Method to determine the single curve IV characteristic parameter of solar cell

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Abstract. Solar cell I-V curves demonstrate the relationship between the current and voltage across the cell at the existing conditions of irradiance and temperature. I-V curves provide important information on how to optimally configure a solar system for a given set of environmental conditions. Important parameters for the function of solar cells include: V_{oc}, I_{sc}, V_{mp}, I_{mp} and P_{mp}, which can be experimentally measured. However, the circuit parameters of the saturation current density (I_0), ideality factor (n), series resistance (R_s) and shunt resistance (R_{sh}) for a given solar irradiance and ambient temperature can be obtained by solving the governing equations of the solar cell. The purpose of this paper is to determine the I_0, n, R_s, and R_{sh} of a solar cell by measuring a single IV-curve and using the standard model of a solar cell under different irradiance intensity levels (600-1000 W/m^2, temperature 25 ^{o}C). From the results of these experiments we found that, the value of I_0 is between 4.78×10^{-5}A to 7.19×10^{-5} A and n is between 1.33 to 1.39. I_0 and n increase at higher irradiance intensity due to increasing recombination current. On the other hand, the parasitic resistances R_s and R_{sh} decrease at higher irradiance intensity.

1. Introduction

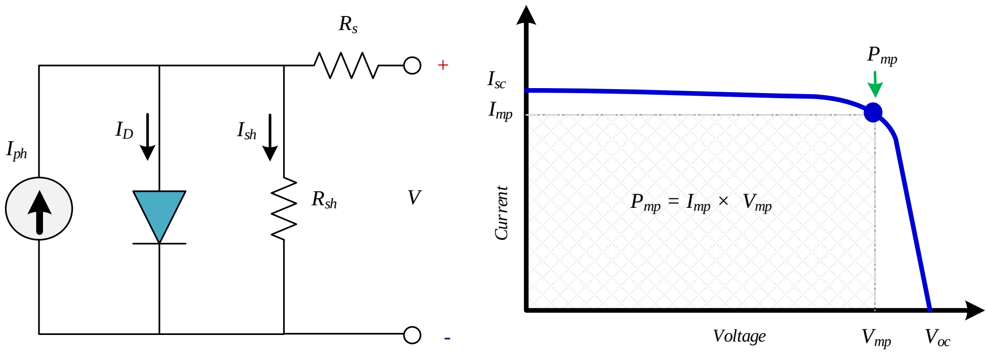
Energy is an important factor for social and economic development. Thailand currently has many ongoing energy projects in the ASEAN region, including its gas production plan, oil plan, energy efficiency plan (EEP), renewable energy development plan (AEDP) and power development plan (PDP), using the Smart Grid Plan (SGP). Solar energy is a renewable energy, which is important for the production of clean electricity. From the Alternative Energy Development Plan (AEDP2015) in 2036, a target of 6 GW of installed solar system was expected, but by 2017 3GW was already installed. In addition, the IRENA report, issued in November 2560 by the International Renewable Energy Agency in cooperation with the Thai Ministry of Energy, stated that Thailand should have a total capacity of 17 GW of installed solar energy capacity in 2036, nearly three times its original target [1]. While solar energy demand is increasing, it is necessary to develop a s high quality and effective solar system. Therefore, it is necessary to have a detailed knowledge and understanding of the operation of the individual solar cells.

A photovoltaic module (PV module), which consists of a number of solar cells in a series, can directly convert solar energy into electrical energy. Each cell contains a p–n junction. The common technique of modeling a PV module is to create an equivalent circuit, which can be described by a one-diode or two-diode models. The former is widely recognized for simulating the performance of PV modules. The one-diode mathematical model and the equivalent circuit for a PV module can be represented by equation (1) and is shown in figure 1(a). The equivalent circuit consists of three paths of currents, the photocurrent (I_{ph}), diode current (I_d) and parallel resistance current (I_{sh}). However, the equivalent circuit can be used not only for a PV module including several cells, but also for an individual cell or a PV array including several PV modules [2].

The most important parameters of solar cells can be determined by the I–V characteristic which is shown in figure 1(b). These parameters include the short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), voltage at maximum power point (V_{mp}), current at maximum power point (I_{mp}) and maximum output power (P_{mp}). When we consider the equation (1) the important parameters are the saturation current density (I_0), ideality factor (n), series resistance (R_s) and shunt resistance (R_{sh}). R_s is the series resistor that takes into account losses in cell solder bonds, interconnection, junction box, etc. R_{sh} is the shunt resistor that takes into account the current leakage through the high conductivity shunts across the p-n junction. The four parameters are latent variables and then cannot be measured directly, but they are important parameters for the working principles of solar cells.

