Estimation of parameters for a model of polycrystalline solar cells**

J. Shainidze,* L. Kalandadze, O. Nakashidze and N. Gomidze

Department of Physics, Shota Rustaveli State University, Batumi, Georgia

In many countries of the world the main factor for increasing energy potential and saving the environment is exploiting nonconventional energy. Renewable energy is mostly connected with solar radiation. Mastering solar energy depends, above all, on technological advancement. The main goal of scientists is to increase the efficiency of photoelectric converting systems and decrease their cost. Parameters correctly computed from relevant solar cell characteristics or a set of experimental data are required for controlling photovoltaic (PV) systems. However, experimental or accurate characteristic (i.e., the current (I)–voltage (V) curve) data for a PV module may not be readily available. The present paper describes calculations of solar cell parameters, based on polycrystalline silicon, using experimental and theoretical approaches. Finding appropriate model circuit parameters of solar cells is crucial for performance evaluation, control, efficiency computations and maximum power point tracking of solar PV systems. Based on our results, some suggestions are provided.

Keywords: fill factor, photovoltaics, solar energy, volt–ampere characteristics

1. Introduction

Mastering the exploitation of of solar energy is directly connected with development of technology. Scientists wish to increase the efficiency and decrease the price of photoelectric converters. New silicon-based structures have been introduced, enabling some decrease of optical and recombination losses.[1–3] A solar cell or photovoltaic (PV) module is electrically

* Corresponding author. E-mail: jabashainidze@gmail.com

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1 Smets, A.H.M., Jäger, K., Isabella, O., van Swaaij, R.A.C.M.M. and Zeman, M. *Solar Energy: The Physics and Engineering of Photovoltaic Conversion Technologies and Systems*, pp. 138–141. Cambridge: UIT (2016).

2 Avsajanashvili, G. *Solar Energy and Helio Resources*, pp. 34–35. Tbilisi: TSU (2014) (in Georgian).

3 Shockley, W. *Electrons and Holes in Semiconductors with Applications to Transistor Electronics*, pp. 55–57. Princeton: van Nostrand (1950).

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represented by an appropriate circuit with specific parameters. Control parameters must be correctly computed from solar cell characteristics and, where available, a set of experimental data for the PV system. The technology of integrated microcircuits based on silicon has greatly developed in recent years and has benefited the production of solar cells: enabling a drastic increase in their parameters and improvement in the efficiency of laboratory solar cells almost to the theoretical limits. The efficiency of a photoelectric converter is defined by its current–voltage characteristics and it is one of the most important parameters. Therefore, the main task today is to control and optimize these characteristics, which also comprises the bringing to perfection of methods for their measurement.

Using theoretical calculations based on polycrystalline silicon, and experiments carried out on a solar cell common on the market today, we studied the following parameters of solar cells: current–voltage dependence, short circuit current (I_{SC}), open circuit voltage (V_{OC}), fill factor (FF) and conversion efficiency.[1–5]

2. Theory

Theoretical calculations have been based on known standard parameters of polycrystalline silicon: photocurrent density J_{SC} = 350 A m^{-2} and V_{OC} = 0.67 V at a temperature T = 300 K. Assuming that the solar cell behaves as an ideal diode, FF can be calculated as a function of V_{OC}:[4–7]

$$\mathrm{FF} = \frac{v_{OC} - \ln(v_{OC} + 0.72)}{v_{OC} + 1} = 0.84 \tag{1}$$

where

$$v_{OC} = \frac{V_{OC}}{k_B T / q} = \frac{0.67}{0.0258} = 26.8 \tag{2}$$

is normalized voltage, k_B is Boltzmann's constant and q the elementary charge.[4]

The conversion efficiency η is calculated as the ratio of maximum generated power to incident power:[1]

$$\eta = \frac{J_{SC} V_{OC} \mathrm{FF}}{I_{in}} = 19.7\% \tag{3}$$

where I_{in} is irradiance of incident light having AM1.5 spectrum, which is a reference solar spectral distribution based on the solar irradiance received on a sun-facing plane surface tilted at 37° to the horizontal. The total irradiance of this spectrum is 1000 W m^{-2} and is close to the maximum received at the surface of the Earth on a cloudless day.[1]

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4 Green, M.A. *Solar cells: Operating Principles, Technology, and System Applications,* pp. 79–81. Englewood Cliffs, New Jersey: Prentice-Hall (1982).

5 Afanassiev, V.V., Terukov, E.I. and Sherchenkov, A.A. *Silicon-Based Thin Film Solar Cells*, pp. 21–26. St Petersburg: Electrotechnical University "LETI" (2016) (in Russian).

6 Bessel, V.V., Kucherov, V.G. and Mingaleeva R.D. *Study of Solar Photoelectric Cells*, pp. 16–21. Moscow: Gubkin University of Oil and Gas (2016) (in Russian).

7 Kosiachenko, L.A. and Grushko, E.V. Open circuit voltage, fill factor and conversion efficiency of CdS/CdTe solar cells. *Fizika i Tekhnika Poluprovodnikov* **44** (2010) 1422–1429.

