of the intensity of solar radiation \( G \) and temperature \( T \) of solar cell. The air mass factor is constant (AM = 1,5). The efficiency, shown in Figure 8, is acquired by the measurements on a poly-crystalline solar cell. Figure 8 shows that the maximum efficiency of the poly-crystalline solar cell is at the intensity of solar radiation \( G=800 \text{ W/m}^2 \).

4. Conclusion

The aim of this work is to evaluate the poly-crystalline solar cell. The efficiency of tested poly-crystalline solar cell is up to 14 % in good conditions of solar radiation. The poly-crystalline solar cells are the most widely used and are suitable for larger roof areas and the installation in the open air. The poly-crystalline solar cells are very suitable for our climatic conditions, while they are suitable for diffuse radiation. With the poly-crystalline solar cells is achieved up to 4 % higher annual efficiency than with the mono-crystalline solar cells.

Bibliography


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