This research is to determine the characteristic parameters of a single crystalline silicon solar cell from a single IV-curve measured under illumination condition, using the one diode model, to extract the four parameters of I_0, n, R_s and R_{sh} [3,4,5].

$$I = I_{ph} - I_d - I_{sh} = I_{ph} - I_0\left[e^{\frac{q(V+IR_s)}{nkT}} - 1\right] - \frac{V+IR_s}{R_{sh}} \tag{1}$$



(a) One-diode equivalent circuit (b) I–V characteristic

Figure 1. (a) An equivalent circuit and (b) I–V curve of a solar cell.

2. Experimental Methods

In this paper, a new unused cell (size 104.04 cm^2 of the area as in figure 2) was used to determine the solar cell's parameters under different illumination levels in the range of 600-1,000 W/m^2 at 25 °C and comparing the I-V curves from the measurements to a simulated cell, and then extracting the parameters by a single I-V curve.

Figure 2. Single crystalline silicon solar cell.

Substituting in for the values of I_d and I_{sh} in equation (1), we find I_0, n, R_{sh} and R_s. At V_{oc} the equation becomes:

$$I_{PV} - I - \frac{V+IR}{R_{sh}} = I_0 \left[\exp^{\left(\frac{q(V+IR_s)}{nkT}\right)} - 1 \right] \quad (2)$$

Near I_{sc}, R_{sh} will dominate, and R_s will dominate near V_{oc} [3]. Then

$$\left[I_{PV} - I - \frac{V}{R_{sh}} \right] = I_0 \exp^{\left(\frac{qV}{nkT}\right)} \quad (3)$$

In this paper, we propose to use a voltage range of less than 200 mV to determine I_0 and n. In the case of R_{sh} and R_s, we use the slope around $I=I_{sc}$ for R_{sh} and the slope around $V=V_{oc}$ for R_s, which are given by equation (4) and equation (5) respectively. These values can be calculated by a linear fit of I–V characteristics around the short circuit current point and around the open circuit voltage point, respectively. The shunt and series resistances are calculated using the following expressions [6]:

$$R_{sh} = -\left(\frac{dV}{dI}\right)_{I=I_{sc}} \quad (4)$$

$$R_s = -\left(\frac{dV}{dI}\right)_{V=V_{oc}} \quad (5)$$

3. Results and discussion

Measurements of IV-curves under irradiance intensities between 600-1000 W/m^2 at 25 ^{o}C is shown in figure 3 with red dashed lines with simulation data shown in black solid lines. It can be seen that the model and actual data match well, except in region B (near the maximum point). This is due to the ideality factor being voltage dependent [7]. Decreasing the light intensity mainly reduced the short-circuit current of the solar cells while the open circuit voltage only slightly changed. The light generated current is proportional to the flux of photons onto the cell, therefore the short-circuit current is directly proportional to the light intensity [8]. Therefore short-circuit current increases at a rate of 3.37×10^{-3} A/(W/m^2). And the power output of solar cell increases by 1.44×10^{-3} W/(W/m^2) as the light intensity is increased. All parameters are shown in table 1. The fill factor, at the standard test condition (STC), was 0.724.

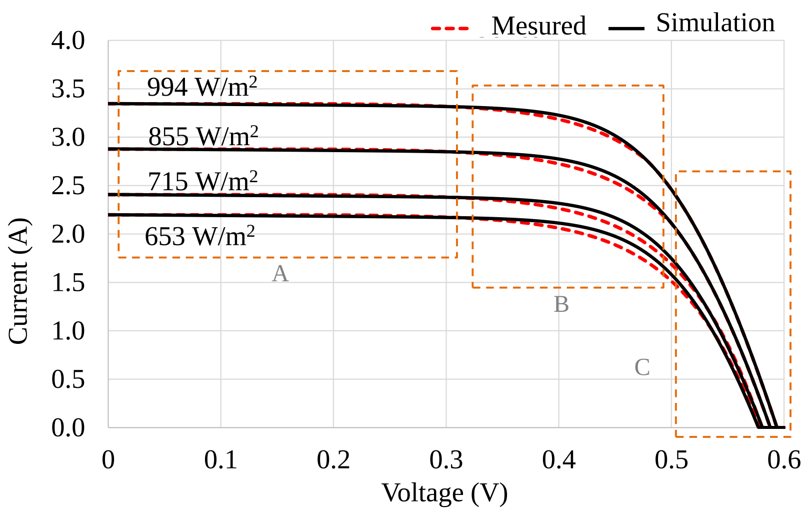


Figure 3. Comparison of I-V curve by measurement and simulation.