Typical external parameters of polycrystalline silicon solar cell are: J_{SC}=350 A m^{-2}, V_{OC} up to 0.65 V and FF in the range 0.75–0.80. The conversion efficiency lies in the range 17–18%. Eqn (1) describes the maximum achievable FF; in practice it is often lower due to the presence of parasitic resistive losses.[1]

3. Experimental and results

Experiments were carried out on a regular solar cell manufactured by NUZAMAS, found and purchased online (Fig. 1), with the following characteristics: dimensions 90 × 60 × 2 mm, maximum output voltage V_{max} = 6 V, maximum output power P_{max}= 0.6 W (manufacturer's declaration).

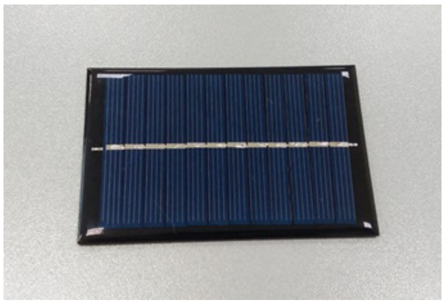

Figure 1. The NUZAMAS solar cell investigated in this paper.

A simple circuit was built according to Fig. 2. Using a multimeter we measured V_{OC}, I_{SC}, I_{mpp} (current at the maximum power point), V_{mpp} (voltage at the maximum power point) and by changing the external resistance *R* measured the current *I* and voltage *V* produced by the solar cell at different values of *R*, starting at 0 Ω and increasing it by 5 kΩ increments. Results are shown in Table 1, and the current–voltage characteristics of the solar cell are plotted in Fig. 3.

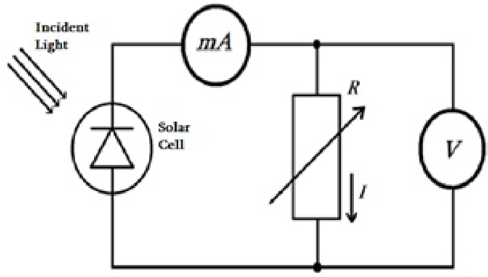

Figure 2. Circuit diagram used for the measurements (see text), where *R* is the variable resistance, *V* the voltmeter and *mA* the ammeter.

Table 1. Experimental data for the NUZAMAS cell: voltage, current and power for different external resistances.

R / kΩ	V / V	I / μA	P / μW
0	0.0	49.9	0.00
5	0.5	49.6	24.80
10	0.9	48.8	43.92
15	1.2	48.5	58.20
20	1.6	47.9	76.64
25	1.8	46.4	83.52
30	2.1	45.8	96.18
35	2.4	44.7	107.28
40	2.6	43.5	113.10
45	2.9	41.9	121.51
50	3.1	40.9	126.79
55	3.2	39.8	127.36
60	3.4	38.9	132.26
65	3.6	37.5	135.00
70	3.7	35.9	132.83
75	3.9	34.8	135.72
80	4.1	32.8	134.48
85	4.2	31.1	130.62
90	4.3	27.5	118.25
95	4.4	23.7	104.28
100	4.5	18.0	81.00
∞	5.3	0.0	0.00

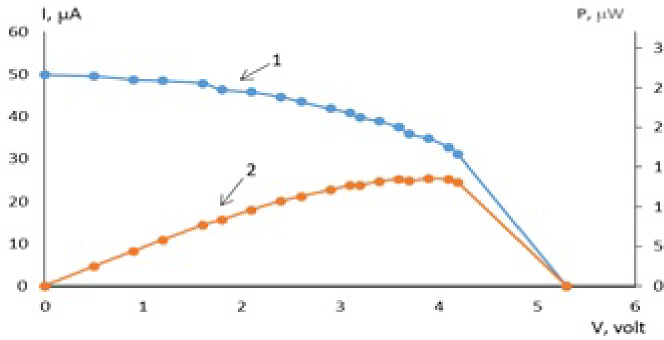

Figure 3. Dependences of the electric current (curve 1) and power (curve 2) on voltage for the NUZAMAS polycrystalline silicon solar cell.

From our experimental data we determined: I_{SC} = 49.9 μA, V_{OC} = 5.3 V, I_{mpp} = 34.8 μA, V_{mpp} = 3.9 V. Using these results, fill factor and conversion efficiency (η) were calculated:[1]

$$\mathrm{FF} = \frac{(V_{mpp} I_{mpp})}{(I_{SC} V_{OC})} = \frac{3.9 \times 34.8}{49.9 \times 5.3} = 0.51 \tag{4}$$

$$\eta = \frac{J_{SC} V_{OC} \mathrm{FF}}{I_{in}} = \frac{49.9 \times 5.3 \times 0.51}{1000} = 0.13 = 13\% \tag{5}$$

4. Discussion and conclusions

Our theoretical and experimental results showed that an ordinary solar cell readily found on the retail market has a low fill factor and conversion efficiency and produces less electric current and voltage than according to the manufacturer's description. The manufacturer of a PV system typically provides information on open circuit voltage, short circuit current and maximum power points, but it is the parameters of fill factor and conversion efficiency that are crucial for performance evaluation, control, efficiency computations and maximum power point tracking of solar PV systems.