Table 1. The parameter of the I-V curves measured under different irradiance intensity.

Parameter	Irradiance Intensity (W/m^2)			
	653	715	855	994
Voltage at maximum power point (V_{mp},V)	0.44	0.44	0.45	0.45
Current at maximum power point (I_{mp}, A)	1.93	2.11	2.53	2.95
Maximum output power (P_{mp}, W)	0.85	0.94	1.14	1.34
Open-circuit voltage (V_{oc}, V)	0.58	0.58	0.59	0.59
Short-circuit current (I_{sc}, A)	2.20	2.41	2.88	3.35
Series resistance (R_s, Ω)	3.72×10^{-2}	3.39×10^{-2}	2.87×10^{-2}	2.51×10^{-2}
Shunt resistance (R_{sh}, Ω)	9.94	9.67	8.97	8.55
Saturation current density (I_0, A)	4.78×10^{-5}	5.42×10^{-5}	6.83×10^{-5}	8.19×10^{-5}
Ideality factor (n)	1.33	1.35	1.37	1.39

Figure 4 shows the changes in the saturation current and ideality factor, depending on the light intensity between 600-1000 W/m^2. The saturation current and ideality factor increase linearly with an increase in the incident radiation. The increase of the saturation current and ideality factor are caused by the increase in the recombination current due to the increase in electron and hole density [9]. Figure 5 shows a small change in the series resistance (R_s) and shunt resistance (R_{sh}), as the light intensity varies from 600 W/m^2 to 1000 W/m^2. This may be due to the existence of local inhomogeneity leading to non-uniform current flow or to more charge leakage across the p–n junction in the cell.

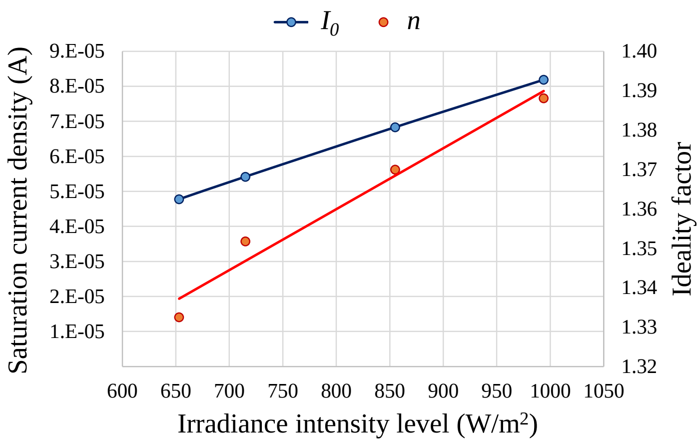


Figure 4. I_0 and n as a different irradiation.

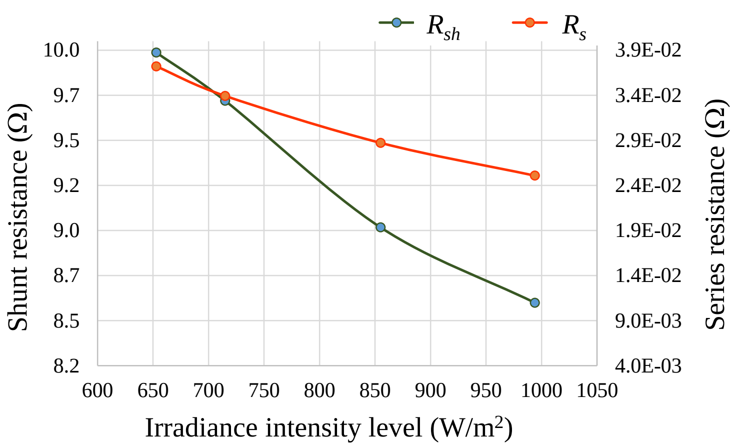


Figure 5. R_s and R_{sh} as a different irradiation.

4. Conclusions

This study extracted the values of the characteristic parameters of a solar cell (I_0, n, R_{sh} and R_s), with a single current-voltage measurement. This method was studied under different illumination conditions of a crystalline silicon solar cell. Results obtained indicate that the increase in the saturation current density and ideality factor are caused by an increase in the recombination current. R_{sh} and R_s both decreased slightly under higher irradiance intensity. The method shown here can be used to investigate changes in I_0, n, R_{sh} and R_s over time to measure the degradation solar cells.

Acknowledgment

The authors gratefully thank Dr. Kyle Vitautas Lopin and Naresuan University for funding support (R2560C187) of this work.

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